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October 31 - November 2, 1990

Davis, California



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This proceedings summarizes the research results presented at a symposium on oak woodlands and hardwood rangelands in California. Sixty-six papers are included, focused on six major topics, namely: regeneration and restoration of oaks, wildlife habitat considerations, monitoring trends, land use planning, management strategies, and ecology and management of Engelmann oak. These papers form the state of knowledge for this important ecological zone in California, and help to frame management, policy, and conservation strategies for this resource.

Retrieval Terms: oaks, oak management, range management

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Foreword

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Proceedings of the Symposium on Oak Woodlands and Hardwood Rangeland Management

October 31 - November 2, 1990, Davis, California

Richard B. Standiford, Technical Coordinator

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Standiford, Richard B., tech. coord. 1991. **Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November** 2, **1990; Davis, California.** Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 376 p.

Retrieval Terms: oaks, oak management, range management

This proceedings contains 66 papers presented at a symposium on oak woodlands and hardwood rangelands in California. The objective of this symposium was to provide the state of our knowledge on the ecology, inventory, uses, and management of oak woodlands in California. It was structured around six major topics:

- Regeneration and restoration of oaks and other hardwood species;
- Wildlife habitat relationships;
- Factors influencing conversion of hardwood rangelands and policies to mitigate these conversions;
- Management strategies to ensure sustainability of the hardwood range resource;
- Ecology, management, and conservation of Engelmann oak; and
- Monitoring, classifying, and analyzing the hardwood range resource.

These research studies can be used to address conservation and long-term sustainability of California's oak woodlands and hardwood rangelands.

PREFACE

On October 31 through November 2, 1990, a research symposium was held at the University of California, Davis, on oak woodlands and hardwood rangeland management. These areas are an important natural resource in California, occupying almost 10 million acres in the state. They are ecologically important because of the richness of the biological resources found on them, and economically important as the source of more than 70 percent of the state's forage resource. As an indication of the importance of these areas, 1990 declared the "Year of the Oak" by the California State Legislature.

This symposium was designed to provide the state of our knowledge on the inventory, ecology, uses, and management of oak woodlands in California. More than 350 scientists, resource managers, and individuals attended this symposium. It was structured around six major topics presented in plenary session. Each of these sessions had a chair who was responsible for selecting papers presented, and for coordinating the technical review of the papers. The topics included at the symposium were:

- Regeneration and restoration of oaks and other hardwood species (chair—James Griffin, Hastings Natural History Museum, University of California, Berkeley),
- Wildlife habitat relationships (chairs—Bill Laudenslayer, Service Pacific Southwest Research Station, USDA Forest; and Ken Mayer, California Department of Fish and Game),
- Factors influencing conversion of hardwood rangelands and policies to mitigate these conversions (chairs—Cathy Bleier, California Department of Forestry and Fire Protection; and Tom Scott, University of California Integrated Hardwood Range Management Program),
- Management strategies to ensure sustainability of the hardwood range resource (chairs—James Bartolome and Lynn Huntsinger, Department of Forestry and Resource Management, University of California, Berkeley),
- Ecology, management, and conservation of Engelmann oak (chair—Tom Scott, University of California Integrated Hardwood Range Management Program), and
- Monitoring, classifying, and analyzing the hardwood range resource (chair—Robert Ewing, California Department of Forestry and Fire Protection).

This is the third in a series of symposia dealing with hardwoods and oaks in California. The first was held in 1979 in Pomona,[1] and the second was held in 1986 in San Luis Obispo.[2] The information presented in this publication builds upon the knowledge base of these earlier symposia, also published by the Pacific Southwest Forest and Range Experiment Station (now Pacific Southwest Research Station).

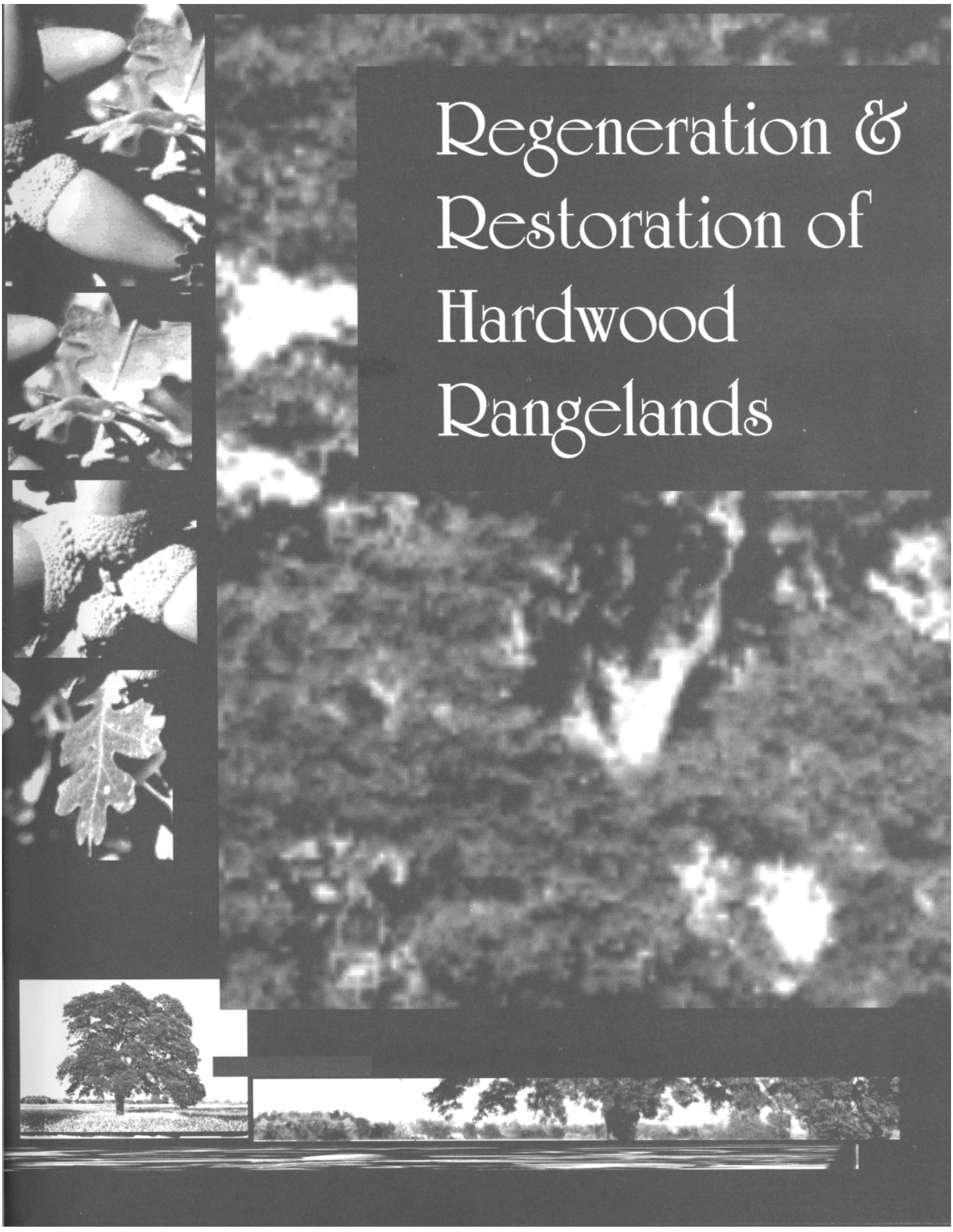
Included within this publication are 66 research papers. Approximately 70 percent of the studies reported on at this symposium were either directly or indirectly funded as a part of the Integrated Hardwood Range Management Program. This program, jointly managed by the University of California (UC) and the California Department of Forestry and Fire Protection (CDF), was started in 1986 with funds from the State legislature. It is designed to address the long-term sustainability of the State's oak woodlands and hardwood rangelands by developing basic information on the ecological and managerial processes of hardwood rangelands through an aggressive research program, and applying this knowledge base to conservation issues through an extension outreach effort.

We are especially grateful to the individuals who made this symposium a success. In addition to the session chairs listed above, Dennis Pendleton of University Extension at UC Davis was co-coordinator of the entire symposium. Debbie Roberts of University Extension at Davis oversaw the logistical details of the symposium. Pam Muick of UC Berkeley chaired an excellent poster session. Robert Schmidt of UC Berkeley was instrumental in developing the idea for this symposium, and served on the steering committee. We also appreciate the financial support of the Pacific Southwest Research Station, CDF, UC, the California Department of Fish and Game, the California Department of Parks and Recreation, and the U.S. Bureau of Land Management. Several groups endorsed this symposium, leading to a diverse audience of individuals interested in oak woodland management. These included the Society for Range Management, the Society of American Foresters, the California Oak Foundation, the California Farm Bureau Federation, the Western Chapter of the Ecological Society of America, and the California Native Plant Society.

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[1]Plumb, T.R., tech. coord. 1980. **Proceedings of the symposium on the ecology, management, and utilization of California oaks;** June 26-28, 1979; Claremont, CA: Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 368 p.

[2]Plumb, T.R.; Pillsbury, N.H., tech. coords. 1987. **Proceedings of the symposlum on multiple-use management of California's hardwood resources;** November 12-14, 1986; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 462 p.



Regeneration & Restoration of Hardwood Rangelands

Minimum Input Techniques for Valley Oak Restocking[1]

Elizabeth A. Bernhardt Tedmund J. Swiecki[2]

Abstract: We set up experiments at four locations in northern California to demonstrate minimum input techniques for restocking valley oak, *Quercus lobata.* Overall emergence of acorns planted in 1989 ranged from 47 to 61 percent. Use of supplemental irrigation had a significant positive effect on seedling growth at two of three sites. Mulch, of organic materials or polypropylene landscape fabric, significantly increased growth at all four locations. Seedlings enclosed in individual wire cages were effectively protected from browsing by deer or cattle.

The valley oak, *Quercus lobata* Née, has been eliminated from much of its former range in California due to clearing for agricultural and urban development. Furthermore, natural regeneration may be insufficient in many parts of its remaining range to maintain current stand densities (Bolsinger 1988, Muick and Bartolome 1987). Artificial regeneration is therefore necessary to restore many stands that have been lost or degraded. Effective, low-cost restocking techniques are needed if significant areas of valley oak woodlands are to be restored.

To gain insight into the influence of restocking techniques on survival of valley oak in restocking projects, we visited and evaluated a number of valley oak restoration projects throughout California that were undertaken in the past 10 years. Overall, water deficit and vertebrate damage were the most important factors affecting seedling survival at the sites we evaluated (Swiecki and Bernhardt 1989). These factors are also the most commonly cited constraints to seedling establishment reported in the literature (Danielsen 1990, Griffin 1971, Gordon and others 1989, Knudsen 1987, Rossi 1980). We incorporated information from our review of these past restoration projects and from the literature into a conceptual model that indicates the types of inputs required to obtain successful seedling establishment under different site conditions (Swiecki and Bernhardt 1989).

In1989, we established a number of demonstration projects designed to test the assumptions of our conceptual restoration model. The projects are located at four sites in northern California. Valley oaks are present in the vicinity of all project sites, but are almost completely lacking within the areas selected for restocking. Restocking methods selected for each project were tailored to the site conditions and represented varying levels of cultural inputs, starting from the minimum deemed necessary to establish seedlings.

This paper reports the results of restocking techniques for the first season at all sites and the second season in one location.

METHODS

We set up demonstration projects at four sites: the California Academy of Sciences' Pepperwood Ranch Natural Preserve in Sonoma County; the Napa County Land Trust's Wantrup Wildlife Sanctuary in Napa County; The Nature Conservancy's Cosumnes River Preserve in Sacramento County; and the City Vacaville's Hidden Valley Open Space reserve in Solano County.

General Methods

At all locations, locally-collected acorns were used and. volunteers assisted with the plantings. The Cosumnes site was planted in December of 1988. All other locations were planted from late October through early November of 1989 as described below. For most treatments, planting sites were prepared by turning over and breaking up the soil with a shovel. At each site, four intact acorns were planted on their sides at a depth of about 5 cm, spaced 15 cm apart in a square pattern. At Wantrup, soil was not turned over prior to planting, and acorns were inserted into cracks in the soil opened up with a shovel.

At all locations except Cosumnes, individual seedlings were protected from browsing by deer or cattle with one of two types of protective cages, both of which were 122 cm tall and about 45 cm in diameter. The cages were made of readily available materials and designed to minimize costs of materials and installation. Individual exclosures to protect seedlings from browsing by both cattle and deer (Vaca cages) were constructed of welded 2 by 4 in mesh galvanized 12 gauge wire fencing. Each cage was secured on one side to a T-post and on the opposite side by a 86 cm length of steel reinforcing bar (rebar) which was driven into the soil at least 30 cm. Cages to prevent deer browsing (deer cages) were not designed to withstand cattle and were only used in nongrazed areas. They were constructed of lightweight I in diameter wire mesh (poultry netting). Deer cages were secured to a 150 cm length of rebar or a T-post on one side and a 60 cm length of rebar on the opposite side. Relative costs of the materials and approximate times required for exclosure construction are shown in table 1.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31 - November 2, 1990, Davis, Calif.

[2]Plant Pathologists, Plant Science Consulting & Research, Vacaville, Calif.

Table 1—*Cost (1989) and labor estimates for components of some treatments.*

(Treatment	Materials cost	Assembly time	Installation time/site
Vaca cage	$5.36	5-6 min	5-7 min
Deer cage	$2.92	4-5 min	3-4 min
Landscape fabric	$1.04	1-2 min	1-2 min
Drip irrigation[1]	$174.30	—	—

[1]1000 ft drip line, emitters, an fittings for 50 sites.

Nonwoven polypropylene landscape fabric (Typar®, Reemay, Inc.) was used to mulch sites in some treatments. The material was cut in 90 cm squares, and two slits about 30 cm long were cut in a "X" pattern in the center of each square. The fabric was fastened to the ground with a 10 cm long steel staple in each corner after the acorns were planted. The Typar® fabric, which breaks down when exposed to ultraviolet light, was covered with 5-7 cm of wood chip mulch following the manufacturer's recommendation.

Data on seedling emergence, condition, and height were recorded periodically for each location. Unless otherwise noted, height and survival data presented here were collected between 15 August and 27 August 1990, and emergence data is cumulative to this period. Mean height of all seedlings and mean height of the tallest seedling for each planting site were calculated and analyzed. In all cases, results for both were similar, and only mean heights of the tallest seedling are reported.

We analyzed the effects of treatments on emergence and condition frequencies using contingency tables and categorical data modeling procedures. Heights were analyzed using analysis of variance. Mean separation in preplanned comparisons was made using least significant difference following a significant F ratio. Where experimental designs became unbalanced due to missing data, least square means (SAS Institute, Inc. 1988) were used. Single degree-of-freedom contrasts were also used to test for differences between selected treatments. The significance level of differences and effects referred to as significant is $P < 0.05$.

Vacaville

The Vacaville location was chosen as the more favorable of two available planting locations on city-owned land. It is an urban open space buffer between housing developments, and consists of two adjacent south-facing hillsides of about 7 acres each. A remnant oak woodland which includes valley oak and interior live oak (*Q. wislizenii* A. DC.) is present on the top of the easternmost hillside. Herbaceous vegetation is largely annual grasses and forbs, but substantial populations of purple needlegrass (*Stipa pulchra* Hitchc.) are spread across both hillsides. Short duration grazing was used in the spring of 1990 for fire suppression. The east hillside was grazed from 28 March to about 23 April at a density of one head per acre. Cattle from an adjoining field were allowed access to the western hillside from 1 April to about 15 May. Soil is a clay loam averaging 75-100 cm deep. We detected subsurface compaction in various spots across both hillsides and exposed rock is visible near the crest of both hills.

At the start of the project we anticipated that damage by cattle, moisture stress due to weed competition, soil depth and compaction, and vandalism would be the most likely factors to limit restocking success. Vaca cages were installed on all but a single treatment to protect seedlings from cattle. Landscape fabric mulch was used on two treatments to reduce weed competition and conserve soil moisture. A thin mulch of dry grass was used in the remaining treatments. Two different methods were used to compensate for soil compaction. In one treatment, a two-person power soil auger with a 10 cm diameter bit was used to loosen the soil to a depth of 45 to 60 cm. For two other treatments, we probed the soil at potential planting sites with a 6 mm diameter steel rod in an attempt to differentiate between more and less favorable microsites. Sites where the probe could be inserted to a depth of 45 to 60 cm were assigned to the "deep probe" treatment, and sites where the probe could be inserted no more than 30 cm were assigned to the "shallow probe" treatment.

Overall, 5 treatments were tested in this location, with 30 planting sites per treatment on each hillside. The treatments were:

V1. No protection, grass mulch, sites prepared only with a hand trowel at planting.

V2. Vaca cage, grass mulch, deep probe sites.

V3. Vaca cage, grass mulch, shallow probe sites.

V4. Vaca cage, landscape fabric mulch, nonaugered sites.

V5. Vaca cage, landscape fabric mulch, augered sites.

Pepperwood

The Pepperwood Ranch Natural Preserve is located in the North Coast Ranges between Santa Rosa and Calistoga. The planting locations are two adjacent fields, one currently grazed by cattle and the other nongrazed. A few mature valley oaks are present around the edges of the nongrazed field. Cattle had access to the grazed field from late October to mid May, and there was little residual herbaceous cover at the end of this period. The nongrazed field has a heavy weed cover, with high populations of Harding grass (*Phalaris tuberosa* L. var. *stenoptera* [Hack.] Hitchc.), although other weeds and native grasses including *Stipa pulchra* are also present. The topography of both fields is very uneven and soil depth is variable, with areas where the underlying bedrock is exposed or very close to the surface. Soil texture is a clay loam. Wet seeps and seasonal creekbeds are present in parts of the fields.

We anticipated that browsing by cattle and deer, and water stress due to shallow soils and weed competition would be the major factors limiting restocking. To avoid the limitation of soil depth and make the best use of available soil moisture, we concentrated our planting sites along the seeps and creekbanks, and avoided areas with extremely shallow soil. We tested both landscape fabric and wood chip mulches for weed control and moisture conservation. An irrigated treatment was also tested in the nongrazed field. Sites were irrigates once a month, begin-

ping 1 June and ending 1 Sept. Each plant received approximately 40 L of water per irrigation through 4 L/h drip emitters. All sites in the nongrazed field were protected with deer cages and those in the grazed field were protected with Vaca cages.

We planted 40 sites per treatment in the grazed field, and 24 to 33 sites per treatment in the nongrazed field. The treatments were:

P1. No mulch (both fields).

P2. Wood chip mulch (both fields).

P3. Landscape fabric mulch (both fields).

P4. Landscape fabric mulch, irrigated (nongrazed field only).

Wantrup

The Wantrup Wildlife Sanctuary planting sites are located on the nearly level floor of the Pope Valley. Large valley oaks are widely scattered across the valley floor and a higher density of mature oaks is found along a seasonal creek channel that crosses through the planting site. Soil averages 30 cm of silty loam overlying silty clay loam to a depth of 150 cm or more. We planted in three adjacent fields. Field 1 has been grazed heavily for many years, and is currently grazed from December through June. There is little residual herbaceous cover after seasonal grazing. Field 2 is an area surrounding the seasonal creek, which was fenced to exclude cattle about 5 years earlier. Weed cover is very dense and includes heavy stands of Harding grass and yellow star thistle (*Centaurea solstitialis* L.). Field 3 had been grazed less heavily than field 1 in previous years, and was not grazed at all in 1990. The weed cover is intermediate between fields 1 and 2, and is dominated by Harding grass.

Browsing by deer and/or cattle, moisture stress due to weed competition, and damage by rodents were the factors which we anticipated would limit restocking at this location. Vaca cages were used in the grazed field and deer cages in the remaining fields to protect seedlings from browsing. Most planting sites were chosen to avoid areas of high rodent activity, although some planting sites in field 1 were intentionally located in close proximity to an active ground squirrel colony for comparative purposes. Several methods of weed control were also tested. In each field, a strip about 4 m wide was tilled in September 1989 with a tractor-mounted disc to remove weeds. Sites were planted in the tilled areas and in adjacent nontilled areas in each field. Planting sites were alternately mulched with moldy hay at planting or left nonmulched. For one treatment in the nontilled portion of field 2, applications of glyphosate (Roundup®) were made 1 month prior to planting and again in the winter 1 to 2 months after planting for weed control. The herbicide was applied in a 150 cm radius around the planting site, avoiding the area immediately adjacent to the planting site in the postplanting application. A drip irrigation treatment was also tested in the untilled portion of field 3. Plants were irrigated once weekly with 20 L of water per site, starting 13 May 1990.

The basic planting was set up as a 3 by 2 by 2 factorial: three fields with nontilled/tilled and nonmulched/mulched treatments in each. Twenty sites were planted for each treatment. The three treatments tested in addition to the 12 treatment combinations from the factorial design were:

WI 3. Field 2, nontilled, nonmulched, herbicide.

W14. Field 3, nontilled, nonmulched, irrigated.

W15. Field 3, nontilled, mulched, irrigated.

Heavily-browsed natural valley oak seedlings and saplings were located in some parts of field 1. On 6 June 1989, we set up several types of protective cages around 26 of these seedlings and saplings. An additional 27 unprotected valley oak seedlings and saplings were paired with nearby protected plants of similar height and condition. Four protected and six unprotected saplings were located within an area bounded by a 120 cm tall barbed wire fence that excluded cattle but not deer. Heights of all seedlings and saplings were measured at the start of the experiment and remeasured on 21 August 1990.

Cosumnes

The Cosumnes River Preserve is on level ground in the Sacramento Valley. We set up two experiments in a 4 acre field which had been cleared and leveled long before acquisition by The Nature Conservancy. The field is bordered by a slough with a narrow band of existing valley oak riparian forest and is infrequently flooded in the winter. The soil is a poorly drained sandy clay loam underlain by calcareous clay and a hardpan at varying depths throughout the field. Herbaceous vegetation varies throughout the field, but is generally dominated by a variety of introduced winter and summer annual grasses and forbs.

An ongoing program of valley oak restocking has been underway at the preserve, and our experimental sites were planted by Conservancy volunteers according to the standard procedures at the preserve. Planting sites were prepared by scraping all vegetation off the soil surface in a 0.5 m radius circle. Two acorns were planted at each site within a 12 cm diameter plastic collar that extended approximately 12 cm below ground. A cylinder of aluminum window screen extending about 30 cm above ground level and folded closed at the top was attached to the top of the plastic collar (Bush and Thompson 1989), and served as the only protection against vertebrates. The screen cages were opened on top when seedlings shoots reached the tops of the cages. Planting sites are arranged on a regular grid and spaced about 3 to 4 m apart.

Since plantings were already in place at the start of our project, we limited our treatments to modifications of the Preserve's currently used post-planting inputs. Sites are routinely irrigated biweekly from the beginning of June through the end of August via drip irrigation with approximately 32 L applied per irrigation. Our experimental treatments included the reduction of irrigation frequency from biweekly to monthly, foregoing irrigation entirely, and using a mulch around the planting site for weed control and moisture conservation.

In plot 1, on the southern end of the field, a 2 by 2 factorial design was employed to test effects of irrigation frequency (2 or 4 week) and mulching, with 53 to 55 sites per treatment. Hay mulch was applied to mulched treatments on 31 May 1989. On

the northern portion of the field (plot 2), alternate rows received the standard biweekly irrigation (67 sites) or were not irrigated (79 sites). All irrigated treatments received their first irrigation on 2 June 1989. Planting sites where seedlings were already dead or had not emerged by 31 May 1989, were excluded from the experiments. Some sites were lost in 1990 when a fire break was plowed along one side of the planting. Height data was recorded every 2 weeks throughout the irrigation season in 1989 and 1990, and heights at the end of the first season were recorded 21 November 1989.

RESULTS

Seedling Emergence

At Vacaville, overall, 61 percent of planted acorns produced seedlings. The percent of sites with at least one emerged seedling did not differ significantly between treatments or fields, and ranged between treatments from 89 to 100 percent. When monitoring the planting in the spring of 1990, we found that the landscape fabric was misaligned at many of the sites. To ensure seedling emergence, we enlarged the slits in the fabric or repositioned shoots that were trapped under the fabric. Had this not been done, overall emergence in the fabric mulched sites would have been decreased.

At Pepperwood, 47 percent of the planted acorns produced seedlings. Emergence by planting site was significantly higher overall in the grazed field (89 percent) than in the nongrazed field (74 percent). Emergence by site was greatest overall in the wood chip mulch treatment (96 percent) and lowest overall in the nonmulched treatment (73 percent). While rates of emergence for these treatments were similar in both fields, emergence through the landscape fabric mulch was much lower in the nongrazed field (58 percent of sites) than in the grazed field (95 percent of sites).

At Wantrup, 53 percent of the planted acorns produced seedlings. There were no significant differences in emergence between the three fields. A significantly higher percentage of nonmulched sites (87 percent) had emerged seedlings than did mulched sites (77 percent). Emergence was also higher in sites that had been tilled (92 percent) than in the nontilled sites (71 percent).

Seedling Growth

At Vacaville, average heights of the tallest seedling at each site differed significantly between treatments and hillsides in the 2-way analysis of variance. Even though cattle were on the fields at Vacaville for only 4 to 6 weeks, the average height of unprotected seedlings was significantly less than that of protected seedlings (below). There was no significant difference in height between seedlings in deep probe and shallow probe sites, or between those in augered and nonaugered sites. Among seedlings protected from cattle browsing, those mulched with fabric were significantly taller than nonmulched seedlings. Average seedling heights for all treatments were as follows:

Treatment	Average seedling height (cm) East hill	West hill
V1. No protection	12	8
V2. Vaca cage, deep probe	17	16
V3. Vaca cage, shallow probe	18	14
V4. Vaca cage, fabric mulch, nonaugered	24	20
V5. Vaca cage, fabric mulch, augered	21	23

The irrigated treatment (P4) was not included in the 2-way analysis of variance for Pepperwood, since it was not replicated in both fields. In the 2-way analysis, average seedling heights were significantly greater in the grazed field than in the nongrazed field, and nonmulched seedlings were significantly shorter than those in either of the mulched treatments:

Treatment	Average seedling height (cm) Nongrazed	Grazed
P1. No mulch	8	9
P2. Chip mulch	10	13
P3. Landscape fabric	10	12
P4. Irrigated	11	—

In the 1-way analysis of variance for treatments in the nongrazed field, which included the irrigated treatment, there was no significant treatment effect on seedling height.

At Wantrup, average heights of the tallest seedling ranged from 8 cm in the nonmulched, nontilled treatment in field 1, to 16.5 cm in the irrigated, mulched treatment in field 3. Seedling heights in the irrigated treatments did not differ significantly from those in nonirrigated mulched treatments in the 1-way analysis of variance of all treatments. Seedling heights in the herbicide treatment were near the overall average for all treatments.

We conducted a 2-way analysis of variance of the data from field 3, with mulching and 'method' (nontilled/nonirrigated, tilled/nonirrigated, and nontilled/irrigated) as the main effects. Both mulching and `method' were significant in the analysis of variance, but the interaction term was not. Mulched seedlings were significantly taller than nonmulched seedlings, and irrigated seedlings were significantly taller than those in the other two 'methods'.

Irrigated and herbicide treatments were omitted from the 3-way analysis of variance comparing the effects of fields, tillage, and mulching. In the full interaction model, only fields and mulching significantly affected seedling height. Overall least square means of mulched seedling heights were 12 cm compared to 10 cm for nonmulched seedlings. Seedlings growing in field 3 were significantly taller (12 cm) than those in field 1 (10 cm).

Established natural seedlings and saplings at Wantrup that were protected from grazing grew significantly more than those left unprotected:

Average height change (cm) from 6 June 89 to 21 Aug 90	Protected seedlings	Unprotected seedlings
Area grazed by cattle and deer	+24	-5
Area grazed by deer only	+27	+2

Although deer were highly effective at suppressing height growth, saplings browsed only by deer did not exhibit net height decreases, as was common in the saplings exposed to cattle.

By August of the first growing season (1989), seedlings in mulched sites were significantly taller than those in nonmulched sites at Cosumnes Plot 1, but the effect of irrigation frequency was nonsignificant (table 2). Due to the amount of deer browsing that occurred in the plot in 1990, we analyzed the maximum seedling height recorded during the season rather than the final heights recorded in August 1990. In this analysis, effects of both irrigation frequency and mulch on total height were significant (Table 2). We analyzed second season growth with analysis of covariance, using height in November 1989 as the covariate to correct for the influence of initial height on second-season growth. In this analysis, the differences between maximum height in 1990 and height in November 1989 did not vary significantly with treatment, although the effect of initial height was highly significant.

In plot 2, there was no effect of irrigation on height the first summer but a significant increase in height with irrigation the second summer. The large increase in height with irrigation evident the second year (table 2) was at least partially due to increased shoot survival in the irrigated seedlings. Since many of the nonirrigated seedlings were resprouts, their shoots were shorter than those in the irrigated treatment which were able to make continued growth from the previous year's stems. The average soil depth to hardpan was shallower in plot 2 than in plot 1, and irrigated seedlings in plot 2 were considerably shorter than seedlings in plot 1 which received the same amount of irrigation (table 2).

Table 2—*Average height (cm) and percent of valley oak seedlings browsed at Cosumnes Franklin Plots 1 and 2.*

Treatment	Height 9 22 Aug 8	Max Height 21 Aug 90	Pct browsed
Plot 1:			
Mulched, 2 week irrig	36	62	71
No mulch, 2 week irrig	27	49	53
Mulched, 4 week irrig	33	55	63
No mulch, 4 week irrig	24	39	37
Plot 2:			
No mulch, 2 week irrig	16	31	22
No mulch, no irrig	14	19	3

Seedling Condition

Vaca cages and deer cages installed at Vacaville, Pepperwood, and Wantrup effectively prevented browsing of seedlings by large herbivores. Deer cages in the nongrazed areas were unmolested, but some of the Vaca cages were damaged by cattle. The most common damage was denting of the wire cylinder, which did not usually impair the cage's function. At Wantrup, light weight vineyard posts were used in place of T-posts, and 11 percent were bent by cattle. In other locations, T-posts were sometimes tilted when pushed by cattle when the soil was wet (7.6 percent at Pepperwood, 0.8 percent at Vacaville). Fourteen gauge wire mesh Vaca cages used at Wantrup were also more seriously bent than the 12 gauge cages used at Vacaville and Pepperwood. Rarely, cattle were able to completely dislodge the protective cage. Two cages (0.8 percent) were removed by vandals at Vacaville, but were located and replaced.

At Vacaville, overall 79 percent of the seedlings which emerged were still green on 27 August 1990. Browsing damage to seedlings was visible in 26 percent of the uncaged (VI) sites and in 1 percent of the protected sites. Only 3 percent of the sites showed evidence of rodent digging and seedlings in 5 percent of the sites showed foliar damage from chewing insects.

At Pepperwood, 97 percent of the seedlings were still green on 24 August 1990. Seedlings in 13 percent of the sites showed evidence of having been browsed, presumably by gophers, mice, or voles. There was significantly more browsing in the nongrazed field than in the grazed field, and browsing was most common in the chip mulch treatment (P2). Only 4 percent of the sites showed evidence of rodent digging and 4 percent of the sites showed foliar damage from chewing insects.

At Wantrup, the percentage of green seedlings in all treatments dropped from 87 percent on 1 July to 50 percent on 1 August, and to 22 percent by 21 August 1990. This decrease was not due solely to lack of moisture, because shoot survival in the irrigated treatment dropped from 72 percent on August 1 to 27 percent by August 21. Stem girdling caused by either small rodents or insects was apparently the cause of at least some of the observed shoot mortality. Within field 3, seedlings at 96 percent of the irrigated sites were girdled, whereas seedlings at 54 percent of the nontilled sites and 32 percent of the tilled sites showed similar damage. This symptom was not observed in field 1. Overall, 6 percent of the sites showed foliar insect chewing damage.

Although seedlings in only 0.8 percent of the sites were browsed, 14 percent of sites were disturbed by rodent digging. Eighty-three percent of all disturbed sites occurred in field 1 near the active ground squirrel colony. In this field, rodent digging was significantly more common in the nonmulched sites (58 percent) than in the mulched sites (30 percent). In field 1, 76 percent of undisturbed sites but only 31 percent of the disturbed sites contained seedlings with live shoots by 21 August.

At Cosumnes plot 1, seedlings in only 3 sites (1.4 percent) had died by 21 August 1990. In plot 2,4 percent of the plants in the irrigated treatment, but 43 percent of the plants in the nonirrigated treatment, died during the first summer and did not resprout in 1990. Thirty-seven percent of those seedlings in the nonirrigated treatment whose shoots died the first season resprouted from the crown in 1990. In plot 2 in 1990, 39 percent of the nonirrigated seedlings, but only 2 percent the irrigated seedlings were resprouts. The seedlings at Cosumnes were not

protected from deer once they grew beyond the screen cages. The frequency of browsing damage during the summer of 1990 increased with increasing seedling height (table 2).

DISCUSSION

Choosing methods for planting valley oaks in rangeland situations involves trading off the costs of cultural inputs with desired and expected survival and growth rates. The increase in growth and survival that may be obtained with high levels of cultural inputs must be balanced against the additional cost and effort expended. Furthermore, cultural inputs may have unexpected negative consequences as well as positive effects, and the balance between positive and negative effects may vary from site to site. Finally, if the limiting factors at the planting site are not adequately characterized, cultural inputs may overcome one set of limiting factors only to have growth and survival limited by other factors.

Although caging individual planting sites is relatively expensive in terms of materials and labor, our data and previous reports (Griffin 1971, Rossi 1980) indicate that protection from browsing is necessary where restocking is to occur in areas grazed heavily by either cattle or deer. Where existing seedlings or saplings can be located, such as at Wantrup, caging to protect against deer and cattle may be the only input required for restocking. Furthermore, overall costs can be reduced if cages are removed and reused after trees have grown above the browse line.

In our experience, protecting seedlings with either Vaca or deer cages has not been associated with any obvious negative effects. However, Vaca cages may require maintenance, since they can be damaged by cattle. It may be possible to reduce or eliminate maintenance requirements by using higher grade materials. For example, substituting a second T-post for the rebar stake would substantially increase the strength of the cage, but would require a higher initial investment in materials and labor. Damage to Vaca cages was lowest at Vacaville, where the period of grazing was relatively short, indicating that damage may increase with the intensity or duration of grazing. Thus, the grazing pattern should also be considered when weighing the costs and benefits of different cage designs and materials.

The necessity of protecting against damage by rodents to obtain adequate restocking is less certain. The impact of rodent herbivory on seedling establishment and growth are highly variable from location to location. For example, while Griffin (1980) reported extensive seedling destruction by gophers in the Carmel Valley, others (Knudsen 1987, Bush and Thompson 1989) found that seedling losses due to gophers were relatively minor. Knudsen (1987) blamed mice and voles for seedling and acorn losses of valley oak. An unprotected planting of valley oaks was completely destroyed by ground squirrels within weeks in a heavily-infested area in Cheseboro Canyon, whereas 60 to 100 percent of the protected seedlings in the same area survived the first year (Pancheco 1987).

In our sites, damage by rodents was insignificant at Vacaville and the nongrazed field at Pepperwood, despite a complete lack of protection against rodents. In contrast, rodent damage, primarily caused by ground squirrels, significantly reduced shoot survival in field 1 at Wantrup. However, since severe rodent damage was localized near an obviously active colony, reasonable control of rodent damage could be obtained at this location by simply avoiding the most heavily colonized portions of the field. The cup and screen planting method, which was used at Cosumnes, was developed in part to protect seedlings from herbivory by rodents and insects. However, due to the variable nature of rodent damage, and the low overall incidence of insect damage, this particular input is probably unnecessary in many locations. Furthermore, in favorable sites, screens must be opened within the first growing season to accommodate seedling growth. Considering the labor required for installation and follow-up maintenance, the relatively short period of protection provided, and the need for supplemental protection in areas grazed by cattle or deer, the usefulness of this technique for valley oak restocking may be limited to rather specific situations.

Competition for soil moisture may be an important factor limiting natural regeneration in many areas. Introduced Mediterranean annual grasses and forbs have largely replaced native perennial bunchgrasses in the oak understory (Gordon and others 1989). There is experimental evidence to support the widely-held belief that introduced annual grasses and taprooted forbs deplete soil moisture more rapidly than native perennial grasses (Danielsen 1990, Gordon and others 1989). Knudsen (1987) noted that survival of natural valley oak seedlings increased as grass density decreased. Griffin (1971) obtained 100 percent seedling establishment from valley oak acorns planted in cleared plots during a drought year (1967-68), while all seedlings died by May in adjacent grassy plots.

Methods to conserve soil moisture include mulching and weed control. Both the synthetic and organic mulches we used significantly increased seedling height at every location, and data from Cosumnes showed a clear benefit of mulching even among irrigated sites. Mulch not only conserves soil moisture but also serves to moderate soil temperatures (Brady 1974), which may have a beneficial effect on root growth. At Pepperwood, wood chip mulch was as effective as landscape fabric in promoting emergence and growth, and may be the preferred treatment because of the lower input required.

Irrigation is commonly used to augment soil moisture. However, the relatively high cost of materials (table 1) and labor associated with this input generally limits its use in extensive restocking of rangelands. Although irrigation increased seedling growth at Cosumnes and Wantrup, it had no significant effect on seedling height in the first season at Pepperwood. Furthermore, shoot survival at Wantrup was not significantly better in the irrigated treatment than in several of the nonirrigated mulched treatments. Continued monitoring of long-term growth and survival is necessary to determine the relative effectiveness of moisture conservation versus augmentation. However, we

were able to successfully establish moderate to high percentages of oak seedlings without irrigation in several locations in the third year of drought conditions.

Several cultural inputs showed unexpected negative consequences. At Wantrup, irrigated seedlings suffered more chewing damage to their stems than did nonirrigated seedlings, resulting in decreased shoot survival rates. Although mulch increased seedling growth, some mulched treatments showed lower rates of seedling emergence. At the Vacaville site, we found that the installation method we used frequently resulted in faulty alignment of the slits in the landscape fabric relative to the emerging seedlings. We expect that this problem may also have contributed to the low emergence at sites mulched with landscape fabric in the grazed field at Pepperwood. The hay mulch used at Wantrup may also have acted as a barrier to seedling emergence.

In some cases, cultural inputs may overcome one set of limitations only to have growth and survival limited by other factors. For example, at Cosumnes, irrigation is being used to accelerate plant growth by alleviating soil moisture limitations. As a result, browsing by deer may now be the most important factor limiting plant growth. Data collected during 1990 showed that the deer most frequently browsed taller seedlings (table 2). We believe that the lack of significant treatment effects on growth from November 1989 to August 1990 may in large part be due to deer browsing of the most vigorous seedlings. Due to the high planting density at this site, some seedlings may be able to escape deer browsing long enough to get above the browse line. However, in areas with high deer populations and low tree densities, even frequent irrigation may not accelerate plant growth enough to offset deer browsing impacts.

The effects of the treatments presented here are known only for the first 1 to 2 seasons after planting. However, it does appear that valley oaks can be restocked using low input techniques tailored to overcome site limitations. Continued monitoring of the plantings will be necessary to determine if treatment effects persist or become damped out as seedlings become more established. Results from previous projects (Swiecki and Bernhardt 1990) indicate that long-term survival may bear little relation to first year survival. With longer-term survival data, the cost-effectiveness of the different inputs could be calculated on the basis of the cost in materials and labor per each successful seedling.

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Valley Oak Seedling Growth Associated with Selected Grass Species[1]

Karen C. Danielsen William L. Halvorson[2]

Abstract: Valley oak (*Quercus lobata* Née) has exhibited inadequate regeneration since the last century. Seedlings become established, but few develop into saplings. We hypothesized that the invasion of alien annual grasses into native perennial grasslands has increased oak seedling mortality by decreasing soil moisture availability. We conducted greenhouse experiments to test if the alien annual grass *Avena fatua* L. and the native perennial grass *Stipa pulchra* Hitchc. differentially effect soil moisture and valley oak seedling growth. Results showed that valley oak seedlings in the *A. fatua* treatments grew significantly smaller than seedlings in the *S. pulchra* treatments. In addition, valley oak seedling growth showed a positive correlation with soil moisture during the growing season. The results suggest that the introduction of alien annual grasses has reduced valley oak seedling growth and survivorship by limiting soil moisture availability.

It appears that, since the early 1900's, valley oaks have shown limited regeneration because of high seedling mortality (Griffin 1976, Bartolome and others 1987). Just prior to this time period, settlers introduced alien annual plants both accidently and purposely. These alien plants replaced much of the native plant species composition which, according to some researchers (Clements 1934, Beetle 1947, Barry 1981), consisted primarily of perennial bunchgrasses. Presently, alien annual grasses dominate valley oak habitat (Swirsky and Halvorson 1984, Swirsky 1986). Some researchers have suggested that this replacement of native grasses by alien grasses may be linked to the observed high seedling mortality (Welker and Menke 1987, McCreary 1989).

Field surveys revealed that soil moisture generally measured lower in alien grasslands than in native grasslands during the growing season (White 1967, Hull and Muller 1977). Jackson and Roy (1986) demonstrated that annual grasses grow and utilize soil moisture faster than perennial grasses. This faster rate of decline in soil moisture associated with alien annual grasses may be a significant factor effecting valley oak seedlings.

Phytophysiological studies demonstrated that when soil moisture declines slowly oak seedlings avoid water stress by accumulating solutes in their cells which promotes the influx of water. The accumulation of solutes lowers cell water potential without significantly reducing cell water content. If soil moisture declines too rapidly, however, water content decreases before cellular solutes can accumulate and water stress ensues (Osonubi and Davies 1981, Flower and Ludlow 1986, Welker and Menke 1987, Gordon and others 1989). Water stress limits plant growth (Kramer 1969, Matthews and Boyer 1984) and eventually results in the collapse of cell walls and senescence of the plant (Flower and Ludlow 1986). Consequently, competition for water by alien annual grasses may induce severe water stress in valley oak seedlings that results in slowed growth and ultimately death.

This paper reports on a greenhouse experiment designed to determine if valley oak seedlings established with alien grasses experience reduced growth as compared to those established with native grasses. We conducted a second greenhouse experiment to compare the soil moisture associated with alien and native grasses.

METHODS

Seeds of valley oak; the native perennial grass, *Stipa pulchra;* and the alien annual grass, *Avena fatua,* were collected from the Santa Monica Mountains of the Transverse Ranges north of Los Angeles, CA. The experiments were conducted in the greenhouse of California State University, Los Angeles.

In the first experiment, we measured valley oak seedling growth using waxed cardboard tubes lined with polyethylene bags as planting containers.

During the first week of December 1987, we planted *A. fatua* seeds into each of 50 containers (density = 2000/m^2), and we transplanted one-year-old *S. pulchra* plants into each of another 50 containers (basal cover = 11 percent). Density and basal cover approximated field conditions (Heady 1958, White 1967, Gordon and others 1989). Last, we left 50 containers devoid of grasses for controls. During the last week in December, after the grasses had become established, we planted one germinated acorn per container.

Throughout the experiment, we watered 75 of the containers to simulate dry years (25 for each grass treatment) and 75 to simulate wet years. Dry year treatments received 5 times less water than wet year treatments. Precipitation data from the Santa Monica Mountains (U.S. Weather Bureau) served as a basis to determine this watering regime.

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In February 1988, as valley oak seedling shoots emerged, we initiated the biweekly recording of the growth measurements: height, number of leaves, and length of the largest leaf. In September 1988, we removed the valley oak seedlings and recorded final root and shoot lengths and dry weights.

In the second experiment, we measured soil moisture between December 1988 and May 1989. We used an experimental design similar to that used in the growth experiment. However, we did not use controls, and we reduced the sample size of each grass treatment to 10 containers. Each month we extracted two soil samples from different levels from each container. We measured the soil moisture (water potential) of the samples using a thermocouple psychrometer (Decagon SC-10). For further details on methodology and data analysis refer to Danielsen (1990).

RESULTS

Growth Experiment

In all treatments, valley oak seedling shoots emerged during February and March (*fig. 1*). Though all acorns were viable and developed roots, some never developed shoots; particularly in the *Avena fatua* treatments.

Seedling Growth Experiment

Simultaneous analysis of seedling height, number of leaves, and length of largest leaf for the sampling dates combined (*fig. 2* and *3*) showed that seedlings in the controls grew significantly larger than seedlings in the grass treatments for both the dry and wet year regimes (canonical variates test, sample size = number of emerged shoots, probability <.05). Between grass treatments, seedlings in the *S. pulchra* treatments grew significantly larger than seedlings in the *A. fatua* treatments.

A comparison of the maximum averages for each growth variable (*table 1*) further illustrates that seedlings grew largest in the controls and smallest in the *A. fatua* treatments. Data for each growth variable and sampling date were analyzed separately (Kruskal-Wallace test). For all three growth variables in both the dry and wet year regimes, significant differences between the controls and the grass treatments and between the differing grass treatments occurred during March and April.

From May through August, significant differences continued to occur for all three growth variables between the control and grass treatments. Between the grass treatments, significant differences continued to occur for the height and length of largest leaf variables.

Seedling Root and Shoot Measurements

Seedling roots and shoots in the controls were significantly longer and heavier than those in the grass treatments in both the dry and wet year regimes (*tables 2* and *3*). Between the grass treatments, in the dry year regime, seedling shoots in the *S. pulchra* treatments were significantly longer and heavier than those in the *A. fatua* treatments.

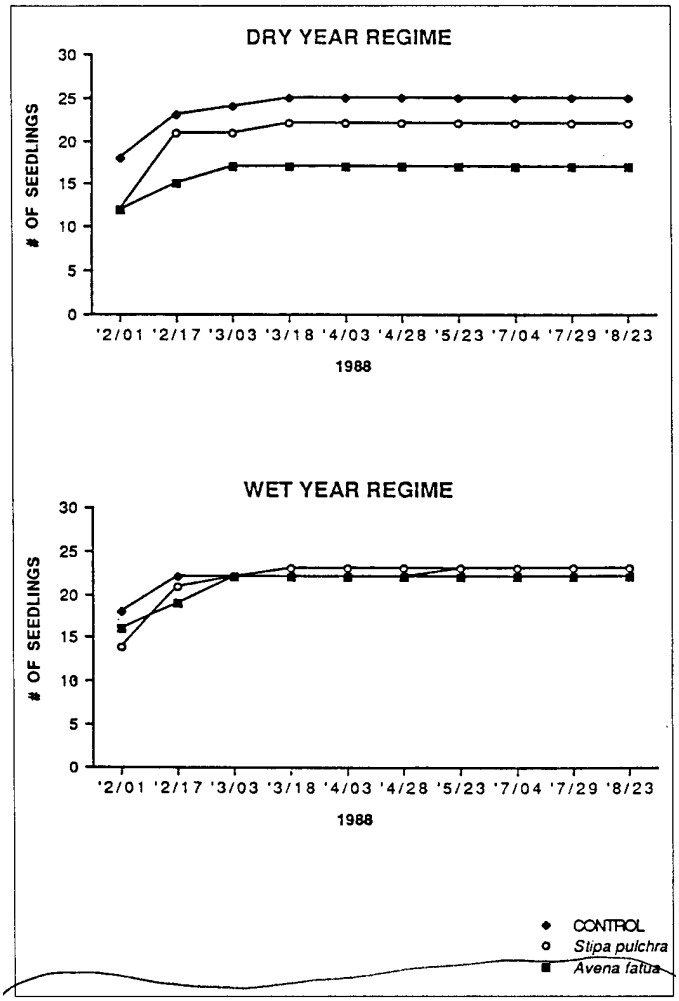


Figure 1—Number of valley oak seedlings with emerged shoots for each sampling date.

Root/shoot ratios were calculated to determine allocation of biomass. Valley oak seedlings in the *A. fatua* treatments showed greater root/shoot ratios than seedlings in the controls or *S. pulchra* treatments. Dry weight root/shoot ratios, in the dry year regime, averaged 10.0 in the *A. fatua* treatments, 3.7 in the *S. pulchra* treatments, and 5.9 in the controls. In the wet year regime, dry weight root/shoot ratios averaged 6.0 in the *A. fatua* treatments, 2.6 in the *S. pulchra* treatments, and 4.0 in the control treatments. Length root/shoot ratios, in the dry year regime, averaged 8.3 in the *A. fatua* treatments, 3.9 in the *S. pulchra* treatments, and 2.8 in the controls. In the wet year regime, length root/shoot ratios averaged 5.1 in the *A. fatua* treatments, 3.4 in the *S. pulchra* treatments, and 2.2 in the controls.

Soil Moisture Experiment

Soil water potentials remained high in both grass treatments from December through February. The maximum mean soil

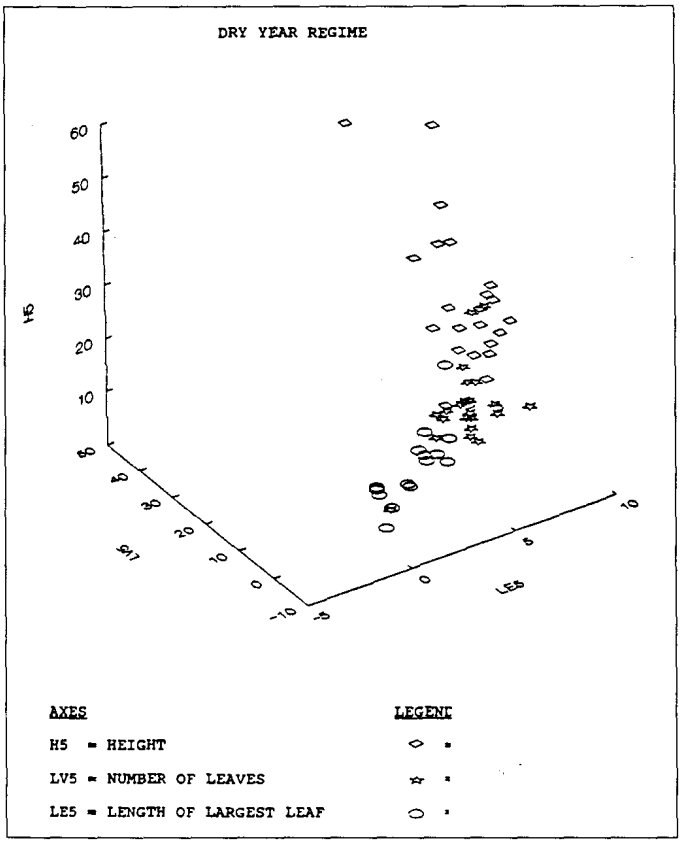


Figure 2—Overall growth in dry year regime: height, number of leaves, and length of largest leaf were plotted for each valley oak seedling with respect to grass treatment for sampling date, 3 April 1988. Simultaneous analysis of these growth variables for the sampling dates combined showed significant differences between the control and grass treatments and between the differing grass treatments (canonical variates test, N=# of seedlings with emerged shoots, p<.05).

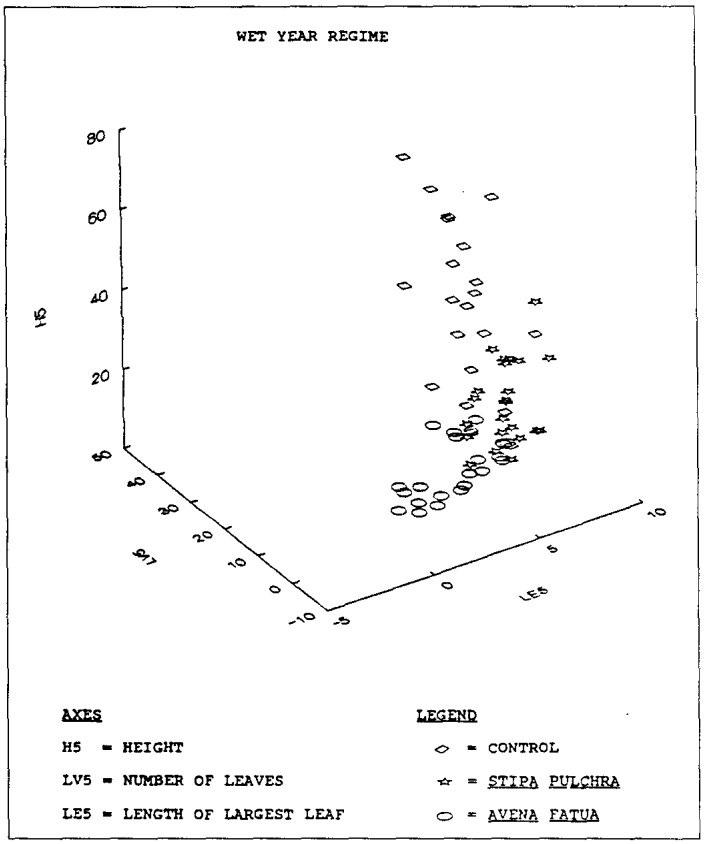


Figure 3—Overall growth in wet year regime: height, number of leaves, and length of largest leaf were plotted for each valley oak seedling with respect to grass treatment for sampling date, 3 April 1988. Simultaneous analysis of these growth variables for the sampling dates combined showed significant differences between the control and grass treatments and between the differing grass treatments (canonical variates test, N=# of seedlings with emerged shoots, p<.05).

water potential during December measured -425.6 (38.08 SE) J/kg.

During March, potentials decreased; particularly in the *A. fatua* treatments. In the dry year regime, upper level mean potentials measured only 3 percent of the maximum measured in December in the *A. fatua* treatments and 6 percent in the *S. pulchra* treatments. Lower level mean potentials measured 6 percent of the maximum measured in December in the *A. fatua* treatments and 8 percent in the *S. pulchra* treatments. In the wet year regime, upper level mean potentials measured 9 percent of the maximum in the *A. fatua* treatments and as much as 58 percent in the *S. pulchra* treatments. Lower level mean potentials measured 9 percent of the maximum in the *A. fatua* treatments and 70 percent in the *S. pulchra* treatments. Analysis of the soil water potential data in March showed significant differences between the grass treatments at both levels in the wet year regime (Mann-Whitney U-test, sample size = 5, p<.05).

During April, in the wet year regime, mean potentials remained lower in the *A. fatua* treatments than those in the *S. pulchra* treatments (2 percent and 5 percent of the maximum, respectively, at the upper level; and 7 percent and 12 percent of the maximum at the lower level). In the dry year regime, mean potentials in the *A. fatua* treatments actually increased at the lower level. The senescence of the *A. fatua* resulted in potentials equal to or higher than those in the *S. pulchra* treatments (upper level: 1 percent of the maximum in both treatments; and lower level: 12 percent of the maximum in the *A. fatua* treatments and 7 percent in the *S. pulchra* treatments). Analysis of the soil water potential data in April showed no significant differences between the grass treatments.

DISCUSSION

Indications of water stress in valley oak seedlings were most prevalent in the *Avena fatua* treatments, followed by the *Stipa pulchra* treatments, and finally the controls. Oak seedlings allocate water and, subsequently, biomass in order of roots, stems, and leaves. Consequently, during the growing season, oak seedlings initially respond to water stress with reduced leaf growth (Kramer 1969). Seedling leaves measured significantly smaller in the *A. fatua* treatments than in the *S. pulchra* treatments or the controls. Furthermore, seedlings in the *A. fatua*

Table 1—*Maximum averages of valley oak seedling height (measured in centimeters), number of leaves, and length of largest leaf with respect to grass treatment. Standard error in parentheses. For all three growth variables in both the dry and wet year regimes, significant differences occurred between the control and grass treatments and between the differing grass treatments (Kruskal-Wallace test, N=# of seedling emerged, p<05).*

	HEIGHT (CM)	# OF LEAVES	LENGTH (CM)
PRY YEAR REGIME			
Control	28.7 (2.41)	20.8 (l.75)	7.5 (0.22)
S. pulchra	12.3 (l.34)	8.8 (0.71)	6.0 (0.17)
A. fatua	6.7(l.16)	6.2 (0.55)	4.0 (0.47)
WET YEAR REGIME			
Control	38.1 (4.56)	29.0 (2.89)	7.3 (0.28)
S. pulchra	17.2(l.72)	9.7 (0.67)	6.6 (0.32)
A. fatua	10.8 (1.31)	6.8 (0.57)	4.0 (0.26)

Table 2—*Valley oak seedling average root and shoot lengths (cm); final measurements. RL=root length and SL-shoot length. Standard error in parentheses.*

	RL	SL	RS/SL
DRY YEAR REGIME			
Control	92.8 (3.89)	33.7 (3.55)	2.8
S. pulchra	69.7 (3.79)	17.9 (2.04)	3.9
A. fatua	65.5(l.97)	7.9(l.47)	8.3
WET YEAR REGIME			
Control	89.5 (4.23)	39.9 (4.96)	2.2
S. pulchra	74.3 (3.64)	21.7 (2.22)	3.4
A. fatua	72.2 (3.01)	14.1 (1.55)	5.1

Table 3—*Valley oak seedling average root and shoot dry weights (gm); final measurements. RW=root dry weight and SW-shoot dry weight. Standard error In parentheses.*

	RW	SW	RW/SW
DRY YEAR REGIME			
Control	13.0 (0.88)	2.2 (0.22)	5.9
S. pulchra	1.1 (0.07)	0.3 (0.03)	3.7
A. fatua	1.0 (0.07)	0.1 (0.02)	10.0
WET YEAR REGIME			
Control	13.3(l.55)	3.3 (0.45)	4.0
S. pulchra	1.3 (0.19)	0.5 (0.08)	2.6
A. fatua	1.2 (0.12)	0.2 (0.03)	6.0

treatments produced the fewest number of leaves.

A high root-to-shoot ratio also indicates water stress (Gordon and others 1989). The valley oak seedling root/shoot ratio for the length measurement averaged highest in the *A. fatua* treatments and lowest in the controls. The root/shoot ratio for the dry weight measurement averaged highest in the *A. fatua* treatments and, interestingly, lowest in the *S. pulchra* treatments; not in the controls. Roots of seedlings in the controls, unlike in the grass treatments, developed woody tissue. Therefore, in the controls, secondary growth, not necessarily water stress, produced higher weight root/shoot ratios. Nevertheless, the resulting root/shoot ratios demonstrate that seedlings in the *A. fatua* treatments experienced the greatest water stress.

As previously mentioned, oak seedlings exposed to a rapid decline of soil moisture experience water stress and display reduced growth during the growing season. Oak seedlings exposed to a slower decline of soil moisture are subjected to less water stress, through physiological adjustments, and continue growth. *A. fatua* grew rapidly in February and March, and reduced available soil moisture. *S. pulchra* grew more slowly and utilized less soil moisture. The valley oak seedlings grew largest in the controls, next largest in the *S. pulchra* treatments and smallest in the *A. fatua* treatments.

In April, *A. fatua* became senescent and soil water absorption decreased. *S. pulchra* growth accelerated with an accompanying increase in soil water absorption. In the dry year regime, soil water potentials were higher in the *A. fatua* treatments than in the *S. pulchra* treatments. In the wet year regime, available soil moisture in the *A. fatua* treatments allowed the development of new leaves on four valley oak seedlings. However, seedlings remained significantly larger in the *S. pulchra* treatments than in the *A. fatua* treatments.

In this experiment, valley oak seedlings grew most rapidly in February and March. During this growing season, soil water potentials corresponded with valley oak seedling growth. After the growing season, soil water potentials failed to significantly alter established seedling growth patterns. Consequently, the phenology of the different grass species, and the resulting soil moisture availability during the growing season, determined the ultimate size of the valley oak seedlings.

Other studies have obtained similar results. Adams and others (1987) observed reduced seedling survival of valley oak and blue oak (*Quercus douglasii* H.& A.) in the presence of alien annuals. Gordon and others (1989) documented a significant positive correlation between soil moisture availability associated with alien annuals and blue oak seedling growth. Welker and Menke (1987) noted that soil moisture loss caused by decreased amounts of mulch resulting from cattle grazing also limits blue oak seedling growth.

CONCLUSION

In this research, associated grasses inhibited the growth of valley oak seedlings. The particular species of grass, however, determined the degree of inhibition. Seedlings in the *Stipa pulchra* (a native grass species) treatments grew significantly larger than seedlings in the *Avena fatua* (an alien grass species) treatments. Furthermore, soil moisture measured lower in the grass treatments, particularly in the *A. fatua* treatments, and thus correlated with seedling growth. Therefore, these results suggest that the replacement of native perennial grasses by alien annual grasses has reduced valley oak seedling growth and survivorship by limiting soil moisture availability.

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Effect of Acorn Planting Depth on Depredation, Emergence, and Survival of Valley and Blue Oak[1]

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Abstract: During 1989 in east-central San Luis Obispo County, California, we studied the relationship of valley oak (*Quercus lobata*) and blue oak (*Q. douglasii*) acorn planting depth and number of acorns per planting site to acorn depredation, seedling emergence, survival, and height. Acorns were planted at three depths (1.3, 5.1, and 10.2 cm) at each of 960 planting sites with one or three acorns per site. Animal depredation of acorns was significantly ($P < 0.05$) greater for valley oak and seedling emergence and survival were significantly higher for blue oak. Depredation of valley oak acorns decreased significantly with deeper planting; depredation of blue oak acorns was significantly greater at the most shallow planting depth than at the two deeper depths where it was about the same. Although between-depth differences were not significant ($P > 0.05$), seedling emergence and survival of valley oak seedlings at the two deepest planting depths were better and almost identical. Conversely, blue oak seedling emergence and survival were significantly better at the two most shallow planting depths, and there was a strong, but insignificant, trend toward the best blue oak emergence and survival at the 5.1-cm depth. Regardless of planting depth, planting several acorns per planting site significantly decreased depredation and increased seedling emergence and survival for both oaks, and height for valley oak. Study results indicate that under the environmental conditions at the study site, the 5.1 cm (2 in) planting depth provided the best balance between lesser acorn depredation and greater seedling emergence and survival for blue oak; the 5.1 cm and 10.3 cm (4 in) depths provided the best balance for valley oak.

Poor natural regeneration of several of California's native oaks (*Quercus* spp.) has increasingly been recognized. Blue and valley oak are not regenerating sufficiently to maintain current stand densities. Factors that contribute to the regeneration problem include conversions of oak woodlands to urban and agriculture lands, increased fuelwood cutting, and competition from introduced Mediterranean annual grasses.

Artificial regeneration is an important option available for replacement of lost oaks. Although successful oak regeneration techniques have been developed (Griffin 1971; Russell 1971; Wright and others 1985; Johnson and Krinard 1985; Johnson and others 1986; Vande Linde 1987; McCreary 1989), animal depredation of direct-planted acorns is a common problem. Studies have examined several methods to reduce animal depredation. Johnson and Krinard (1985) concluded that a large-sized clearing around the planting site minimized animal damage. Russell (1971) believes that effective repellents would be a cost-efficient animal deterrent which needs to be developed. Cages surrounding planting sites keep animals out (Adams and others 1987), but are also expensive and take time to install.

Acorns planted at or just under the soil surface are more likely to be depredated than acorns planted at deeper depths (Russell 1971; Griffin 1971; Johnson and Krinard 1985; Borchert and others 1989). Optimal planting depth, however, has not been determined, at least not for California oaks. This paper reports on the response, in terms of animal depredation, seedling emergence, survival, and growth to valley and blue oak acorn planting depth and number of acorns planted per planting site.

STUDY AREA

The study site was established on the Santa Margarita Ranch in east-central San Luis Obispo County about 23 km northeast of San Luis Obispo (fig. 1). The climate of the area is Mediterranean, characterized by warm, dry summers and cool, wet winters. Average monthly temperatures range from 8° C in January to 23° C in July. Average annual rainfall totals about 53 cm. Typically, no rain falls during May to October.

Topography of the area is gently rolling to hilly. Residual soils, formed in place on sedimentary or secondary rocks, predominate. The dominant vegetation community is foothill oak woodland (Barbour and Major 1988). Dominant tree species in the oak woodlands include blue and scrub oak (*Quercus dumosa*) on xeric sites and coast live oak (*Q. agrifolia*) and valley oak on the more mesic sites. Gray pine (*Pinus sabiniana*) is frequently interspersed with the oaks. A variety of brush, forbs, and annual grasses occupy the oak woodland floors and grassy openings.

Since European settlement of coastal central California, the predominant land use of the Santa Margarita Ranch has been livestock production. Currently, the ranch is stocked moderately with cattle. All data were collected on the ranch during January to October 1989 within a 1.8-m tall welded-wire fence exclosure constructed around 0.6 ha of grazed pastureland. Forbs, predominantly filaree (*Erodium* spp.) and annual grasses covered the exclosure; no trees or brush occurred within the exclosure.

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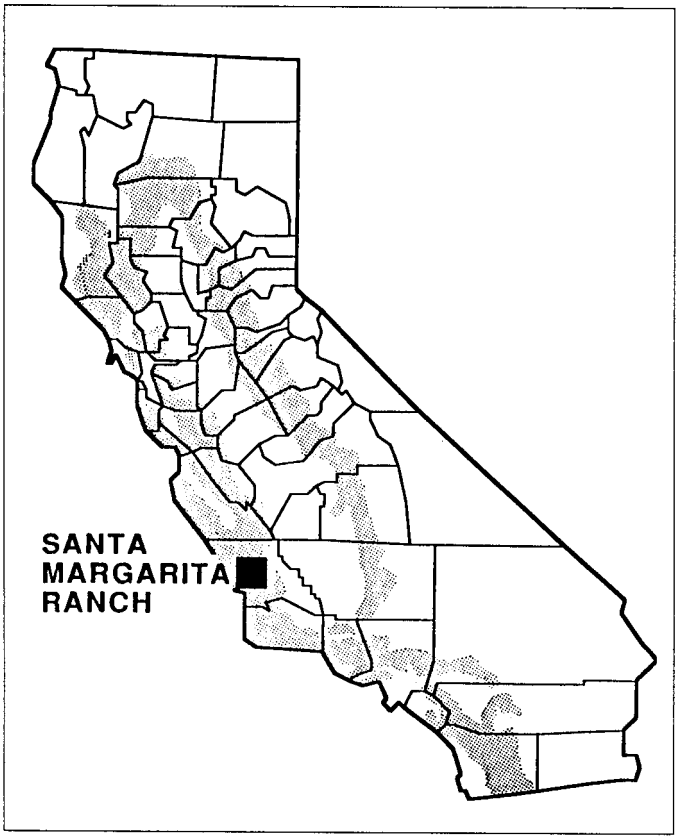


Figure 1—Location of the Santa Margarita Ranch in west-central San Luis Obispo County, California.

METHODS

Acorn Collection and Storage

In October 1988, valley and blue oak acorns were collected from trees on the Santa Margarita Ranch. The fungicide Captan was applied to the valley oak acorns, but not to the blue oak. All acorns were then refrigerated at 2° C until planting.

Site Preparation

In January 1989 in the 0.6-ha exclosure, 960 planting sites were laid out in a 2.4- by 2.4-m (8- by 8-foot) grid divided into four replicates of 240 planting sites each (randomized complete block design). The large distance between planting sites was used in an attempt to reduce the likelihood of a potential acorn depredator which, if it happened to find one planting site, would be more likely to find another. Twelve treatments were assigned randomly to each replication using the following variables: blue oak or valley oak; planting depths of 1.3, 5.1, or 10.2 cm (0.5, 2.0, or 4.0 in, respectively); and one or three seeds per planting site.

Each planting site was marked permanently with an aluminum identification tag wired to a steel rebar stake. In all replications, treatments were assigned randomly in groups of five planting sites. During 2-11 January 1989, acorns were planted the same compass direction and distance from the steel stakes by use of a template in the shape of an equilateral triangle with 10.2-cm sides. For one-acorn sites, an acorn was planted at the top angle and at each angle at three-acorn sites.

Two tools were used to plant the acorns at the proper depth. Whenever possible, a 2.5-cm diameter soil-sampling tube, marked with depth gradations (1.3, 5.1, and 10.2 cm) was used. At unusually rocky planting sites, holes were dug with a 3.8-cm diameter soil auger. The augered holes were measured with a ruler to ensure proper depth for planting. Soil removed with the soil-sampling tube or auger was replaced and firmed against the seed.

To minimize competition from grasses and forbs, herbicides were applied to the site twice: 1.1 kg atrazine and 0.7 kg oxyfluorfen per ha on 14 and 15 February and 1.1 kg glyphosate per ha on 10 March 1989. A backpack spray pump was used to make 1.5-m swaths centered on each row.

Site Monitoring

On-site rainfall was measured with a Taylor rain gauge. Rainfall data was taken after each storm from January to May 1989. Rainfall data for the same months was obtained from the US Weather Bureau, Salinas Dam Weather Station (3 km east of the study site). Average annual rainfall for the study site was obtained from the US Weather Bureau, Paso Robles, California (33 km north of the site).

Two soil samples were taken from the site in March 1989 and analyzed by the Soil Science Department, California Polytechnic State University, San Luis Obispo. The two locations for the samples were determined ocularly to represent the extremes in soil that occurred.

In order to document the kinds of animals present on the site, live trapping and observational animal scans (Fagerstone 1984) were conducted during March and April 1989. Trapping sites were laid out on a 11- by 11-meter grid. There were 49 trap sites consisting of forty 7.6-cm and nine 12.7-cm Sherman live traps. Trapping was done twice: 8-9 and 21-23 March.

During 15 March to 3 April, a total of 1710-minute periods of observation was made with a pair of field binoculars from a vehicle parked along a blacktop road about 20 m from the exclosure. Number of animals seen on and around the 0.6-ha study plot was recorded. Animal sign and species occurrence was not documented prior to study start up and planting, but cursory observations did not indicate any appreciable differences from during the study.

Oak Monitoring

Above-ground animal depredation was monitored twice a week during January to March. Acorn depredation was deter-

mined by examining each planting site for digging and other signs of animal activity, such as acorn shell remains. Suspected depredation was confirmed ocularly at 1.3-cm planting sites and by examining manually the digging for acorns planted 5.1 cm deep. Since the 10.2-cm depth was too deep for these methods, a ruler was inserted into the hole to measure the depth of digging and to feel for an acorn.

Seedling emergence data was collected weekly from the time the first seedling emerged in March and until emergence of the last seedling in July. Seedlings were located by ocular examination of each planting site. Upon emergence, each seedling was protected from animal damage with a 13-cm diameter aluminum-screen cage pinned to the ground.

Seedling survival and growth data were recorded in October 1989. Survival was determined ocularly. Each seedling was placed in one of two categories: alive or dead. All leaves had to be completely brown for the seedling to be dead. Seedling height was measured (nearest cm) from ground level to the tip of the terminal bud. One outside row (32 planting sites) was omitted from the analysis of height data because of heavier herbicide application.

Fate of Acorns Not Emerged

Since acorns could have been depredated from underground, a sample of acorns that did not appear to be depredated, but did not produce a seedling, was dug up to determine their fate. In December 1989, 20 planting sites in each of the four replications (118 acorns) were selected randomly for sampling. Each site was dug to the proper planting depth with a shovel and the soil sifted to help ensure finding the acorns, if present.

Data Analysis

For analysis of animal depredation, the three-acorn planting sites were considered depredated only when all three acorns were gone. For seedling emergence analysis, only one seedling had to come up at a site for it to be successful. If more than one seedling emerged at a three-acorn site, the tallest living seedling in October 1989 was used to assess seedling survival and height. This approach seemed reasonable at three-acorn sites because a practical application of planting multiple acorns is to increase the chance that one vigorous seedling is produced.

General trends of the data were determined using Macintosh EXCEL. Macintosh Statview II (Feldman and others 1987) was used to perform ANOVA to test the treatment effects on percent depredation, emergence, and survival. A multiple-factor factorial, non-repeated measures, balanced model (Winer 1971) was used to compute the ANOVA table shown at top of next column:

Source	degrees of freedom
Planting Depth	2
Species	1
Number of Seeds	1
Planting Depth by Species	2
Planting Depth by No. of Seeds	2
Species by No. of Seeds	1
Planting Depth by Species by No. of Seeds	2
Blocks	3
Error	33
Total	47

If there were significant interactions among any of the treatments (species, planting depth, and number of acorns per planting site) for any variable (acorn depredation; seedling emergence, survival, and height), the table of interaction means was examined to determine the cause of the interaction and how it may affect interpretation of the significant main effects. For each variable, a Duncan's multiple-range test (Steel and Torrie 1960) for the main effects was conducted to determine which treatment means were significantly different at the $P \leq 0.05$ level. Since seedling height data had an unequal number of observations, Student's *t*-tests were used to test the significance of seedling height differences for each of the three treatments.

In table 1, rainfall is compared between 1988 and the year of the study, 1989. Table 2 shows the means of the variables (acorn depredation; seedling emergence, survival, and growth) for the treatments (acorn species, planting depth, and number of acorns per planting site). Figure 2 illustrates the differences in means of the acorn depredation and seedling emergence variables for the species, acorn depth, and number of acorns per planting site treatments.

RESULTS

Site Monitoring

The year 1989 was very dry for San Luis Obispo County (US Weather Bureau, Sacramento, California). At the Salinas Dam Weather Station only 26 cm of rainfall were recorded compared to an average annual rainfall of 53 cm. During the first five months of 1989, 14.6 cm of rain fell on the study plot

Table 1—*Rainfall (cm) recorded at the Salinas Dam Weather Station during January to May in 1988 compared to rainfall recorded during the same months in 1989 on the study site.*

	Year	
Month	1988	1989
January	7.2	3.6
February	5.1	4.1
March	4.7	5.3
April	7.1	0.8
May	0.2	0.8

Table 2—Average fate of 960 sites planted at three depths: 1.3 (0.5 in), 5.1(2 in), or 10.2 cm (4 in), with either one (1) or three (3) valley (V) or blue (B) oak acorns per site during January to October 1989 on the Santa Margarita Ranch study plot, San Luis Obispo County, California.

Acorn Planting Depth (cm)	Depredation (pct)[d]				Emergence (pct)[d]				Survival (pct)[d]				Height (cm)			
	V		B		V		B		V		B		V		B	
	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
1.3 (0.5 in)	100 [a]	86	75 [a]	45	0 [a]	4	23 [a]	51	0 [a]	4	20 [a]	50	- [a]	9	6 [a]	8
5.1 (2.0 in.)	75 [b]	50	18 [b]	0	9 [a]	23	34 [a]	63	5 [a]	20	25 [a]	55	4 [a]	10	6 [a]	7
10.2 (4.0 in.)	29 [c]	28	6 [b]	6	5 [a]	28	13 [b]	28	5 [a]	25	10 [b]	25	7 [a]	9	5 [a]	6

[a,b,c] Pairs of means (averaged over number of seeds) not followed by the same letter within a column are significantly different ($P \leq .05$) by Duncan's multiple-range test and, for height, by Student's *t* tests.
[d] All percentages are based on 960 planting sites.

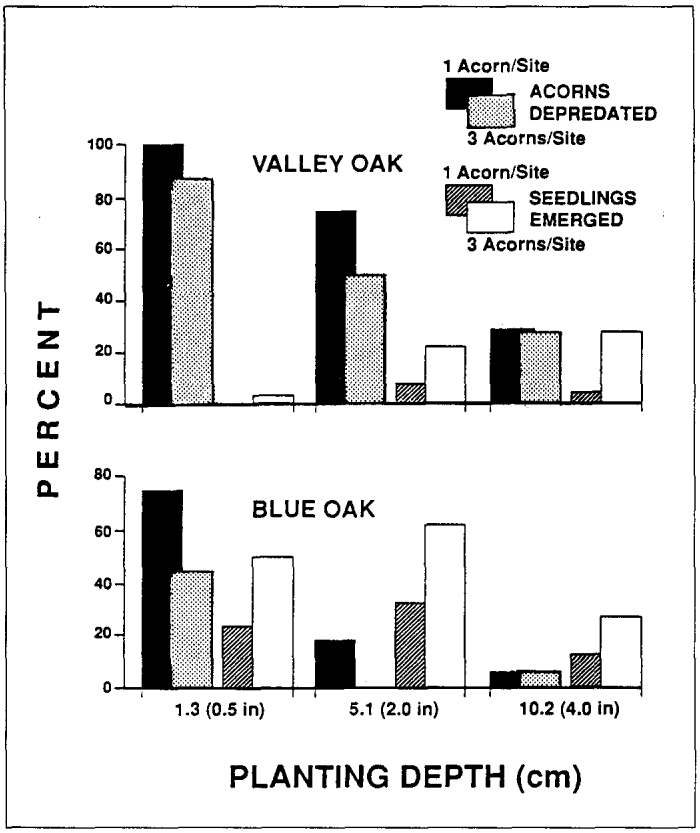


Figure 2—Percent valley oak and blue oak acorns depredated and seedlings emerged from three planting depths (1.3, 5.1, and 10.2 cm) at one- and three-acorn planting sites on the Santa Margarita Ranch study plot, San Luis Obispo County, California.

compared to 24.3 cm recorded at the Salinas Dam Weather Station during the same months in 1988 (table 1).

Since the results of the two soil tests were similar, they are averaged here. The soil texture was a sandy loam comprised of 75 pct sand, 12 pct silt, and 13 pct clay. It held only 24 pct water at saturation. The pH was 6.2. Organic matter (nitrogen: 89 kg per ha) was more than average for the soils of the area and, due probably to the residual from grazing, the phosphorus was very high (69 ppm dry weight). Potassium, calcium, and magnesium (123,623, and 41 ppm dry weight, respectively) were all low due to leaching of the sandy soils and because the soils had low ability to retain nutrients.

In March 1989 during the first trapping period, 28 deer mice (*Peromyscus maniculatus*) were caught in Sherman live traps (98 trap nights) and nine during the second period of trapping (147 trap nights). No other animals were captured. Fresh California ground squirrel (*Spermophilus beecheyi*) digging was common after March within and around the study plot. The fact that ground squirrels were not trapped in any of the 12.7-cm Sherman live traps may be due to trap design: the live traps had aluminum rather than woven-wire sides. Ground squirrels are relatively wary of entering the aluminum traps (R. Schmidt, pers. comm.).

California ground squirrels were observed during the seventeen 10-minute observational scans: three times on the study site and 32 times on the surrounding area. No other potential mammal acorn depredators were sighted within or around the study plot. Potential avian depredators were not seen on the site. Although periodic checks were made during January to October 1989, pocket gopher (*Thomomys* spp.) mounds were observed only on the area outside the study plot.

Oak Monitoring

There were significant differences for the variables acorn depredation, seedling emergence, survival, and height for most levels of the three treatments (oak species, depth the acorns were planted, and the number of acorns planted per planting site) of this study. There were also significant species by planting-depth interactions; valley oak and blue oak did not respond (in terms of acorn depredation, seedling emergence, and survival) in the same way to the depth the acorns were planted. Each variable is explained below.

Acorn Depredation.— Of the 960 planting sites, nearly half (43 pct) were depredated. Valley oak acorns were depredated significantly more (61 pct) than blue oak (25 pct).

Depredation was also much different among planting depths, ranging between 100 pct at one-acorn sites for valley oak planted 1.3 cm deep to 0 pct at three-acorn sites for blue oak planted 5.1

cm deep. Depredation of valley oak acorns decreased from 93 pct at 1.3-cm planting depth to 29 pct at 10.2 cm; with one and three-acorn sites combined, these differences were significant. In contrast, blue oak depredation decreased significantly from 60 pct at the 1.3-cm depth to 9 pct at 5.1 cm, but did not change significantly between the 5.1 and the 10.2-cm (6 pct) depths. The fact that animal depredation of valley oak acorns decreased about equally between planting depths but blue oak did not, resulted in a significant oak species by planting depth interaction. Finally, for blue oak and valley oak acorns planted at 1.3 and 5.1 cm, depredation was significantly less at three- than one-acorn planting sites. This difference did not occur at the 10.2 cm planting depth where depredation was nearly equal.

Depredation of acorns began within about a week of planting and continued until mid-March, when emergence of non-depredated acorns began. Occasional depredation of acorns occurred until the end of July. At most planting sites that were depredated, a small hole about 3 cm in diameter was dug, apparently by deer mice, to the depth the acorn was planted. A much greater amount of digging at other depredated planting sites suggested the acorns were taken by ground squirrels. There was no evidence of digging at planting sites by any other kind of animal.

Seedling Emergence.—Valley and blue oak seedlings emerged from mid-March to the end of June. A seedling came up at 23 pct of the 960 planting sites. Seedlings grew at significantly more blue oak (35 pct) than valley oak (12 pct) planting sites.

Few valley oak seedlings emerged (4 pct) at the 1.3-cm sites. At the 5.1- and 10.2-cm planting sites, about equal proportions emerged (16 pct and 17 pct, respectively). On the other hand for blue oak, the most (49 pct) seedlings emerged at the 5.1 cm planting depth; significantly fewer (21 pct) emerged at the 10.2-cm depth. This between-species difference in seedling emergence accounts for the significant species by planting depth interaction—the lowest seedling emergence for valley oak was at 1.3 cm planting depth but at 10.2 cm for blue oak. Finally, one-acorn sites produced significantly fewer seedlings than three-acorn sites: 5 pct vs. 18 pct and 23 pct vs. 47 pct for valley oak and blue oak, respectively.

Seedling Survival.—Nearly all the blue oak and valley oak seedlings that grew in spring 1989 (a seedling at 23 pct of the 960 planting sites) were still alive the following October (a seedling at 20 pct of the planting sites) when the last data on seedling survival were taken. Therefore, results of the ANOVA for seedling survival are nearly identical to those for seedling emergence: the same significant differences on survival were detected between species, acorn planting depth, and numbers of acorns planted per planting site. Also similar to the emergence results, there was a significant species by planting depth interaction for seedling survival.

Seedling Height.—The average height of all seedlings in October at the end of their first growing season was 7.0 cm. Valley oak seedlings were significantly taller than blue oak seedlings (8.3 cm and 6.5 cm, respectively) but, importantly, average heights of valley and blue oak seedlings from acorns planted at 1.3-, 5.1-, and 10.2-cm depths were about the same (9.0, 8.2, and 8.3 cm tall, respectively, for valley oak; 6.8, 6.7, and 5.8 cm tall, respectively, for blue oak). Finally, average seedling height was greater at three- compared to one-acorn planting sites (9.2 and 5.2 cm tall for valley oak; 6.8 and 5.8 cm tall for blue oak); the difference was significant for valley oak.

Fate of Acorns Not Emerged

In December 1989, we searched for 118 acorns (80 planting sites) that had not apparently been depredated nor produced a seedling. Of these, 70 pct had produced both a root and a sprout, but the sprout had not grown above the surface of the ground, and 12 pct appeared inviable. The fate of the remaining 18 pct, which were not found, could not be determined, but there was no evidence of animal depredation.

DISCUSSION

Planting Depth: 1.3 vs. 5.1 vs. 10.2 cm

Acorns planted at 1.3 cm were more easily detected by deer mice and ground squirrels present in the study plot than those planted deeper (5.1 or 10.2 cm). Observational scans and live trapping on the study plot indicated these surface-feeding rodents were quite common. The acorns planted just below the soil surface were especially susceptible to depredation from above ground. But, even if the acorns had not been depredated, other studies (Griffin 1971; Russell 1971; Johnson and Krinard 1985) indicate they might not have germinated due to adverse soil conditions near the surface: temperatures average higher and evaporation of soil moisture occurs at a faster rate. In this study, these conditions were compounded by the low rainfall and the sandy soils with low water-holding capacity.

On the other hand, the deeper-planted acorns, especially those planted at 10.2 cm, were depredated less because they were less easily detected by smell and the small rodents present on the study plot generally do not dig deep to get acorns (Russell 1971; Johnson and Krinard 1985; Borchert and others 1989). Had gophers been active in the study site, depredation of the more deeply-planted acorns would have likely been greater (Russell 1971).

It is not completely clear why many of the acorns that germinated at a depth of 10.2 cm did not come up. The long-term grazing of the study site has likely compacted the soil, making soil penetration more difficult. Matsuda and McBride (1987) attributed mortality of germinated blue and valley oak acorns to hard soils that did not allow root penetration. But, in this study, it seems that compacted soil would have equally impeded seedling emergence of acorns planted at depths of 1.3 and 5.1 cm. Especially for blue oak, planting 10.2 cm deep apparently resulted in such a large distance for the shoots to penetrate that many were not successful in emerging from the soil.

It is of interest that in spite of the environmental conditions at the study site and acorn physiological constraints, in contrast to blue oak, valley oak seedling emergence and survival did not decrease between the two deeper planting depths. Our data do not provide enough evidence to adequately judge this observation, but it suggests that the relatively large valley oak acorns may produce a seedling from acorns planted quite deep. Moreover, especially for valley oak, had rainfall been average and/or the soil had higher water-holding capacity, seedling emergence from the deepest planting depth (10.2 cm) may have been much better. Because of the advantage of lesser animal depredation that planting acorns at deeper depth affords, it may be useful to test success of deep-planted acorns under several water (rainfall) and soil conditions.

Species: Valley Oak vs. Blue Oak

The planting depth by oak species interactions in the ANOVA tests indicated that these factors acted together on acorn depredation, seedling emergence, and seedling survival. A possible explanation for greater depredation of valley oak acorns compared to blue oak, even at deeper planting depths is, simply, that valley oak acorns are larger. Barnett (1977) did a study with pignut hickory (*Carya glabra*) and white oak (*Quercus alba*) in which the hickory was depredated at a higher rate than the oak. Barnett attributed this to the stronger odor of the hickory nut due to its larger size; it was easier than the smaller white oak for predators to locate. Similarly in this study, the larger valley oak acorns may have exuded a stronger odor which attracted predators more, even at the deepest planting depth. It seems unlikely that use of the fungicide Captan on the valley oak, but not on blue oak acorns, increased depredation differentially. According to Sid Sakamoto (pers. comm.), Captan does "not attract small mammals." In fact, for seed-eating birds, Captan has been used as a repellent.

Number of Seeds: One vs. Three

This study confirms the validity of the acorn-planting technique: several acorns per spot. Three-acorn planting sites had less acorn depredation and better seedling emergence, survival, and height. Notably, apparently 10.2 cm (4 in) was adequate space between acorns to minimize the likelihood of finding all three once one was located—at least for the kinds of animal depredators on the study plot. The higher emergence and survival rates at three-acorn sites indicates that competition between seedlings was not a problem during the first growing season. Greater average height, moreover, of seedlings at three-acorn sites was due, simply, to the opportunity to select the tallest of three seedlings. The advantages of planting multiple acorns are noteworthy because acorns are easy to collect and planting several per planting site is not much more expensive or difficult than planting one.

RECOMMENDATIONS

The following management recommendations are suggested:

(1)Plant acorns about 5.1 cm (2 in) deep. This will help reduce animal depredation but not be too deep for seedlings to come up. Somewhat deeper planting may be better in areas or years of high rainfall and/or soil with good water-holding capacity.

(2)Plant several seeds per planting site, spaced at least 7 cm (several inches) apart.

(3)Plant the oak species which is most suited to the rainfall and soil conditions of the area.

Planting at the recommended depth does not preclude the need to protect the planting site. Planting at the optimal depth may increase the chance of success of protected sites, and may make successful planting more likely when protection of the planting site is not practical.

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Effects of Shade on Blue Oak and Coast Live Oak Regeneration in California Annual Grasslands[1]

Pamela C. Muick [2]

Abstract: Canopy effects and annual vegetation have been shown to strongly influence oak seedling survival. From the many elements composing canopy, shade was selected for experimental manipulation. A split-plot, multifactorial experiment was designed to test whether blue oak (*Quercus douglasii*) and coast live oak (*Q. agrifolia*) could establish seedlings in annual grasslands outside of canopy influence, and if there were differences in the responses of the two species to shade and sun treatments. All herbivory was excluded from three plots. All plots were constructed outside of direct canopy influence, and the annual herbaceous vegetation was not manipulated. Even under conditions of prolonged, severe drought, blue oaks and coast live oaks were able to establish seedlings from acorns in annual grasslands. Although the initial emergence of coast live oak seedlings from acorns was greater than that of blue oak in the first year, more blue oak seedlings were alive a year later. The survivorship of both species was significantly enhanced by the shade treatment.

The statewide oak regeneration survey concluded that in many locations, regeneration was inadequate to maintain existing stands. Additionally, the occurrence of regeneration was considered highly site specific. Seedlings of blue oak (*Quercus douglasii)* and coast live oak (*Q. agrifolia*) occupied the canopy understory quite successfully. Yet taller, sapling-sized blue oaks were rarely located under tree canopies and were found on the edge of the canopy and in the open. In contrast, coast live oak seedlings and saplings were both found beneath tree canopy (Muick and Bartolome 1987).

During the survey and subsequent field work I observed another phenomena. Evergreen oak species—coast live, interior live (*Q. wislizenii*), and canyon live (*Q. chrysolepis*)—appeared to be regenerating more successfully throughout the state. In certain locations live oak saplings, which looked like maiden trees rather than stump sprouts, were growing under the canopy of mature blue oak stands. The presence of live oak saplings, plus the absence of deciduous oak saplings, suggested that locally important changes in oak woodland species composition were taking place.

Shade tolerance is a term, most commonly used by foresters, to describe the relative ability of a species to grow and thrive under a forest canopy. A tolerant species can grow and thrive under tree canopy, whereas an intolerant species can thrive only away from the main canopy or in the open. The major canopy effect limiting species in arid environments is thought to be reduced soil moisture; light is rarely limiting in temperate forests (Spun: and Barnes 1980). Sudworth (1908) described coast live oak as highly tolerant of canopy condition and blue oak as highly intolerant. Based on data, observations, and relative tolerance ratings, I hypothesized that blue oaks were unable to grow to sapling size under tree canopy.

In evaluating the effects of canopy, I considered the relationship between canopy and shade. The effects of shade and tree canopy are best considered as overlapping, but not equivalent, variables. Tree canopy intercepts solar irradiance resulting in a zone of reduced light beneath and around the tree. However, shade is only one of several components comprising canopy effects.

The effects of canopy include other attributes besides reduced light. Soil moisture, nutrient status, soil texture, and pathogens are usually quite different beneath a tree than in a comparable site without tree cover. Shade itself is variable, and depends upon the amount of light blocked, and areal, daily, and seasonal patterns. Although tree canopy may be a dominant source of shade in oak savannas and woodlands, shade can also result from topographic relief, rock outcrops, and shrubs and herbaceous vegetation.

At the Sierra Field Station, Momen (1987) evaluated the effects of canopy on water potential of blue oak seedlings in grazed and ungrazed locations. The lowest values of seedling water potential occurred in grazed areas beneath tree canopy, which also had the higher densities of annual grasses. Momen concluded that the prospect of blue oak seedling survival is greater in the grazed, open environment than beneath canopy.

Cruzan (1981) found that all coast live oak seedlings growing in the full sun died. In the shade and vegetation removal experiments, increased shade and/or decreased annual vegetation led to higher percentages of seedling survival. The negative effects of annual grass and forb species on oak seedling survival have been reported by many authors (Griffin 1980, Welker and Menke 1987, Gordon and others, 1989).

Other researchers have tested the effects of herbivore exclusion (Borchert, and others 1989) and compared the effects of canopy with non-canopy areas (Momen 1987, Welker and Menke 1987). To date no California researchers have tested blue oak canopy components away from the canopy environment. Therefore I decided to manipulate a single effect of the canopy, shade, while holding annual vegetation, seed source, and rodent populations constant. For the purposes of this study, shade can be considered as either a canopy effect or a variable independent of canopy.

This paper reports on my investigations to determine 1) if blue oak and coast live oak could establish in annual grasslands

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outside of canopy influence, and 2) if, at the seedling stage, the species exhibited different responses to shade or sun outside of canopy influence. The experiments were carried out in exclosures which protected the seedlings from all vertebrate herbivores. Vertebrates have been demonstrated to consume both acorns and seedlings in many locations (Borchert and others 1989, Griffin 1980).

THE EXPERIMENT

Field experiments were conducted at the Hastings Natural History Reservation, Carmel Valley, Monterey County, in the Inner South Coast Ranges. At Hastings I selected three annual grassland sites, formerly "old fields", each within about 10 meters of an existing oak stand. Sites were located at similar elevations but on different soils representing a spectrum of Hastings' soil types. Robertson Saddle (2) is the most arid site and also receives the most insolation. Tire Flat (3) is the most mesic site and receives the least insolation. North Field (1) is mid-way between the other two sites in terms of insolation, but is more similar to Tire Flat in terms of soil type and moisture.

In order to eliminate the influences of vertebrate herbivores, exclosures were thoroughly fenced, both above and below ground. A backhoe was used to dig a trench around a rectangular area measuring approximately 6 meters by 8 meters. Trenches were excavated to a thick, claypan that was considered to define the lower limit for burrowing rodents. Depth to claypan varied across the plots and ranged from 1 to 3 meters. During construction and fence building, soil disturbance and compaction on plot surfaces was minimized. Most of the rodents remaining within the plot after construction were removed by trapping. The top of the exclosure was not fenced. Exclosures were rested for about one year and the plots were planted in December, 1988.

I used a split-plot, multifactorial experimental design. Each 6 m by 8 m exclosure plot was divided into four quarters of similar size, with buffer strips defined between plots and next to the fences. Two diagonally opposed quarters were assigned to the shade treatment, while the other two were unshaded and served as controls. An evenly spaced grid of sixteen cells, each cell measuring about 30 cm on a side, was superimposed on each quarter-plot. Species and treatments were assigned to each cell according to a pre-determined, interspersed random pattern. The 16 acorns in each cell were from the same parent tree, in the case of blue oak, or from the same population, in the case of coast live oak.

Planting was accomplished by wedging the soil open with a trowel, then dropping an acorn, sideways, into the 5 to 7 cm deep crevice. The opening was closed and about 100 ml of water was poured over each spot after planting. All acorns were planted within two days in December of 1988.

For the shade treatment shadecloth tarps were positioned over the two shade treatment quarter plots, in each of the three exclosures, in February of 1989. The six tarps were sewn from shadecloth which was rated to block out 50 pct of overhead sunlight (®Weathashade). Each tarp was suspended horizontally, about 1 to 1.25 meters above the ground, and three corners were fastened to the exclosure fence. The fourth and inside corner of the tarp was attached to a fencepost driven into the middle of the plot.

Data were collected monthly. I counted the number of seedlings emerged and alive, calculated average number of leaves and stems, and measured the height of seedlings and annual vegetation. I also noted and quantified other data including evidence of arthropod herbivory.

RESULTS

The following results are based on the emergence and above ground mortality data. Emergence was defined as the presence of a shoot or stem with leaves by June 1989. Survival was defined as the presence of a stem with green leaves or a green stem, in June 1990. The responses of the seedlings varied

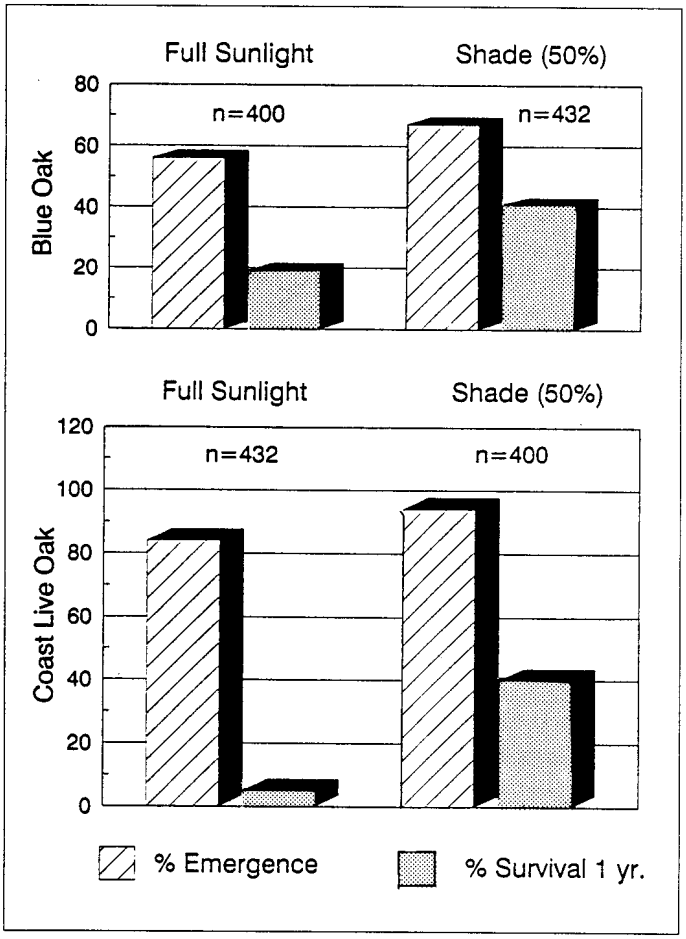


Figure 1—A graph of emergence and survival of blue oak and coast live oak seedlings by treatment.

between plots, however, several general and significant patterns emerged (figure 1).

Emergence and Survival by Species

A very high percentage of coast live oak, on both sun and shade plots, emerged (table 1). Of the 832 acorns planted in December of 1987, 739 (89 pct) had emerged by June of 1989. However, a year later in June of 1990, the population of coast live oak seedlings had decreased dramatically. Only 181(22 pct) coast live oak seedlings survived and of those 89 pct (all but 20) were found under the shade treatment.

Only 515 (62 pct) of the 832 blue oak acorns produced an above-ground stem by June 1989. However, a year later in June 1990, 30 pct of those planted or almost half of those that had emerged were alive. Of the 251 surviving blue oak seedlings 75 pct were located under the shadecloth.

Patterns of Emergence and Survival

Coast live oak acorns gave rise to many more seedlings than did blue oak acorns. Using two-way analysis of variance (ANOVA), species and seedling emergence were significantly related (p= 0.05). This may well be related to differences in viability between the two species.

Shade treatments were strongly and significantly related to seedling survival (p= 0.05). On the extremely arid Robertson Saddle plot, only 2 (3 pct) of the previous year's blue oak seedlings and 1 (1 pct) of the previous year's coast live oak seedlings leafed out, all under the shadecloth. On the two more mesic plots, North Field and Tire Flat, greater numbers of blue oak seedlings survived on the sun plots, 32 pct and 26 pct respectively. There was no significant difference between species in their response to the treatments.

DISCUSSION

Shade tolerance of a species can vary over the lifetime of a plant and between individuals. Black oak (*Q. kelloggii*) can persist in the understory for many years, but in order to reach maturity it must have its canopy in the sun (McDonald 1978). Although Sudworth characterized blue oak as highly intolerant, results presented here suggest that blue oak does display some tolerance to experimentally produced shade at the seedling stage. Other authors (Momen 1987 and Welker and Menke 1987) also mention the presence of naturally occurring blue oak seedlings under tree canopy.

The mean annual precipitation at Hastings is 535 mm (21 inches), which usually falls as rain and occasionally as snow during the winter months. As the record shows, drought is not an uncommon event at Hastings (figure 2). In the previous 62 years precipitation was below average thirty-six or 58 pct of the time. Precipitation measured less than 400 mm (15.7 inches) for thirteen of those below average years. During this study, Hastings was undergoing the second and third years of an extreme drought, and precipitation has been below 14 inches annually since the 1987-88 season. Rainfall during 1987-88, the year prior to planting, was 347 nun (13.7 inches). Rainfall during the 1988-89 season, when seedling emergence was counted, was only 328 mm (12.9 inches). Precipitation during 1989-90, the year survival was observed, measured 347 mm (13.7 inches).

No additional water was brought onto the plots after the 100 ml poured over each acorn seed spot at the time of planting in December, 1987. The effects of the shadecloth tarp on the accumulation of additional condensation is unknown; however, snow and fog are uncommon at Hastings.

The high levels of moisture stress measured on blue oak seedlings growing under tree canopy (Momen 1987) and high percentages of seedling mortality measured by Welker and Rice (1987) suggest this a one possible mechanism for the exclusion of blue oak saplings from the beneath the canopy environment (Muick and Bartolome 1987). The strong **positive** relationship between shade and blue oak seedling survival as presented in this study suggests that blue oak regeneration may be enhanced

Table 1—*Summary of seedling emergence and survival by species and treatment.*

Planted in Species	Acorns in 12/1988	Seedlings Emerged Surviving in 6/1989		Seedlings Surviving 1.5 Years 6/1990		Overall Survival 1988-1990
	No.	No.	Pct	No.	Pct	Pct
Blue oak						
FULL SUN	400	222	56	74	33	19
SHADE	432	290	67	177	61	41
Total	832	512	62	251	49	30
Coast live oak						
FULL SUN	432	363	84	20	6	5
SHADE	400	376	94	161	43	40
Total	832	739	89	181	25	22

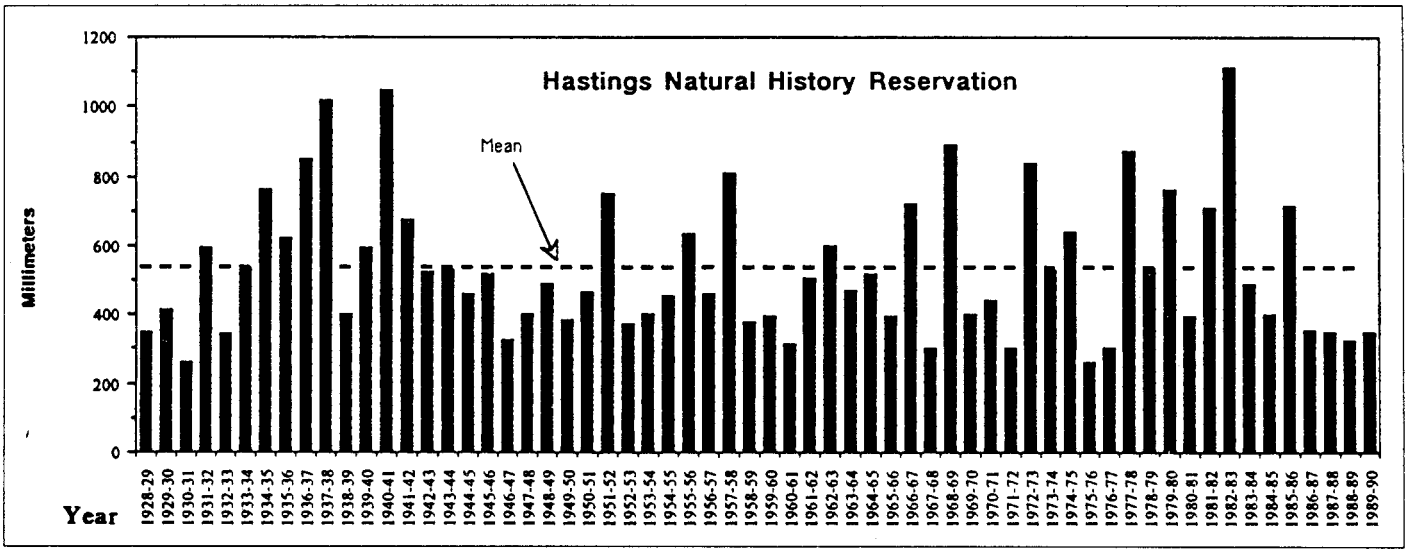


Figure 2—Total annual precipitation measured at Hastings Natural History Reservation: 1928-1990.

by shade. This suggests that one quality of a blue oak regeneration site is non-canopy shade. It may well be that the least likely location for successful blue oak regeneration to occur is under tree canopy.

CONCLUSIONS

Naturalized annual grasses and forbs are frequently associated with the lack of oak regeneration, particularly for blue oaks (Gordon, and others 1989, Welker and Menke 1987). However, even under conditions of prolonged, severe drought, blue oak and coast live oaks were able to establish seedlings from acorns in annual grasslands, when protected from vertebrate herbivory. Both oak species were able to successfully establish seedling populations, based on shoot emergence in the first year. Coast live oak required shade for seedling survival into the following year whereas blue oak seedlings survived on both sun and shade plots. Blue oak survivorship was significantly enhanced by the shadecloth treatment, and blue oak seedlings survived in greater numbers than coast live oak.

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Oak Seedling Establishment in Relation to Environmental Factors at Annadel State Park[1]

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Abstract: As part of an ongoing study of oak ecology in Sonoma County, California, we have begun to evaluate various environmental factors relative to oak seedling establishment at Annadel State Park. These factors, identified at three spatial scales (macro, meso and microscales), were corelated with the presence of oak seedlings in two contrasting northern oak woodland understory types - annual and perennial grass. No significant statistical correlations were found, but this is probably due to the small sample size. Preliminary analysis suggests that positive correlations will be found between seedling densities and late spring and summer soil moisture levels maintained by one or more factors at each scale.

This paper is a preliminary report on an ongoing study of oak seedling establishment at Annadel State Park. The objective of the study is to evaluate environments for oak seedling establishment at three spatial scales in order to identify an appropriate scale for making decisions about regeneration projects. A supplementary objective was to see if we could identify environmental factors at different scales which correlate with oak seedling establishment. Management decisions regarding oak planting, restoration of oak woodlands, and the control of grazing livestock to reduce herbivory must be based on an understanding of the relationship between various environmental factors and oak seedling establishment.

The three spatial scales used in this study will be referred to as the macro, meso, and micro scales. The macro-scale is the scale at which plant communities segregate out over the landscape. This scale is determined by local climate, surficial geology, soil types, drainage patterns, land use history, and fire frequency. The mosaic of plant communities in an area is the best expression of the interaction of environmental factors at the macro-scale. Wells (1962) has analyzed the distribution of oak woodlands near San Luis Obispo working at this scale.

The meso-scale environment for seedling establishment is the scale of variation of environmental factors within the boundaries of a plant community. This scale is to a large degree controlled by the modification of environmental factors by the dominant species in the plant community. Environmental factors to be considered at this scale include biotic factors such as tree crown cover, shrub cover, ground cover, and abiotic factors like soil depth, soil moisture, and slope. Analysis of meso-scale factors has been used in many studies of oak seedling establishment (Griffin 1971).

The micro-scale environment for seedling establishment corresponds to the operational environment proposed by Mason and Langenheim (1957). This is the immediate environment surrounding the acorn and developing seedling which impinges directly upon the seedling. Mason and Langenheim saw this operational environment in terms of physical (e.g., heat, atmospheric moisture, etc.) and biotic (e.g., herbivory, pollination, etc.) factors which impinge directly on the physiology and morphology of the plant. We have attempted to characterize the micro-environment in terms of physical and biological conditions we observed in the immediate proximity to seedlings. Such characteristics as distance to nearest object (rock, tree, log), seedling cover by perennial grass leaves and evidence of herbivory and/or drought were used to define the micro-environment of seedlings.

It has occurred to us that the divergent opinions regarding natural seedling establishment in California oaks might be related to differences in the environmental scale at which different investigators approached the study. Muick and Bartolome (1987) working at what we consider the macro-scale suggested that a number of macro-scale factors (e.g., grazing history, precipitation, soil type) are related to variations in seedling establishment. Snow (1972) and McBride (1974) investigated the relationship between some meso-scale factors and seedling establishment in coast live oak (*Quercus agrifolia*). Their work suggests that the degree of crown cover, moisture availability, and livestock grazing in oak woodlands are key factors in seedling establishment. Griffin (1976; 1980) working at what we consider the micro-scale proposed micro-scale factors such as herbivory by pocket gophers as the primary factor controlling seedling establishment.

This paper reports on how a better understanding of oak seedling regeneration may be obtained by properly focusing on the appropriate environmental scale. It was the expectation of this project to identify that scale in the case of Oregon oak (*Quercus garryana*) in Annadel State Park near Santa Rosa, California.

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STUDY AREA

Annadel State Park is located immediately southeast of Santa Rosa, Sonoma County, California, in the Sonoma Mountains. This north-south trending range, primarily composed of Pliocene Sonoma Volcanics above older sediments (Jenkins 1951) is in the eastern portion of the county ca. 30 km from the Pacific coast. Climate patterns are typically Mediterranean with mild winter temperatures (January mean daily minimum 2-3 °C) and hot summer temperatures (July mean daily minimum 28-29°C) which are often moderated by morning fog. Total annual precipitation is ca. 750 mm/year with dry summers and wet winters (January mean 150 mm) (National Oceanographic and Atmospheric Administration 1989).

The vegetation of the park, typical of that found throughout the southern North Coast Range, is a complex mosaic of communities including coastal prairie, chaparral, northern oak woodland, mixed evergreen forest and coniferous forest. The coniferous forest type is most common in the northeastern third of the park. Mixed evergreen forest occurs on northerly slopes and moist drainages throughout the park, integrating with northern oak woodland, particularly in the center of the park. Northern oak woodland is predominant in the southwestern two-thirds of the park, although tree densities and composition vary with aspect. Oregon oak occurs in relatively high densities on north-facing slopes, while south-facing slopes support more open savannas of Oregon oak-blue oak hybrids (*Q. garryana* x *douglasii*). The northern oak woodlands may also be characterized by understory conditions. Perennial grasses dominate the understories of stands on steep, rocky slopes. Northern oak woodlands occurring on less steep slopes and soils without rocks generally support understories of annual grasses. Chaparral occupies relatively small areas throughout the park, usually on southern or western exposures and on rock outcroppings. The prairie type forms small to fairly extensive meadows throughout the park. It is important to note that these vegetation types form a mosaic; areas occupied by a given type are often small and boundaries between types often abrupt.

The area in which Annadel is located was extensively utilized by European settlers and their descendents (Futini 1976). Major types of activities included cattle grazing (intermittent since 1830s), cobblestone quarrying around the turn-of-the-century and extensive cutting of hardwood for cordwood and charcoal in the 1920s. Cattle ranching was the dominant activity from 1930 to 1970. The park was established in 1972.

Several recent studies have focused on the oak woodland and hardwood forest types in Sonoma County with particular reference to Annadel State Park. Anderson and Pasquinelli (1984) described the northern oak woodland at several sites along a moisture gradient within the county, including two sites in Annadel. They concluded that high oak canopy densities and lack of oak regeneration may result in the future dominance of mixed evergreen forest species at the more mesic end of the gradient. Tunison (1973) investigated the distribution of oak woodland and mixed evergreen forest types on Bennett Mountain in Annadel State Park. Noting the dominance of young Douglas-fir (*Pseudotsuga menziesii*) and Bay (*Umbellularia californica*) in the understory of many oak dominated stands, he tentatively concluded that all of these oak types are seral to mixed evergreen forest. Barnhart (1978) suggested a similar vegetation change, although he pointed out that the complex nature of the coast range vegetation makes it difficult to document successional trends. Wainwright and Barbour (1984) demonstrated the diverse nature of the mixed evergreen forest type in Annadel. Barnhart et al. (1987) examined Douglas-fir invasion into the northern oak woodland type at Annadel State Park. They did not, however, report on oak regeneration in these stands.

METHODS

Two oak dominated woodland types were selected for this study as expressions of the macro scale environmental factors at Annadel State Park. These types were the northern oak woodland with perennial grass understory (perennial grass woodland) and the northern oak woodland with annual grass understory (annual grass woodland).

Five 10m by 10m plots were established in September, 1990 at random in each type and the following data were collected:

1. Oak seedlings
   species, number, height, diameter
2. a. Meso-scale factors
   species, diameter at breast height (DBH), and height of trees > 1.4m tall
   - total crown cover on plot
   - pct. ground cover by perennial grass
   - pct. ground cover by annual grass
   - pct. ground cover by litter
   - pct. ground cover by rocks
   - pct. ground cover by logs
   - pct. bare ground
   - litter depth
   - soil depth
   - soil moisture percentage at 0 to 10cm and 20 to 30cm
   - ground slope
   - aspect of plot

   b. Micro-scale factors
   - distance from seedling to nearest rock
   - distance from seedling to nearest tree
   - distance from seedling to nearest clump of perennial grass
   - distance from seedling to nearest log
   - seedling coverage by leaves of perennial grass
   - litter depth at base of seedling
   - evidence of seedling drought
   - evidence of herbivory on seedling

In addition to the micro-scale factors listed above, the distances from 10 points located at random to the nearest rock, tree, clump of perennial grass, and log were measured within each 10m by 10m plot. The litter depth at these random points and the "coverage" of the ground at these points by perennial grass was also recorded.

Data analysis procedures involved comparison, using Student's "t" test, of the average numbers of seedlings found on each vegetation type. Spearman's Rank Correlation was run to establish whether or not the meso-scale variables were correlated with the number of seedlings occurring on the plots. Regressions were initially run for each vegetation type, then the data from both types were combined for a second set of regression analyses. The micro-scale factors occurring at seedlings were compared to the same factors at randomly located points using Student's "t" test and Wilcoxon Rank Sum test.

RESULTS

An average of 23.0 and 11.8 seedlings were found respectively on the perennial grass woodland and the annual grass woodland plots. The majority of these seedlings were Oregon oak; however, hybrids of Oregon oak and blue oak (*Q. douglasii*), California black oak (*Q. kelloggii*), and coast live oak were also present (table l). Seedlings were larger on the plots located in the perennial grass woodland.

Comparison of the average number of oak seedlings observed in each type, using Student's "t" test, showed no significant difference. Similar comparisons between the two vegetation types of the average number of Oregon oak seedlings or hybrid oak seedlings also showed no significant difference. The results of these statistical comparisons are due to the wide range in seedling densities on the plots. Plot number 3 (perennial grass woodland) supported 73 seedlings while plot number 5 had 6 seedlings; the range was from 0 to 24 seedlings on the annual grass woodland plots. We believe this wide range in seedling densities may reflect both local differences in seed production from plot to plot and random variation in seed production from one tree to another. Statistical comparison of average height and average diameter of seedlings likewise showed no significant differences between the perennial and annual grass woodland plots.

Meso-scale Environmental Factors

Average values were calculated for the meso-scale environmental factors measured in this study on five plots within each vegetation type (table 2). None of these averages was significantly correlated with seedling density in either of the oak woodland types. The lack of significant correlation may be due to the small sample size at this preliminary stage in our study. When data from both sets of northern oak woodland plots were combined, Spearman's Rank Correlation Test showed a significant correlation only between the number of seedlings per plot and litter depth.

The lack of a demonstrable correlation between seedlings and crown cover of either trees or perennial grass may be due, in part, to a curvilinear relationship between these two variables, cover and seedling establishment. Spearman's Rank Correlation Test measures the correlation between the independent and dependent variable assuming a linear relationship. The lack of correlation between soil moisture percentage and the number of seedlings may be spurious because of the unusual characteristics of precipitation in spring, 1990. A heavy storm at the end of May brought soil moisture levels back to near field capacity. This precipitation fell after the annual grasses were senescent. This added soil moisture in the annual grass woodlands was slowly

Table 1—*Number, height, and diameter of seedlings on 100m^2 plots to Oregon oak woodlands at Annadel State Park*

Plot Number	Understory Type	Species	Number	Average Height (cm)	Average Diameter (mm)
1	perennial grass	Quga	3	13.6	3.0
		Hybrid	7	13.0	3.0
		Total	10	13.2	3.0
2	"	Quga	3	8.6	2.0
		Hybrid	4	10.0	2.5
		Total	7	9.4	2.2
3	"	Quga	42	12.2	2.6
		Hybrid	30	9.7	2.4
		Quag	1	30.0	10.0
		Total	73	11.0*	2.5*
4	"	Quga	15	21.0	4.0
		Hybrid	4	13.0	3.5
		Total	19	19.4	3.9
5	"	Quga	6	8.5	2.6
		Total	6	8.5	2.6+
Average	"	Quga	13.8	12.8	2.8
		Hybrid	9.0	11.4	2.8
		Quag	0.2	30.0	10.0
		Total	23.0	12.3*	2.8*
6	annual grass	Quga	6	12.5	2.8
		Hybrid	10	9.1	2.3
		Total	16	10.5	2.5
7	"	Total	0	0	0
8	"	Quga	5	8.4	2.4
		Total	5	8.4	2.4
9	"	Hybrid	24	9.6	3.0
		Total	24	9.6	3.0
10	"	Quga	6	10.2	2.2
		Hybrid	8	8.2	2.0
		Total	14	9.0	2.1
Average	"	Quga	3.4	10.1	2.5
		Hybrid	8.4	9.0	2.4
		Total	11.8	9.4	2.5

* Quag height and diameter omitted from calculation of the average
Quga = Quercus garryana
Hybrid = Quercus garryana X douglasii;
Quag = Quercus agrifolia

Table 2—*Average values for Meso-scale environmental factors measured on 100m² Plots in Oregon oak woodland at Annadel State Park*

Environmental Factor	Understory Type: Perennial Grass	Understory Type: Annual Grass
1. Number of trees/plot	Value	Value
Quga	6.0	4.6
Hybrid	0.2	0.4
Quke	0.2	0.2
Arma	0.4	0.2
Total	7.0	5.2
2. Tree diameter (cm)		
Quga	22.2	31.5
Hybrid	16.0	31.0
Quke	21.0	22.0
Arma	7.0	13.0
Total	20.6	28.5
3. Tree basal area (m^2)		
Quga	0.252	0.307
Hybrid	0.004	0.033
Quke	0.020	0.008
Arma	0.001	0.002
Total	0.277	0.350
4. Tree crown cover (pct)	57.0	67.0
5. Height of dominant trees (m)	11.8	11.2
6. Perennial grass cover (pct)	60.0	5.1
7. Annual grass cover (pct)	5.0	68.0
8. Litter cover (pct)	16.3	15.0
9. Average log cover (pct)	0.1	0.9
10. Average rock cover (pct)	18.1	9.0
11. Bare ground (pct)	0.0	0.2
12. Litter depth (cm)	3.8	3.1
13. Soil depth (cm)	20.1	18.9
14. September soil moisture (pct)		
10 cm depth	9.2	9.0
30 cm depth	12.1	10.3
15. Slope (pct)	23.2	14.6

Quke = *Quercus kelloggii*
Arma = *Arctostaphylos manzanita*
Quga = *Quercus garryana*
Hybrid = *Quercus garryana X douglasii*

depleted during the ensuing summer months by evaporation and transpiration by the overstory oaks and the oak seedlings. The added spring soil moisture in the perennial grass woodland was depleted during the summer by a combination of evaporation and transpiration, primarily from the perennial grasses. In a normal rainfall year we would anticipate lower soil moisture levels in the annual grass woodland because of the normally early depletion by the annual grasses.

Micro-scale Environmental Factors

Analysis of micro-scale environmental factors was focused on local micro-site factors which were assumed to protect oak seedlings from evaporative stress and from herbivory by deer and pocket gophers. Distances to nearby (within 100cm) objects which might afford protective shade and visual or physical barriers to herbivory were measured for each seedling and for 10 points located at random in each plot. Litter depth adjacent to each seedling and at the random points was also measured as was the percentage of seedlings showing browse damage and drought damage. Results of these measurements are shown in table 3. The distance from random points to the nearest object of any type on the plots which might interfere with deer browsing was less than the distance from seedlings to similar adjacent objects. Comparison of the difference in distances using Student's "t" test and Wilcoxon Rank Sum test showed that the difference in each vegetation type was not significant. A greater number of objects, particularly rocks and perennial grass clumps, occurred in the perennial grass woodland. However, the differences in the distances between nearby objects and random points and the differences in the distances between nearby objects and seedlings were not significant when the two vegetation types were compared. Coverage of seedlings by perennial grass leaves, although greater than coverage of random points, was not significantly different in either vegetation type. Likewise, differences in average litter depths at random points were not significantly different from average litter depths adjacent to seedlings. Drought damage was lower in annual grass woodlands than in perennial grass woodlands. Browse damage was greater on plots in the annual grass type. Differences, however, were not significant.

CONCLUSIONS

The lack of any statistical correlation between environmental factors at either the macro, meso, or micro-scale is, we believe, a function of the small sample size available for analysis

Table 3—*Micro-scale environmental factors measured on 100m² plots in Oregon oak woodlands at Annadel State Park*

Environmental Factor	Understory Type: Perennial Grass: Oak Seedling	Perennial Grass: Random Point	Annual Grass: Oak Seedling	Annual Grass: Random Point
1. Average distance (cm) to nearest				
rock	60.6	57.5	92.2	80.7
perennial grass clump	21.5	18.8	71.4	93.2
log	94.7	97.6	86.9	93.2
tree	95.6	97.6	85.0	97.7
object (rock, perennial grass, etc.)	17.3	14.7	58.2	55.4
2. Coverage by perennial grass leaves (pct)	86.4	50.4	6.6	2.0
3. Litter depth (cm)	3.8	3.8	3.1	3.1
4. Drought damage seedlings (pct)	44.3	—	17.5	—
5. Browsed damaged seedlings (pct)	57.4	—	80.0	—

at this time in our study. The variability between plots will most likely be reduced as the number of samples increases. We are convinced from our field observations at Annadel State Park that relationships do exist between seedling establishment and some environmental factors at each of the three spatial scales used in this study.

At the macro-scale we anticipate that an increased sample size will confirm a significant difference between the numbers and sizes of oak seedlings observed on the two northern oak woodland types. The larger number of seedlings and their larger size (height and diameter) suggested by the average number and average seedling size on the perennial grass woodland plots is, we believe, a function of the macro-scale environmental factors which distinguish the northern oak woodland types. We believe these factors to be soil type and aspect, both of which influence water availability to oak seedlings.

Meso-scale environmental factors which we anticipate will show a significant correlation with seedling establishment are soil moisture, rock cover, and litter cover. In a typical rainfall year we should anticipate higher soil moisture in perennial grass woodlands. The unusual pattern of late spring precipitation in 1990 accounts for a leveling of the differences in soil moisture both between the two vegetation types and among plots of each vegetation type. We believe that higher soil moisture levels at the end of the growing season will correlate with greater numbers of oak seedlings.

With increased sample size, the percentage of rock cover should show a significant correlation with seedling density and survival in perennial grass woodlands. Rock cover is significant because it facilitates increased soil moisture due to run-off from the impervious surfaces to the surrounding soil. Rock cover also reduces soil moisture loss due to evaporation, since soil beneath the rocks is protected from solar radiation, thus providing pockets of available moisture later into the growing season. Rocks below ground serve as condensation surfaces for water vapor in the soil, thus concentrating soil moisture near their boundary with the soil. The presence of rocks on the ground may reduce the use of an area by deer.

Percentage of the ground covered by litter should also be shown to correlate with seedling numbers as our sample size increases. We believe that litter cover is significant because it protects acorns from predation and desiccation prior to germination and it reduces evaporation of moisture from the soil. It also is a measure of the area of ground that is not occupied by plants, and therefore under reduced loss of soil moisture to transpiration.

At the micro-scale of environmental factors a larger sample size is not expected to change our observation, based on the current data, that objects such as rocks, logs, or perennial grass leaves protect oak seedlings from herbivory. In both woodland types, the distances from random points to nearby objects were closer than the distance from seedlings to the nearest object. Although the trends in herbivory were greater on annual grass woodland plots, where protective objects occurred less frequently, we do not think that more data will demonstrate the protective effect of nearby objects. The evidence of herbivory we observed was assumed to be the result of deer browsing. This may not be the case. Smaller herbivores, less affected by nearby objects, may be responsible for the herbivory we recorded. If, however, deer are responsible for the observed browsing, their behavior may be more influenced by vegetation type than nearby objects.

Data from the current plots showed a trend toward greater drought injury to seedlings in oak woodlands with perennial grass understories. We think this trend is the result of the unusual pattern of late spring precipitation in 1990 and is not typical. The resulting additional moisture available to oak seedlings on plots with annual grass understories minimized drought injury to the seedlings on these plots. Competition for soil moisture between the perennial grasses and oak seedlings following the late spring rain may account for the trend in greater drought injury to seedlings on the plots with perennial grass understories.

The data base available at this point in our study is insufficient to make conclusions concerning the relative value of the three scales of environmental factor analysis. We look forward to an elucidation of this question when a greater data base is assembled.

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Evaluating Tree Protection Devices: Effects on Growth and Survival-First-Year Results[1]

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INTRODUCTION

The protection of seedlings from animal browsing is critical for the survival and growth of many tree species. This is particularly true in wildland areas and arid areas (McAuliffe, 1986), and oftentimes in urban areas. A variety of techniques and devices have been used to protect seedlings, from using straw stubble to milk cartons to plastic or metal screens. Recently, Tuley (1985) reported the successful use of "tree shelters" to protect oak seedlings in England. Tuley's tree shelters are essentially translucent plastic tubes (up to 6 feet in height and approximately 3 inches in diameter) which are placed over young seedlings. Tree shelters were found to significantly accelerate seedling height growth as well as protect them from animal injury. More recent reports (Frearson, 1987; Potter, 1989; and Bainbridge,1990)have found similar results for other species. Although other protection devices improve survival of young trees, their effects on growth (positive or negative) are not notable or not documented.

This paper reports on the effects of three protection devices on the survival and growth of four tree species. Tree shelters, plastic mesh screens, and wire screens were selected. Since many reforestation and revegetation sites in California occur in areas with little or no summer rainfall, and which frequently are not irrigated, tree survival and growth were evaluated under both irrigated and nonirrigated conditions. The study was designed to address the following questions:

1) are there notable (positive or negative) effects from these tree protection devices on survival and growth?

2) when soil moisture is limiting, are effects equivalent to the irrigated condition?

3) are effects consistent for all test species, or do species -specific effects occur?

4) do any of the devices increase or diminish seedling injury by insects or diseases?

METHODS AND MATERIALS

Experiments were conducted at the University of California Hopland Field Station, Hopland, California (elevation 800 feet). A half-acre plot of pasture land (Sequel loam) was fenced to exclude livestock and deer. All pasture vegetation was controlled with glyphosate prior to planting. The two study plots, irrigated and nonirrigated, were separated by a 20 foot unplanted buffer strip. Using a randomized complete block design, six blocks were established in the irrigated plot and 10 in the nonirrigated plot. Seedlings of blue oak (*Quercus douglasii*), valley oak (*Q. lobata*), interior live oak (*Q. wislizenii*) and Douglas-fir (*Pseudotsuga menziesii*) were planted into auger-dug holes (5 foot centers) on March 15 and 16, 1990. Blue and valley oak-seedlings were 6 months old and growing in leach tubes (germinated Fall, 1989) while interior live oaks were 1-year-old seedlings germinated in Fall, 1988. Douglas fir were 1-year-old bare-root seedlings provided by the California Dept. of Forestry. All seedlings were irrigated and fertilized (Osmocote 14-14-14) after planting. All plants were checked for viability after 2 and 5 weeks, and dead plants were replaced. Once initial establishment was complete, treatments were installed as follows:

1) Ventilated Tree Shelters (VTS) - Tubex(R) tree shelters (2 ft. high) with six 1-inch diameter ventilation holes drilled into sidewalls at 6, 12, and 18 inch levels;

2) Nonventilated Tree Shelters (NVTS) - Tubex(R) tree shelters without ventilation holes;

3) Hopland Tents (HT) - molded plastic mesh screens (1/16 inch diameter openings) which are sealed at one end (18 inches high by 8 inches wide);

4) Wire Screens (WS) - window screening cut and fastened to form a cylinder around a seedling with the top sealed (18 inches high by 9 inches wide);

5) Controls (C) - no protection device.

All devices were secured in place with appropriate stakes. Treatments in the irrigated plot began 4/24/90 while those in the nonirrigated plot began two weeks later.

A drip irrigation system was installed to supply water in the irrigated plot. Single emitters were placed at the base of each plant, delivering water at the rate of 1 gallon per hour. Irrigation began in mid May and continued weekly through October (2 gals/plant/week). Nonirrigated plants were hand-watered three times after planting, with the last irrigation occurring in early June.

Plant height (cm) and stem diameter (mm) measurements were taken 4/24/90 and 9/12/90. Diameter measurements were

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taken 2 inches above ground. Height measurements were made from ground level to the apical bud or meristem of the dominant stem. In cases where codominant stems occurred, competing stems were lightly headed to promote the development of a single stem.

Weed control was maintained by mowing and hand-pulling. Planting basins were kept weed-free.

Soil moisture potentials were measured periodically in the irrigated and nonirrigated plots, and air temperatures inside and outside all tree protection devices were measured on 7/31/90 and 8/1/90.

RESULTS

Survival

Survival of all species was generally good in the irrigated plot (Fig. 1). All valley and live oak seedlings survived, as did 96 percent of the blue oaks. At 83 percent, Douglas-fir survival was lowest. Survival did not appear to be related to treatments.

In the nonirrigated plot, survival was lower (Fig.2). Across treatments, valley and blue oak survival was highest (84 and 82 percent, respectively), while live oak survival was 63 percent. Only two of 50 Douglas-fir seedlings survived. It appears that some irrigation in the summer months is critical for Douglas-fir survival. Among treatments, survival was least in unprotected control plants (45 percent), while protected plants ranged from 53 to 68 percent survival. Excluding Douglas-fir, oak survival ranged from 70 to 90 percent with protection, and 58 percent without protection.

Growth

a. Irrigated Plot

After 5 months, growth response was somewhat variable for both treatments and species (Figs. 3 to 10). In most cases there was a substantial range in height and diameter growth among replicates. Some trees grew a lot while others grew very little. Height growth of controls for all species was less than that of protected plants, while diameter growth was less in most cases. Douglas-fir showed the least increase in height for all species, while valley oak was largest in height and diameter increase.

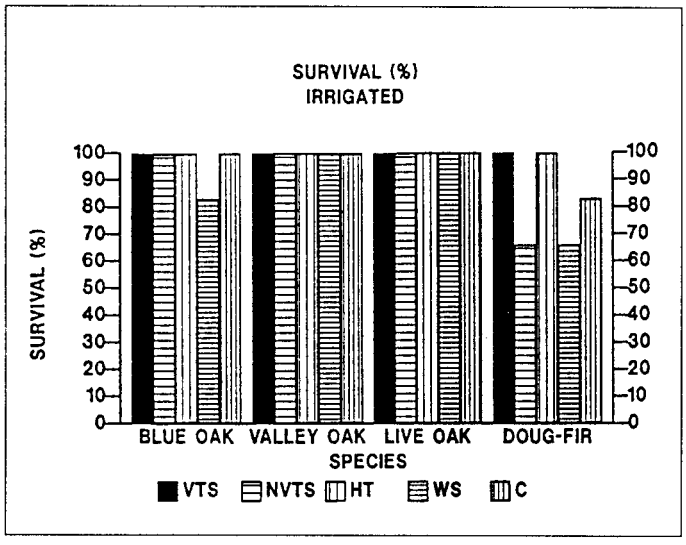
In comparing treatments, a variable diameter response occurred: largest diameter increase was found for a different treatment in each of the species. Across the species, plants in wire screens (WS) were found to have largest diameter increase, while those in non-ventilated tree shelters (NVTS) were least.

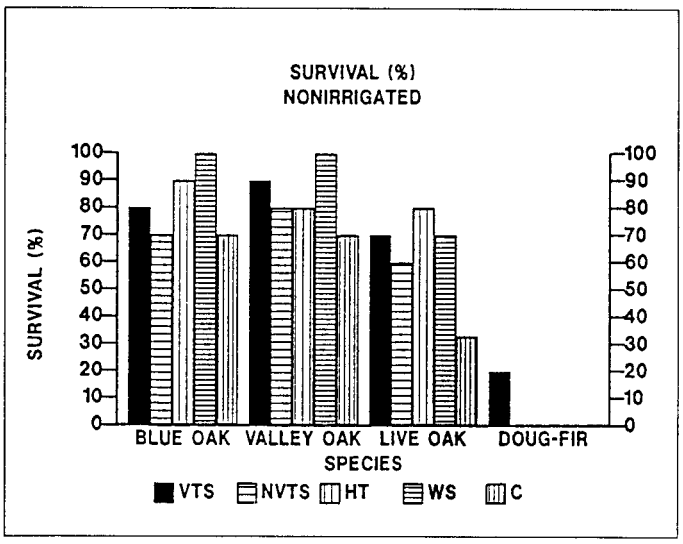
Height increase was largest in tree shelters (both NVTS and VTS) for most species. Greatest growth was found in NVTS in valley and live oak, while least occurred in Hopland tents for blue oaks. Again, all controls were less than treatments.

b. Nonirrigated Plots

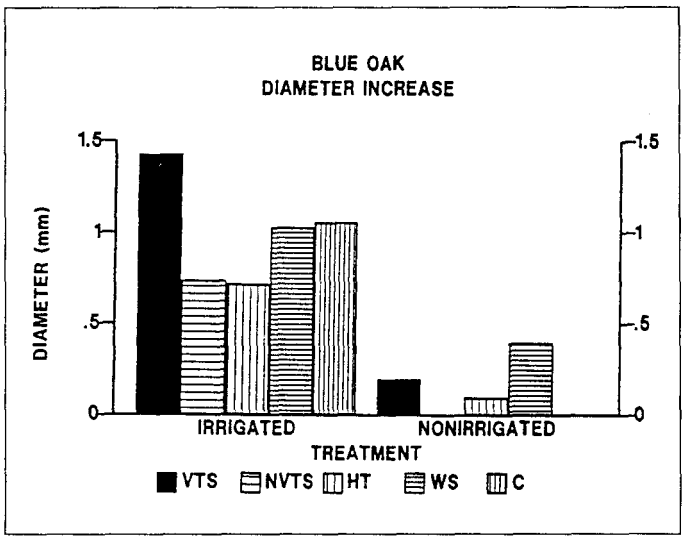
Since only two of 50 Douglas-fir seedlings survived in the nonirrigated plot, analysis of results is confined to oak species. Little growth occurred in the nonirrigated plot. Mean diameter and height differences were approximately 20 and 15 percent, respectively, of the growth found in irrigated plots. Interior live oak generated the most growth with an average 5.2 cm height increase and 0.5 mm diameter increase, while blue oak was slowest, growing only 0.5 cm in height and 0.14 mm in diameter.

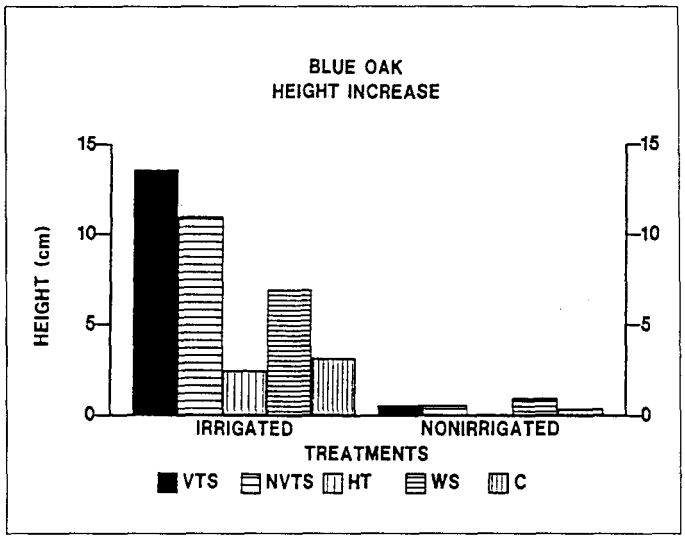
Treatment effects found that wire screens (WS) generated greatest height increases for all species. Least growth was found in ventilated tree shelters (VTS), i.e., aside from control plants which grew less than all treatments.



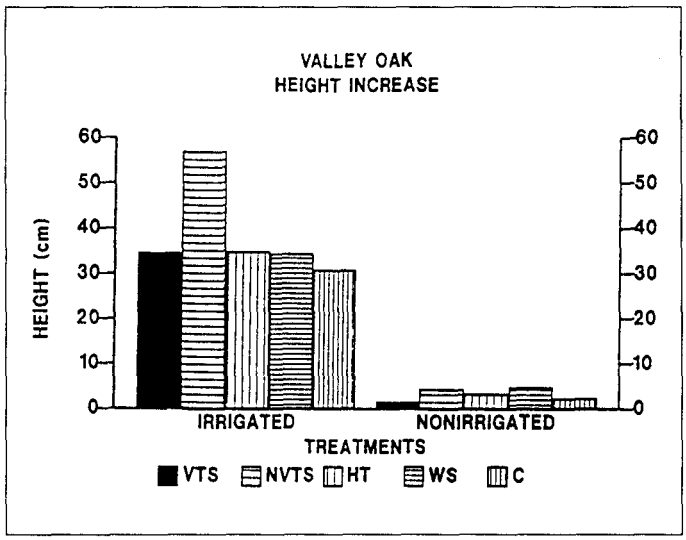


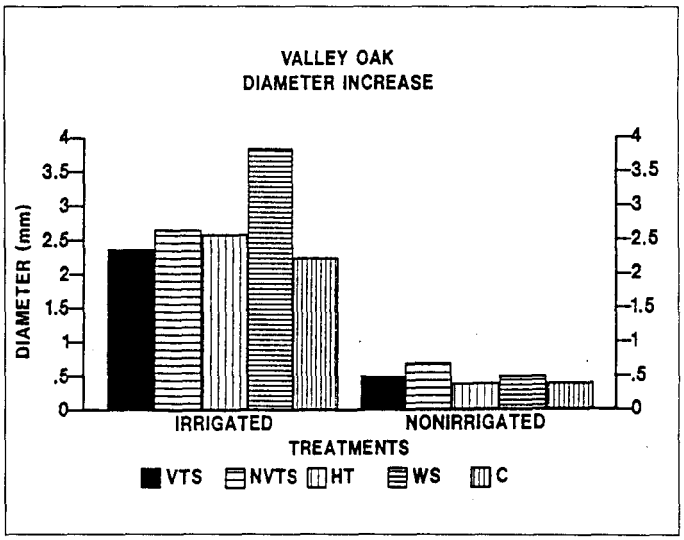
Figures 1 and 2—Percent survival of test species in irrigated and nonirrigated plots. See "Methods" for description of treatments.



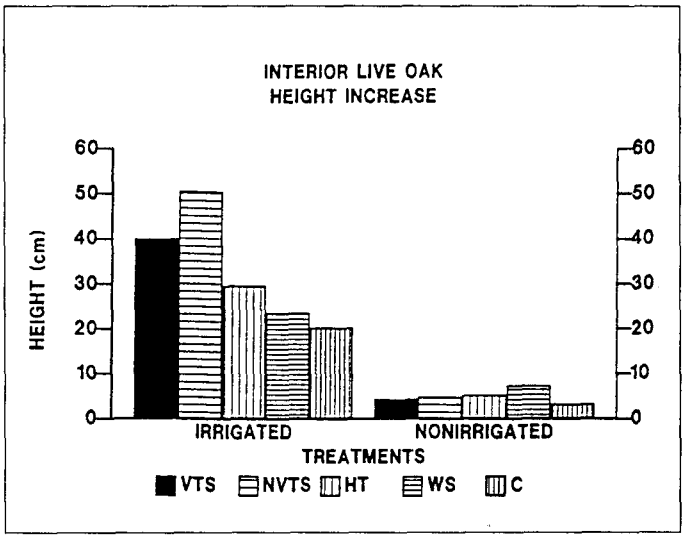


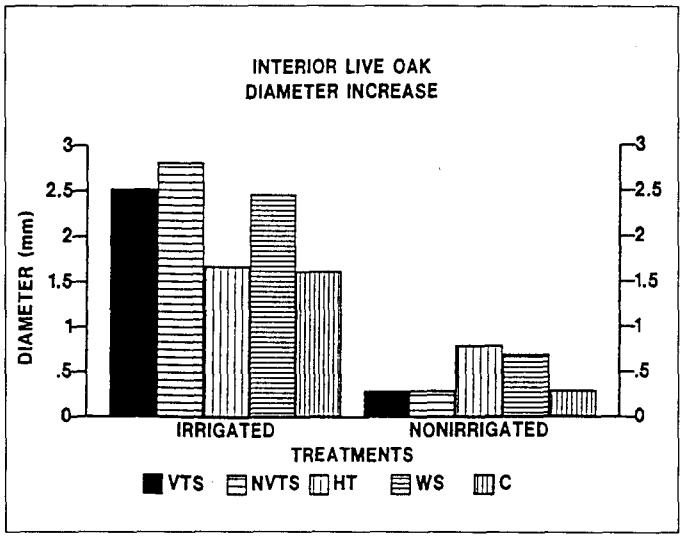
Figures 3 and 4—Height and diameter growth increase of blue oak seedlings *(Q. douglasii)* in irrigated and nonirrigated plots. See "Methods" for description of treatments.



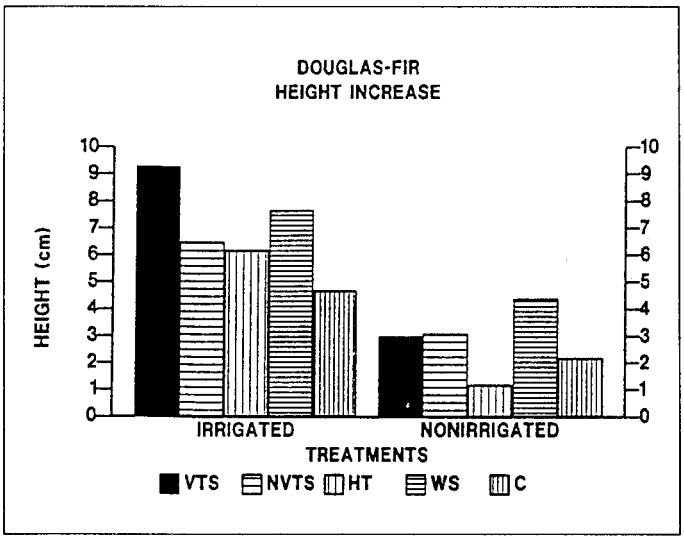


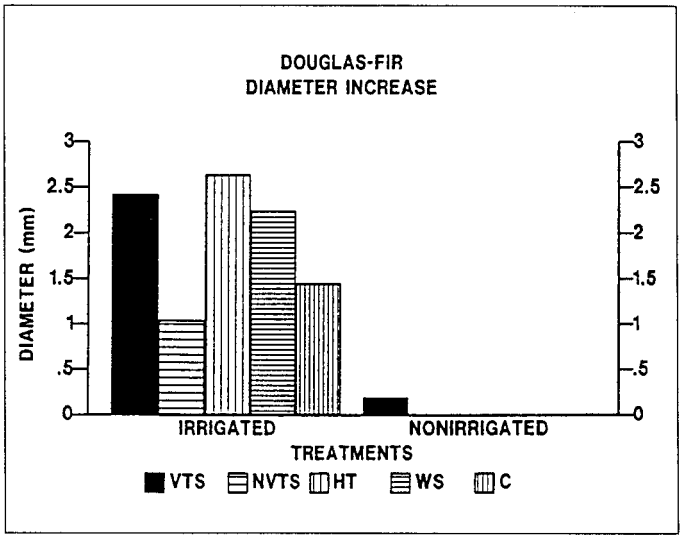
Figures 5 and 6—Height and diameter increase of valley oak seedlings *(Q. lobata)* in irrigated and nonirrigated plots. See "Methods" for description of treatments.





Figures 7 and 8—Height and diameter increases of interior live oak *(Q. wislizenii)* in irrigated and nonirrigated plots. See "Methods" for description of treatments.





Figures 9 and 10—Height and diameter increases of Douglas fir seedlings *(P. menziesii)* in irrigated and nonirrigated plots. See "Methods" for description of treatments.

Temperatures and Soil Moisture

Temperatures inside Hopland tents and wire screens were approximately 4°F higher than the outside temperature (95°F) in both irrigated and nonirrigated plots. Temperatures inside treeshelters (both VTS and NVTS) were approximately 4°F higher and 7°F higher than outside temperature (97°F) in irrigated and nonirrigated plots, respectively.

Soil matric potentials were found to reach a maximum 25 cb at 10 inches in the irrigated plot, and were greater than 100 cb at 10 inches in the nonirrigated plot.

Insects and Diseases

Although grasshoppers were found in several of the protection devices, regardless of type, no significant insect or disease injury was found on any of the plants, protected or unprotected.

DISCUSSION

In nonirrigated areas, survival of all three oak species appears to be enhanced by the protection devices used. Survival of Douglas-fir was very poor without summer irrigation, regardless of whether they are protected or not. This suggests that protection devices can serve two roles:

1) physical protection from animal browse, and

2) modification of the plant environment to reduce factors contributing to plant dehydration. This second role may be particularly important in harsh environments (windy, hot, dry) where both "physiological" and physical protection may be needed.

Results of treatment effects on growth must be considered preliminary at this time. The first five months after planting is often considered an "establishment" period, where root growth is likely a "higher priority" during this phase than top growth. It is interesting to note, however, that protection devices generally did enhance top growth during this time. Of particular interest is the indication that tree shelters accelerate height growth in the oaks studied. This effect would be of significant value in reducing the time required for oaks to develop shoots above the deer browse line. Once established to this point, little or no protection may be needed. This would certainly accelerate many reforestation or revegetation timetables.

In nonirrigated areas, some protection appears helpful in promoting growth. The implication being that these devices allow plants to maintain a more satisfactory internal water balance than unprotected plants. Perhaps water deficits are not as frequent and/or severe when plants are protected. Considering the response of Douglas fir to irrigation, however, this is likely a species specific response, i.e., water deficits which merely slow the growth of one species may be fatal to another.

Treatment effects on growth may be more pronounced in subsequent years. Tuley (1985) found a dramatic increase in height growth of *Quercus petraea* protected by tree shelters in the second and subsequent years. In this study, height and diameter growth will be monitored for another two years.

FURTHER RESEARCH

Naturally occurring seedlings should also benefit from protection. Certainly, physical protection from animal injury would be of value, while growth enhancement would accelerate the establishment period for many species. Studies are, there-

fore, planned to evaluate the usefulness of these devices on naturally-seeded tree species.

ACKNOWLEDGMENTS

Assistance provided by Amy Peters and the staff at the Hopland Field Station is gratefully acknowledged.

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Seasonal Growth Patterns of Blue and Valley Oak Seedlings Established on Foothill Rangelands[1]

Douglas D. McCreary[2]

Abstract: Blue (*Quercus douglasii* Hook. & Am.) and valley (*Quercus lobata* Née) oak seedlings were planted on a foothill rangeland site in 1987 and 1988. Both species were watered their first year but received no irrigation thereafter. They were evaluated during each subsequent spring and summer for survival, weekly height growth and total year-end height. Seedling survival was extremely high for both species and height growth was rapid and vigorous. Blue oak seedlings four growing seasons after planting averaged over 2.3 m and valley oaks after three seasons averaged 2.0 m in height. Yearly height growth occurred in a series of flushes beginning around the end of March. Typical seedlings had either two or three flushes, although the average number per year has been declining. During flush periods, growth was rapid, often exceeding 15 cm per week. The greatest height increment occurred during the second flush. These results suggest that both blue and valley oaks have the capacity to grow rapidly as young seedlings if suitable environmental conditions are maintained.

Two native oak species reported to be regenerating poorly in portions of California are blue oak and valley oak (Bolsinger 1988, Muick and Bartolome 1987). While concern about the natural regeneration of these species has been voiced since the turn of the century (Sudworth 1908), only during the last five years has a large amount of research focused on understanding and solving this problem. Results from these studies have greatly increased our knowledge of the causes of poor regeneration and have demonstrated a variety of techniques for successfully growing and planting seedlings. To date, however, most of the studies have evaluated field performance in terms of survival or year-end size, and little has been reported about phenological development or seasonal growth patterns. Such information can be vital to understanding basic physiological mechanisms operating within seedlings, and can help clarify some of the factors limiting field performance of both natural and planted seedlings. This paper describes the results of an intensive two-year evaluation of blue and valley oak seedlings planted on a foothill rangeland site. It is hoped that this information will provide some insights into the factors influencing juvenile seedling growth and help promote greater establishment success in regeneration plantings.

METHODS

Blue Oak Trial

The first field plot was established in April 1987 with the planting of 120 blue oak seedlings at the Sierra Foothill Range Field Station near Browns Valley, California (elev. 200 m). These seedlings came from acorns collected near Rescue, California (elev. 425 m) and had been grown for one year in plastic boxes approximately 6 cm square by 13 cm deep. They were transplanted into a bare field plot into holes that had been augered to a depth of 90 cm and backfilled. The soil at the site was an Auburn-Las Posas-Argonaut rocky loam and was between 60 and 100 cm deep. Prior to planting, a 21 g fertilizer tablet (20-10-5) was placed approximately 30 cm deep in each hole. Immediately after planting, seedlings were covered with 40 cm tall pieces of aluminum screen to prevent browsing and insect damage. As the seedlings grew taller, these cages were opened at the top and were eventually replaced by 90 cm tall screen cylinders. Several seedlings which died during the first 2 weeks were replaced.

At the time of planting, seedlings were thoroughly watered and were irrigated regularly with drip irrigation throughout their first summer. However, no irrigation was provided during the three subsequent years.

Valley Oak Trial

These seedlings were planted a year later, adjacent to the blue oak plot. The same number of seedlings was planted with the same spacing, augering and fertilization treatments. Seedlings were from acorns collected in Briones Park in Contra Costa County (elev. 100 m) the previous fall and had been grown for approximately four months in 4 by 4 by 15 cm containers. After planting, seedlings were watered during the subsequent summer with varying levels of irrigation as part of another experiment (McCreary 1989). However, no irrigation was provided in 1989 or 1990.

Measurements

At the end of the 1987 growing season (blue oaks only) and the 1988, 1989, and 1990 growing seasons (blue and valley oaks) the survival and year-end height of each seedling were

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recorded. In addition, in both 1989 and 1990 leaf-out date of each seedling was determined, as well as the weekly height increment of the terminal branch of each seedling during 24week periods beginning in early April. Since both species tended to have droopy leaders, terminal height was determined by straightening out the main branch and recording either total seedling height or height increment of the actively growing shoot. If there was no single obvious terminal shoot, the height of the tallest branch was recorded.

In addition to height measurements, the number of flushes in each growing season was also recorded. This was determined by evaluating height increment patterns, as well as examining the terminals for buds, bud swelling, and if flushing occurred, for evidence of bud scars on the stem. From the collected data several variables were also calculated including average weekly height increment, the number of seedlings actively growing during any week (those that grew 2 cm or more), and height increment per flush.

RESULTS

Blue Oak — Survival, Height Growth and Leaf-out Date

Seven seedlings died during the first summer, but no mortality has occurred since. Average height increment during the first year was approximately 25 cm. Since then, however, seedlings have grown rapidly and now average over 2.3 m in height (fig. 1). There was a very consistent pattern of growth during 1989 and 1990. In both years seedlings began leafing out (leaves emerging through the bud scales of the most advanced bud) during a two-week interval, beginning in the last week in March. Average leaf-out date was March 30 in 1989 and March 25 in 1990. There was also a consistent pattern for growth initiation among seedlings within the plot. For both years the difference between the date the first and last seedling leafed out was only 11 days.

Flush Pattern

For both years the first flush of growth lasted about two weeks, with relatively little height increment (fig. 2). By the middle of April, most seedlings had stopped elongating and set a resting bud. The period between the first and second flush varied considerably among seedlings but the average time, about five weeks, was fairly consistent between years. However, while all seedlings had at least two flushes in 1989, there were four seedlings that only had one flush in 1990. By the end of May in both years most seedlings had resumed active growth and were elongating rapidly. The greatest height increment occurred during this second flush. For instance in 1989, second flush increment accounted for 68 percent of the total height growth, while in 1990 it accounted for 83 percent (fig. 3). Not only was

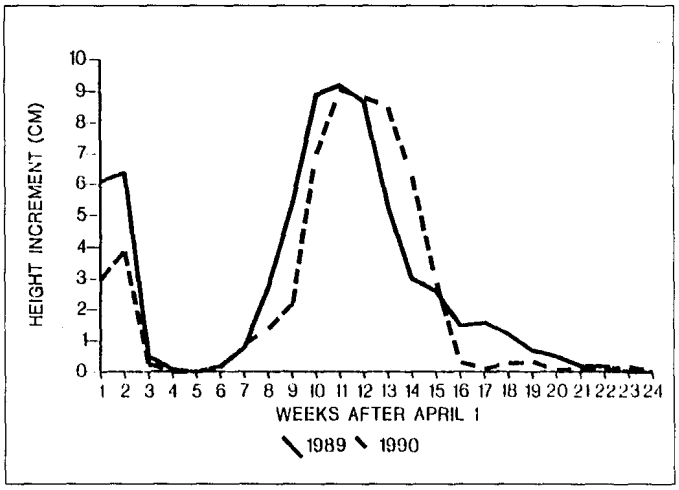


Figure 2—Average weekly height increment of blue oak seedlings in 1989 and 1990.

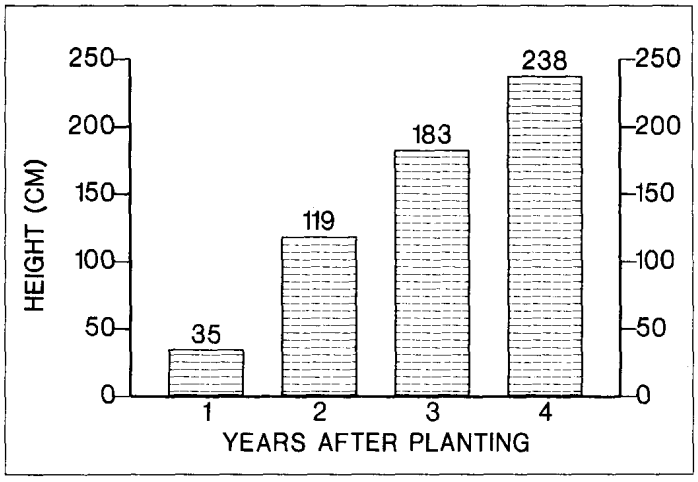


Figure 1—Average total height of blue oak seedlings 1, 2, 3 and 4 years after planting.

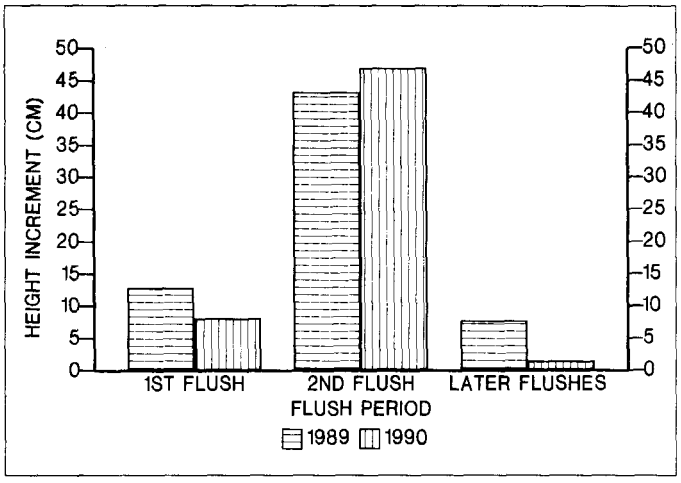


Figure 3—Average height increment per flush (averaged over all seedlings) of blue oaks in 1989 and 1990.

there a large total amount of growth during this period, but the growth rate was exceedingly rapid. During the peak growth period, average height growth of all seedlings in the plot was nearly 10 cm a week, while many individuals grew more than 15 cm. The elongation interval was also far longer than for the first flush, averaging about six weeks. Almost half of the seedlings also had a third flush in 1989. However, the initiation of this flush varied tremendously, from mid-summer until early fall. In general, this flush period was relatively brief and contributed little to total height increment. In 1990, only a handful of seedlings had a third flush, however. The average number of flushes in 1989 was 2.41, compared to an average of 2.08 in 1990.

Valley Oak — Survival, Height Growth and Leaf-out Date

After three seasons, all of the valley oak seedlings that were planted are alive. Average yearly height growth was slightly greater than that of the blue oaks (fig. 4) and seedlings are now just under 2 m tall. Average leaf-out date for the valley oaks was March 30 in 1989, and March 21 in 1990.

Flush Pattern

The same general growth pattern observed for blue oaks was also followed by the valley oaks, with a relatively weak first flush followed by a rapid, vigorous second flush (fig. 5). However, there was greater variability among valley oak seedlings in the growth patterns than for blue oaks. For instance, there was a three-week period beginning around mid-April in both years when not a single blue oak seedling was actively elongating. For valley oaks, on the other hand, at no time between April and mid-June of either year were all seedlings inactive.

The pattern between years was also much more inconsistent for valley oaks. In 1989, the pattern was quite similar to that for the blue oaks, with most seedlings flushing early, setting a bud and then initiating a second flush in early June. In 1990, however, 14 percent of the seedlings did not set a bud in April and continued elongating into the summer. These longer first flushes also resulted in a higher percent of the overall growth accounted for by the first flush than it was in 1989 (fig. 6). As with the blue oaks, the average number of flushes per seedlings was greater in 1989 (2.57) than in 1990 (1.88).

DISCUSSION

One of the most surprising results of this study was the high survival and rapid growth rate of both species, even though no

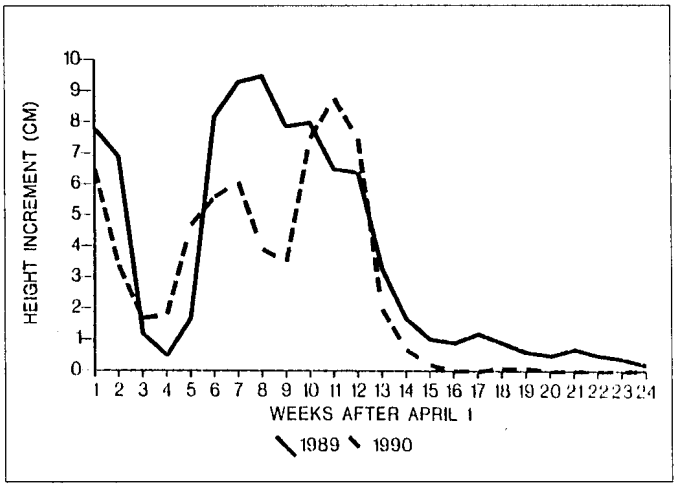


Figure 5—Average weekly height increment of valley oak seedlings in 1989 and 1990.

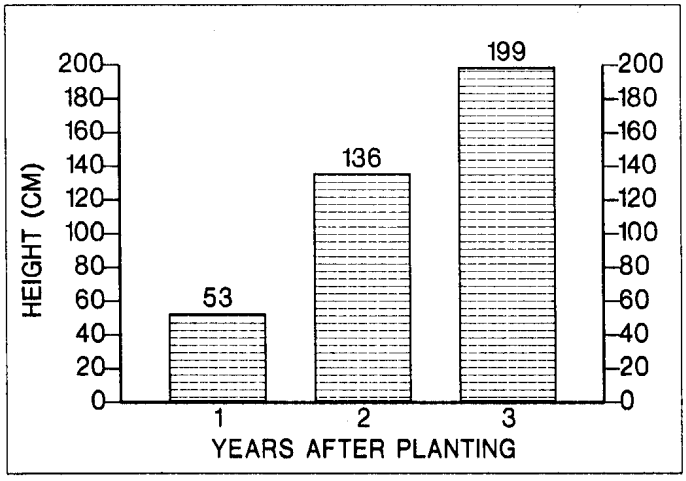


Figure 4—Average total height of blue oak seedlings 1, 2, 3 and 4 years after planting.

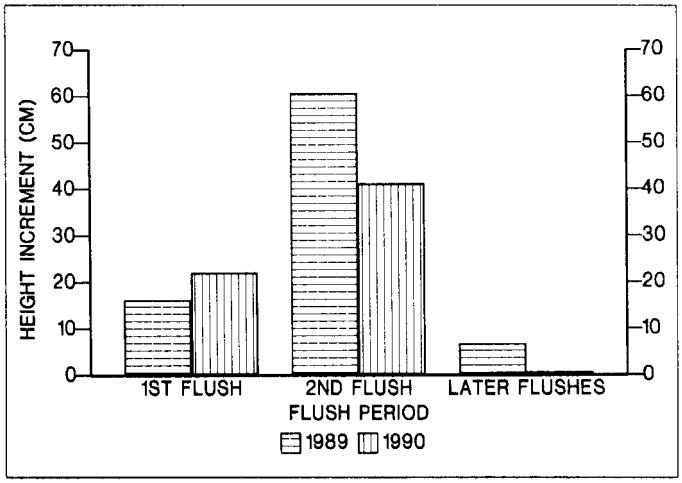


Figure 6—Average height increment per flush (averaged over all seedlings) of blue oaks in 1989 and 1990.

irrigation was provided after initial establishment. This growth occurred in spite of the fact that some seedlings were repeatedly browsed by deer, covered by powdering mildew, and/or chewed on by a variety of insects. Thus, even though both species have been found to have problems naturally regenerating, results from these trials indicate that once established, seedlings are very resistant to mortality factors. Of 240 total seedlings planted, only seven died the first year, and none have died since.

Growth rate for blue oak has also been dramatically greater than expected. While valley oak is reported to grow fairly rapidly under favorable conditions, blue oak is generally characterized as an extremely slow growing species. In this field trial, however, yearly height growth of blue oaks averaged well over 50 cm a year, and there has been no evidence of a significant slowdown. While it is impossible to predict field performance at other sites based upon this one trial, these results suggest that slow growth of blue oaks in the field is probably a result of environmental limitations, rather than an inherent propensity to grow slowly. This is encouraging since one of the greatest barriers to successfully regenerating native oaks is browsing of young plants by deer and livestock before they become tall enough to withstand these pressures. If seedlings can be planted, protected, and maintained in such a way that the growth rate can be significantly increased, the interval during which plants are vulnerable could be greatly reduced. While such intensive management (weed control, augering, screen protection, etc.) is currently costly, it may be ultimately less expensive than repeated plantings, slow growth, and in some cases, land being unavailable for other uses (i.e., livestock production).

Another dramatic finding of this study was the marked periodicity of terminal growth and the great disparity between first- and second- flush increment. This pattern contrasts with that of many conifers grown in similar environments, where the first (and sometimes only) flush results in the majority of height growth and subsequent flushes contribute little. This result was surprising since the buds preceding the first flush for both species were so much larger, robust, and appeared to be more developed than those preceding the second flush.

There are several possible explanations for these growth patterns. In contrast to most conifers, both oak species evaluated are deciduous and were just starting to leaf out when terminal elongation began. It is possible that the initial height growth was therefore limited by lack of photosynthesis. By the time the second flush began, on the other hand, the leaves were fully expanded and able to generate more photosynthate to support terminal growth.

Environmental conditions when these flushes took place were also quite different and may have further contributed to the observed growth differences. At the time of the first flush, soils were very wet, but soil and air temperatures were still relatively cool. By the time the second flush began, however, there was still abundant soil moisture (since the competing vegetation was controlled) but temperatures had increased substantially. For instance in 1989 average air temperatures were 18°C during the first two weeks in April and 22°C during the first two weeks in June, while soil temperatures 15 cm beneath the surface were 17°C and 23°C respectively. Such increases could have substantially influenced growth rates since these temperatures are closer to the optimum range for photosynthesis and other processes favoring growth (Salisbury and Ross 1969).

The final factor which may also have contributed to height growth differences between flushes was competition from root growth. During periods of active root growth, roots act as a sink and can reduce the energy available for the above ground part of the plant. While it is known that there is a periodicity to root growth patterns for most woody species (Kramer and Kozlowski 1979) and there is often a marked peak of root activity in the early spring, not enough research has been done on the two species evaluated here to determine if this was occurring.

A final observation from these trials was that both species seemed very resilient and able to withstand a wide range of environmental conditions. When both species were browsed by deer before mid summer, they quickly resumed growth from previously dormant lateral buds. They also tolerated a tremendous range of temperatures from a low of -9°C to a high of 43°C and even survived a rare foothill snow storm which seriously damaged an adjacent planting of eucalyptus. As young seedlings they were also able to remain actively growing under what appeared to be very harsh conditions. In 1988, for instance, 40 percent of the blue oaks were flushing in August, even though there had been very little rainfall since April and almost all other vegetation on the hillsides had turned brown.

CONCLUSIONS

These trials indicate that planted blue and valley oak seedlings can have high survival and are capable of extremely rapid juvenile growth under favorable environmental conditions. Seedings planted in augered holes containing a slow release fertilizer tablet, and maintained in a weed-free plot, grew an average of over half a meter, a year, even though no irrigation was provided after initial establishment. Only seven of the 240 seedlings died during the first year, and none died thereafter.

Both species also exhibited a determinate growth pattern with stem elongation occurring as a series of flushes separated by periods of inactivity. By far the greatest growth took place during the second flush which commenced near the end of May and lasted for approximately six weeks. Height growth during this period often exceeded 15 cm a week for certain seedlings. The average number of yearly flushes per seedling was generally between two and three, but tended to decrease as the plants became older.

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Blue and Valley Oak Seedling Establishment on California's Hardwood Rangelands[1]

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Abstract: Factors contributing to poor establishment of blue oak (*Quercus douglasii*) and valley oak (*Q. lobata*) in California oak-grassland savannas were studied in a series of acorn seeding experiments initiated in 1985. Exclusion of large herbivores permitted examination of herbaceous interference and small mammal and insect depredation. Herbaceous interference was the most important factor. Average emergence in all blue oak seedings with and without herb control was 45 percent and 29 percent, respectively. The respective values for all valley oak seedings were 60 percent and 46 percent. Average first year survival, expressed as a percentage of acorns planted, was significantly improved by elimination of herbs in both blue oak (30 percent vs. 11 percent) and valley oak (45 percent vs. 25 percent) seedings. Limited data suggests the differential in survival is maintained over time as overall survival declines. With few exceptions, the addition of screen protection to discourage predation significantly enhanced survival and growth. Shade provided by window screen cages is suspected of making an unmeasured positive contribution. Interaction between herbaceous control and protection appears to develop with time.

In the most recent and comprehensive inventory of California's hardwoods, Bolsinger (1988) reports that livestock graze the majority of nearly 3 million hectares of noncommercial woodland where oaks (*Quercus* spp.) are the dominant trees and blue oak (*Q. douglasii*), occupying about 1.2 million hectares, is the dominant hardwood type. The author also states that recruitment in blue oak stands is relatively sparse and almost nonexistent in valley oak (*Q. lobata*) stands. Results of a germination study in Monterey County suggest that unsuccessful blue and valley oak recruitment results from mortality in seedling and sapling stages rather than from inadequate germination and seeding emergence (Griffin 1971). In a later study of regeneration based on analysis of tree rings, McClaran (1985) suggests that the transition from a seedling to sapling and tree stages is more critical in limiting regeneration than acorn germination and early seedling survival.

Clearing of woodlands in rangeland improvement projects and poor natural regeneration were two of 19 concerns identified by the Hardwood Task Force of the California Board of Forestry in its December 1983 draft report (Passof and Bartolome 1985). Development of artificial restocking techniques and identification and quantification of problems associated with these techniques are needed to address the concerns raised and preserve management options in oak woodlands.

This paper examines the potential of artificially sown acorns for establishment of oak in oak woodlands of California. Specifically, we evaluated the impacts of herbaceous interference and small mammal and insect herbivory on emergence, survival, and growth of seedlings. Included is an evaluation of selected techniques for reducing negative impacts.

STUDY SITES

Over a period of 5 years, blue and valley oak acorns were directly seeded in field plots in six counties lying between latitudes 35°15' and 39°15'N (fig. 1). These oak woodland sites in California's Mediterranean-like climate have understories

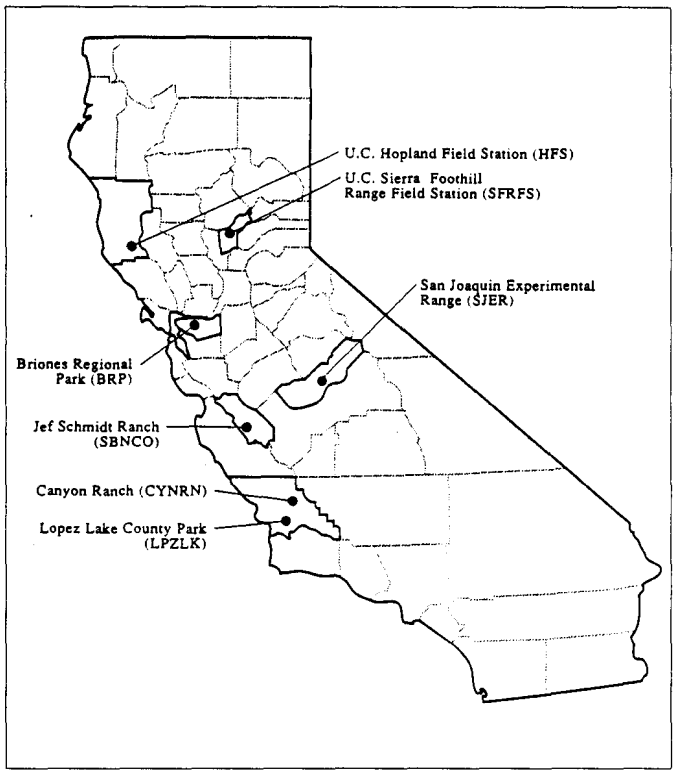


Figure 1—Location of 7 oak-grassland study sites.

[1] Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

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dominated by annual grasses. Throughout the study area, annuals continue to grow until all available soil water is exhausted. A discussion of the ecology and composition of California annual grasslands is presented by Heady (1977). Menke (1989) describes the influence of biomass management (grazing) on productivity and composition.

San Luis Obispo County was the most southerly site for acorn plantings of the two oak species. Valley oak was planted at Lopez Lake County Park (LPZLK) and blue oak on the Canyon Ranch (CYNRN). The San Benito County plantings of both oaks were made on the Jef Schmidt Ranch (SBNCO). In Madera County, blue oak was planted on the U.S. Forest Service San Joaquin Experimental Range (SJER). In western Contra Costa County, the two oaks were planted in Briones Regional Park (BRP), part of the East Bay Regional Park District. In Mendocino County, the two oaks were established at the University of California Hopland Field Station (HFS). In Yuba County, blue oak was planted on the University of California Sierra Foothill Range Field Station (SFRFS). Elevation, rainfall, and soil characteristics (table 1) represent conditions typical of those occurring in natural stands of the oaks found in the Coast Ranges, interior coastal ranges of the San Joaquin Valley, and western foothills of the Sierra Nevada in the Sacramento and San Joaquin Valleys.

METHODS

Acorns were collected from trees in late summer through early fall, dusted with captan and placed in 0.08 mm clear plastic bags with material at the bottom to absorb excess moisture from respiration. The acorns were then placed in cold storage (4°C) until planting. Storage between 1°-4°C is recommended by Korstian (1927) and Harrington (1972) to retard germination without a reduction in emergence potential.

Plantings of blue and valley oak acorns were made in late fall each year (November-December) from 1985-1989. Not all locations were included each year because annual acorn production was irregular and sometimes inadequate for establishment of plantings.

Acorns were sown in open areas away from canopy effects and on terrain as flat as possible to reduce effects of slope exposure and inclination. All work was conducted within deer-proof enclosures to exclude browsing of seedlings by deer and livestock, an acknowledged problem (Franco 1976, Longhurst and others 1979, Menke and Fry 1980) and to prevent depredations by feral pigs (*Sus scrofa* Linnaeus).

At each site, treatments were the factorial set of two levels of herbaceous plants (none and the naturally occurring vegetation) and two levels of protection against small mammal and insect damage (screens and no screens). The experimental design was a randomized complete block with the two levels of herbaceous plant control as main plots and protection applied as a split on main plots.

Main plot treatment each consisted of 100 acorns planted in four rows of 25 each with 30 cm between acorns and rows. Planting depth was 5 cm, a depth suggested for use in controlled environments (Lobel and George 1983) and one considered a minimum to discourage disturbance by mice (Griffin 1971). In other research, this depth has been found to be a good compromise between improved protection from predation and reduced emergence that occurs from planting at a greater depth (Tietje and others 1991).

During planting, acorns with obvious insect damage, usually consisting of exit holes created by larvae of the filbert weevil (*Curculio occidentis* Casey) and filbertworm (*Melissopus latiferreanus* Walsingham), were discarded. Acorns that had

Table 1—Physical parameters at locations included in blue and valley oak seeding studies.

Location	Elevation (m)	Avg. Annual Precip (cm)	Soils		
			Depth (cm)	Estimated AWC[1] (cm cm^{-1})	Series[2] and Surface Texture
			Blue Oak		
BRP	188	48	86	0.15-0.18	Los Osos clay loam
CYNRN	545	28	155	0.14-0.17	Ayar clay loam
HFS	273	94	183	0.14-0.17	Hellman loam
SBNCO	394	36	61	0.10-0.14	Santa Lucia shaly loam
SFRFS	182	72	53	0.11-0.16	Argonaut gravelly loam
SJER	333	48	74	0.09-0.12	Ahwahnee sandy loam
			Valley Oak		
BRP	124	48	193	0.16-0.18	Botella clay loam
HFS	273	94	152	0.14-0.17	Yorkville loam
LPZLK	158	51	183	0.10-0.15	Elder sandy loam
SBNCO	394	36	61	0.10-0.14	Santa Lucia shaly loam

[1]AWC = Available Waterholding Capacity
[2] All are upland soils except Botella and Elder which are alluvial.

germinated in storage were distributed among treatments and replicates to insure uniformity of potential emergence.

During the study, two blue oak seedings had to be planted twice because of depredation. At CYNRN in 1985, feral pigs dug up many acorns before fencing was erected. In the second instance at SFRFS in 1987, deer mice (*Peromyscus maniculatus* Wagner) were the suspected problem. This assumption is based on live trap records at the site.

Measurement of emergence was confounded by small mammal depredations. Some acorns were destroyed early at all locations, both before and after emergence. One seeding at SJER was destroyed in 1985-86 and could not be reseeded. The high population of ground squirrels (*Spermophilus beecheyi* Richardson) present at the time suggests this rodent was responsible. Subsequent seedings at SJER were made after the population was reduced, but control at this site was maintained throughout the study.

Pocket gophers (*Thomomys bottae* Eydoux & Gervais) were common at all sites, and control was practiced where populations were a significant threat. However, no level of control was adequate to prevent losses to this rodent. These depredations may have been encouraged by the geometric planting pattern and relatively close spacing of acorns. In addition, we noted that control of herbaceous plants discouraged depredation.

Emergents in each main plot were randomly split into two groups, protected and unprotected, with protection provided by window screen cages (closed cylinders 15 cm in diameter and approximately 40 cm high) or Foregon (formerly Vexar) 14-strand rigid plastic seedling protectors (screens) 5 cm in diameter and 30 cm high. The large mesh plastic screens were substituted for window screen cages in new plantings when the threat from grasshoppers (*Melanoplus devastator* Scudder) was minimal. As a consequence, the efficacy of this less expensive protection was evaluated in six seedings, two blue oak seedings each at CYNRN and SJER (1987 and 1988) and two valley oak seedings at LPZLK (1987 and 1988). At CYNRN and LPZLK, black tailed jackrabbits (*Lepus californicus* Gray) and rabbits (*Sylvilagus* spp.) are the suspected major predators, and ground squirrels are a threat at SJER. Protection was applied beginning in Spring 1987 to all one-year seedlings and new emergents.

Following 1986 emergence in the 1985 SFRFS seeding, hairnets used in the food processing industry were applied to seedlings in each treatment to protect against defoliation by grasshoppers. In subsequent seasons, window screen cages were used as described.

During the 1985-86 growing season, glyphosate, a systemic herbicide, was applied after planting to control herbaceous growth until oak seedling emergence. After emergence, herbs were hoed. In subsequent seasons, initial herb control in new seedings was obtained using both glyphosate and a soil active herbicide, atrazine, to eliminate existing herbaceous growth and most such growth that might appear after application. The combination was used to reduce labor. In established plantings, two soil active materials, atrazine and oxyfluorfen, were applied annually during winter dormancy for more effective control of herbaceous growth. Potential for damage to emerging oak seedlings discouraged use of the latter chemical during the season of planting.

In one blue and one valley oak seeding, each established in 1985 (CYNRN and LPZLK), herbaceous plant interference was eliminated in all treatments after the first season. This was necessary to provide access. A third seeding at CYNRN in 1986 was established only with control of herbaceous plants.

Observations evaluated by analysis of variance (ANOVA) included emergence, survival measured in the spring of each growing season, and height of plants each fall. When measuring height, the longest stem was used if branching occurred. Unless otherwise noted, significant differences are reported at the 95 percent level of confidence.

Since data were collected over several time intervals, time was a third factor in survival and was considered a second split (Steel and Tome 1960). When there was a significant time interaction, ANOVAs for each time interval were used to assess the treatment effects. This was done to insure a conservative interpretation of data.

When necessary for the ANOVA, raw data were transformed to maintain homogeneity of variances. The results presented are treatment averages for the original measurements.

RESULTS AND DISCUSSION

Emergence

Overall emergence of 14 blue and 10 valley oak seedings was improved through herb control (table 2). Average emergence of blue oak with control was 45 percent. Without control, it was 29 percent. The values for valley oak were 60 percent and 46 percent, respectively.

Effect of Herb Interference on Survival

Average first-year seedling survival of both oak species, expressed as a percent of acorns planted, was significantly greater without herbaceous interference. In 11 blue oak plantings, survival was 33 percent of acorns planted without herbs while 11 percent survived in the control. Survival in eight valley oak seedings with and without herb control was 45 percent and 25 percent, respectively. These significant differences occurred despite some variability among plantings (table 3). SBNCO was not included because herbs could not be controlled, and no survival was recorded in either treatment.

Information on survival over time is limited, but figure 2 shows average survival of 3-year-old blue oak seedlings growing with and without herbs in three plantings. Herb interference clearly has a negative impact on seedling survival. Differences recorded each spring were highly significant ($P \leq 0.01$) and there was a highly significant ($P \leq 0.01$) interaction between treatment

Table 2—*Emergence (percent) with and without herbaceous plant control in 14 blue oak and 10 valley oak seedings and the associated precipitation patterns.*

Location	Planting Season	Seasonal Precip (cm)	Percent Avg Annual Precip	Emergence (pct.) Blue Oak No Herbs	Blue Oak Herbs	Valley Oak No Herbs	Valley Oak Herbs
CYNRN	1985-86	33	118	72a[1]	75a	—	—
	1987-88	27	96	64b	41a	—	—
	1988-89	15	54	71b	15a	—	—
SBNCO	1985-86	45	125	15b	4a	81a	88a
			65	20b	4a	—	—
SJER	1987-88	31					
	1988-89	33	69	59b	41a	—	—
BRP	1987-88	37	77	—	—	72b	15a
	1988-89	35	73	25b	la	84a	87a
	1989-90	37	78	50a	38a	18a	11a
LPZLK	1985-86	63	124	—	—	69a	59a
	1987-88	40	78	—	—	56b	34a
	1988-89	43	84	—	—	55b	30a
SFRFS	1985-86	86	119	78b	53a	—	—
	1986-87	48	67	43a	31a	—	—
	1987-88	54	75	35a	40a	—	—
HFS	1986-87	62	66	60b	41a	32a	26a
	1987-88	73	78	12b	0a	86a	75a
	1988-89	68	72	29b	18a	44a	35a
MEAN				45b	29a	60b	46a

[1]For each seeding and each species, values in rows not followed by the same letter are significantly different ($P \leq 0.05$).

and time. After 3 seasons, control of herbaceous plant interference resulted in survival of 40 percent more seedlings.

Effect of Screen Protection on Blue Oak Survival

The addition of screen protection after emergence to blue oak seedlings produced mixed results the first year. In two seedings (SFRFS 1987 and SJER 1988), screens had no effect on first year survival, possibly due to the episodic nature of some depredation. Average survival with and without protection was 26 percent. Seedling survival in three seedings (CYNRN 1987, HFS 1986 and 1988) was significantly enhanced with screen protection. Average survival with screens at the three locations was 33 percent of acorns planted compared to 26 percent without screens.

Limited information on survival over 3 seasons from four plantings shows that blue oak seedlings survive in higher numbers with screen protection when growing with herb control (fig. 3). The value of protection was apparent at the end of the first season and was highly significant ($P \leq 0.01$) through the 3rd season with a highly significant ($P \leq 0.01$) interaction between treatment and time.

Screen protection and herb control in three seedings (CYNRN 1987, HFS 1986, and SFRFS 1987) were compared over 2 seasons (fig. 4). Interaction between herbs and screens was recorded at the beginning of the 3rd season. Application of

Table 3— *Survival (percent of acorns sown) in 11 blue oak and 8 valley oak seedings after 1 season with and without herbs.*

Location	Seeding	Survival (pct.) Herbs	No Herbs
		Blue Oak	
CYNRN	1985	23a[1]	33a
	1987	21a	36a
	1988	<1a	61b
BRP	1988	0a	18b
HFS	1986	22a	55b
	1988	7a	16b
SFRFS	1985	18a	47b
	1986	7a	25b
	1987	35a	33a
SJER	1987	0a	4b
	1988	2a	35b
MEAN		11a	33b
		Valley Oak	
BRP	1987	14a	62b
	1988	70a	71a
HFS	1986	3a	11b
	1987	38a	69b
	1988	7a	30b
LPZLK	1985	34a	39a
	1987	18a	42b
	1988	13a	34b
MEAN		25a	45b

[1]For each seeding, values not followed by the same letter are significantly different ($P < 0.05$).

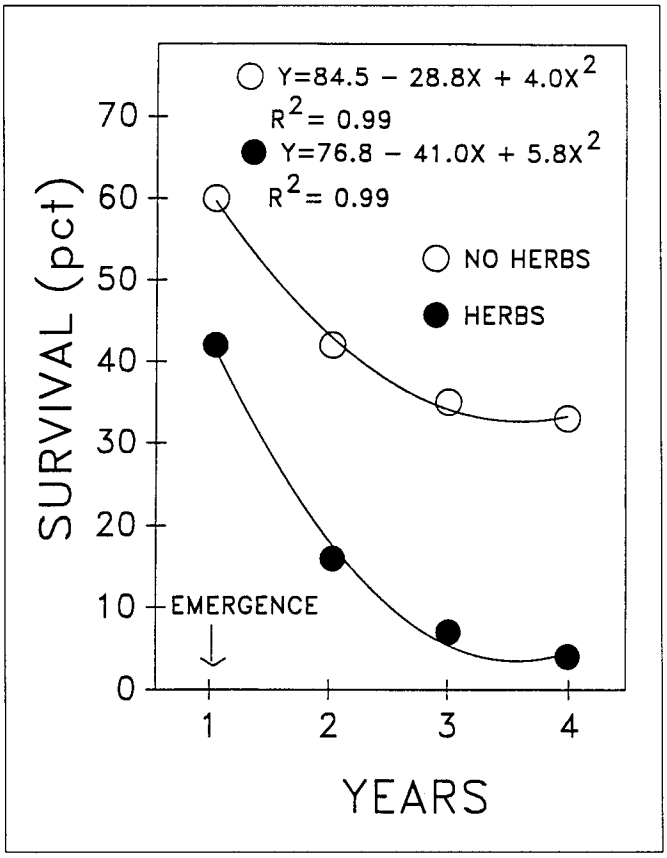


Figure 2—Three-season survival (percent of acorns sown) of blue oak combined over 3 seedings (HFS 1986, SFRFS 1985 and 1986) for plants growing with and without herbs. Observations made in spring after bud break. Difference in survival is highly significant (P ≤ 0.01), and the progressive differential represents a highly significant (P ≤ 0.01) linear interaction between treatment and time.

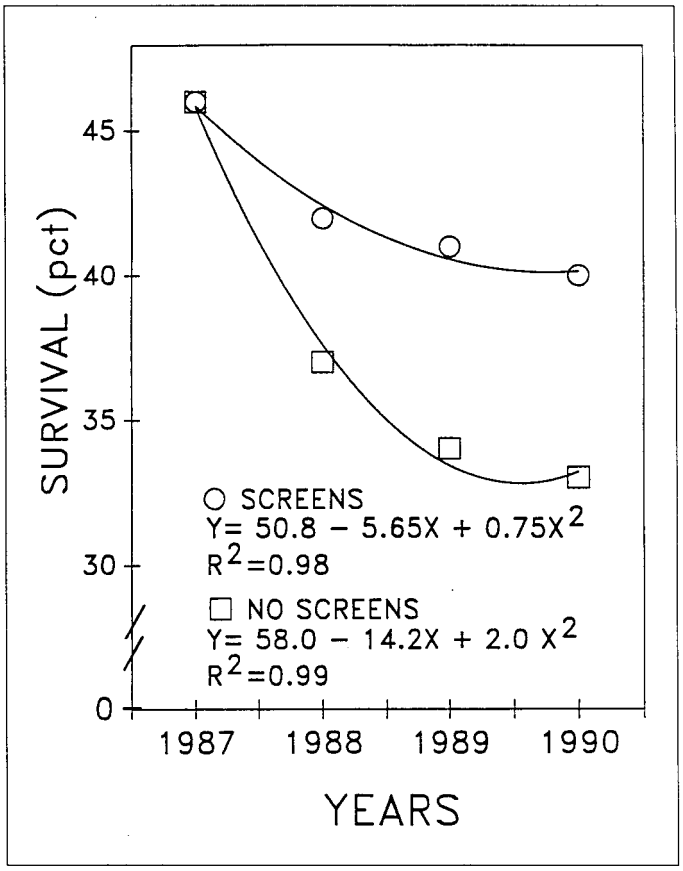


Figure 3—Three-season survival (percent of acorns sown) of blue oak combined over 4 seedings (CYNRN 1985 and 1986, HFS 1986, and SFRFS 1985) for plants growing without herbs and with and without screen protection. Observations made in spring after bud break. Difference in survival is highly significant (P ≤ 0.01), and the progressive differential represents a highly significant (P ≤ 0.01) linear interaction between treatment and time.

screens to seedlings growing with herbs nearly doubled survival. Screens increased survival only one-sixth where herbs were excluded.

Shade, as provided by window screen cages protecting blue oak in two seedings above, may have contributed to the large difference in survival between levels of protection where herbs were uncontrolled. Only 46 percent of incident sunlight is transmitted through window screen cages (measured in $\mu E/m^2/s$ by a quantum sensor). As a result, the environment beneath screens may provide an element of protection against excessive transpiration. That blue oak seedlings are tolerant of reduced sunlight beneath the screen cages is supported by data from other research in which the measured amount of transmitted sunlight did not significantly reduce net carbon gain (Kevin Rice, pers. comm.).

Effect of Screen Protection on Valley Oak Survival

The effect of screen protection on valley oak seedling survival the first season also varied by site. At BRP in 1988, survival was not influenced by window screen cages. Average survival with and without screens was 40 percent. However, use of screens in three seedings at HFS in 1987, 1988 and 1989 did produce significantly higher survival. On average, survival of protected and unprotected seedlings was 42 percent and 26 percent, respectively. Again, no interaction with level of herb control was detected.

In the 1987 and 1988 seedings at LPZLK, a significant difference in first year survival with and without screens (Foregon rigid plastic protectors) was recorded in both seedings, but in this case, survival without screens was greater. Without screens, average survival was 27 percent of acorns seeded compared with 22 percent for protected seedlings. Since most loss at this location occurred from gophers (88 percent in the 1988 seeding), the difference may have been due to their ability to identify and select protected plants.

Levels of both screen protection and herb control in 3 seedings were compared over 2 growing seasons (fig. 4). As with blue oak, interaction between levels of herbs and screens was recorded at the beginning of the third season. After 2 seasons, screens nearly doubled survival where herbs were excluded, but for the same period, survival of protected seedlings growing with herbs was three times that of unprotected seedlings. The greater difference in survival where herbs were

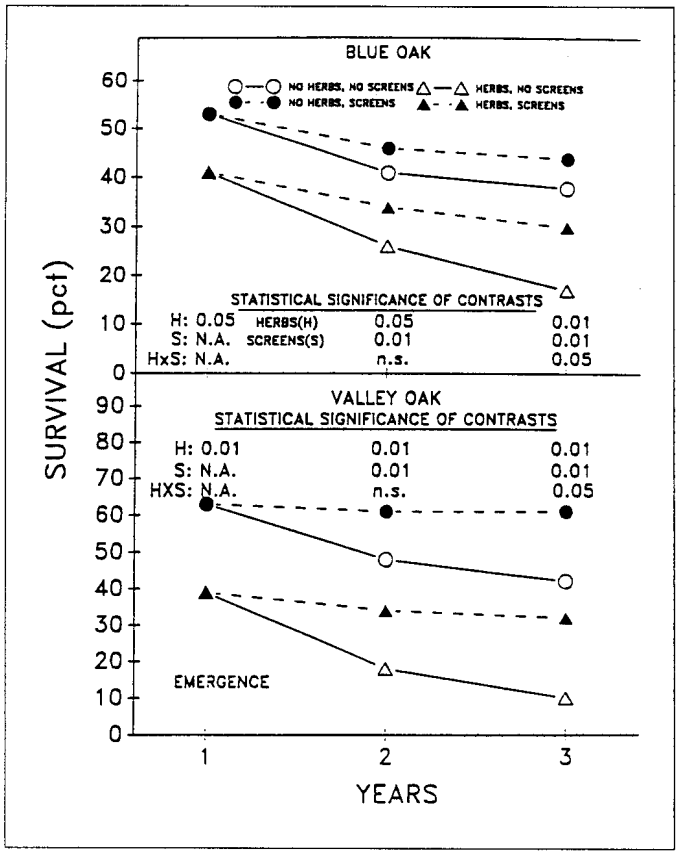


Figure 4—Two-season survival of blue oak combined over 3 seedings (CYNRN 1987, HFS 1986, and SFRFS 1987) and valley oak combined over 3 seedings (BRP 1987 and HFS 1986 and 1987) for all treatment combinations. Observations made in spring after bud break.

uncontrolled repeats the performance observed in blue oak seedings.

Effect of Screen Protection on Growth

Average height of 2-year blue and valley oak seedlings in 3 seedings was compared over all treatment combinations (table 4). The addition of screens in blue oak seedings more than doubled seedling height under the 2 levels of herb control at CYNRN, HFS and SFRFS. This response strongly suggests an interaction between screens and herbs.

The response of valley oak at HFS (two seedings) and LPZLK was equally as dramatic but not consistent between levels of herb control. Screens doubled seedling height where herbs were absent but increased height more than five times where herbs were present.

CONCLUSIONS

Control of herbs appears essential to achieve adequate emergence and first-year survival of blue and valley oak seedlings. Limited data on long-term survival suggests seedling mortality over time is reduced by herb control.

Screens protected seedlings against insects and small mammals and significantly improved survival and growth of both oaks at most locations. Window screen cages provided the best protection against grasshoppers, the principal insect herbivore on seedlings. Screens are recommended for all plantings.

Window screen cages not only protect seedlings from predation but modify the seedling microenvironment. They provide shade, the effects of which we could not separate from protection.

Other predators also appear to be affected by control of herbs (Wright 1985). The elimination of herbs around seedlings seemed to discourage pocket gopher predation. Control of this rodent is recommended in all plantings.

Predation in our studies may have been affected by concentrated planting patterns and characteristics of the exclosures.

We suspect the negative effects of herbaceous interference and predation can be modified by using livestock for phytomass control in carefully managed systems that would limit damage to oak seedlings. Such systems will reduce herbaceous cover and may effectively modify habitat, thus reducing potential predation. Such a strategy needs evaluation.

ACKNOWLEDGMENTS

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Table 4—Average fall height of 2 year-old blue and valley oak each in 3 seedings (blue oak: CYNRN 1987, HFS 1986, and SFRFS 1987; valley oak: HFS 1986, HFS 1987, and LPZLK 1987) growing with and without both herbs and screens.

Species	Fall Ht. (cm)			
	Herbs and No Screens	Herbs and Screens	No Herbs and No Screens	No Herbs and Screens
Blue Oak	4.1a[1]	9.9b	10.1b	20.7c
Valley Oak	2.4a	13.5bc	10.1ab	21.0c

[1]Treatment values for each species not followed by the same letter are significantly different ($P \leq 0.05$). Those for blue oak represent an interaction (Herbs X Screens).

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Acorn Size As A Factor in Early Seedling Growth of Blue Oaks[1]

Jerry Tecklin Douglas D. McCreary[2]

Abstract: Field performance was evaluated for blue oak (*Quercus douglasii* Hook. & Am.) acorns of different size classes (weights) and from different trees which produced predominantly small, medium, or large acorns. Emergence, height, and survival were monitored for two growing seasons. A parallel evaluation, mainly of root characteristics, was conducted in an observation growth box. Acorn size significantly influenced emergence, survival, and height the first year, and influenced height growth the second year. Large acorns produced taller seedlings with heavier total root weight. Acorn size also affected other variables in a significant manner. Parent tree influence was significant for some variables but not for height growth.

In diverse tree species researchers have reported that seed size affects seedling germination and growth (Bonner 1987, 1988). Given the rather large size range one encounters in any acorn collection, the question arises if there could be some advantages to selecting large acorns for artificial regeneration of oaks. Larger acorns are presumably correlated with greater quantities of stored nutrients which might be convertible to larger, more vigorous seedlings with better chance of early survival.

Acorn size has been related to seedling performance with some differing opinions. Korstian (1927) reported "unmistakable advantage in total germination and survival in favor of large acorns" in four eastern oaks, two of which were in the subgenus Quercus, the white oaks. But he maintained these early effects may not be persistent. Others have reported a positive correlation between acorn size and root weight (McComb 1934), and between acorn size and total seedling size and weight in various subgenera (Matsuda and McBride 1986). Yet others have reported no acorn size advantage with regard to germination (Aissa 1983). Bonner (1988) reviewed several studies that cautioned such size advantages may not persist and that genetic factors may be more important than seed size. The present study investigated acorn size and seedling performance of blue oaks (*Quercus douglasii* Hook. & Am.) in California.

[1] Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

[2] Staff Research Associate and Natural Resources Specialist, respectively, Integrated Hardwood Range Management Program, University of California Cooperative Extension, Sierra Foothill Range Field Station, Browns Valley.

METHODS

The study consisted of two parts, both conducted at the University of California Sierra Foothill Range Field Station (elevation 200 m), 20 miles northeast of Marysville. Part 1 was an outplanting of 720 acorns in a field plot fenced to exclude deer and cattle. Part 2 was a growth box study of planted acorns which allowed periodic harvest and measurement of seedlings.

Field Plot

Acorns were knocked or picked from branches of three trees during September, 1988 near Bangor, California, a location 25 kilometers from the field plot and of similar elevation. Tree 1 had acorns that were predominantly small; Tree 2 had predominantly medium-sized acorns; and Tree 3 had large acorns. Representative samples determined the range of acorn fresh weights for each tree collection, and each was sorted into three size classes. The ranges and size classes selected are shown in table 1. Acorns were soaked for 24 hours, air dried, and then stored in plastic ziplock bags at 0-4°C. Prior to soaking, samples of six acorns were taken from each of the size classes to determine moisture content by weighing before and after oven drying. Moisture content of each acorn size class was consistent within the single tree collections regardless of tree source. Trees 1, 2, and 3 differed, however, with moisture contents of 41.9 percent, 47.3 percent, and 50.4 percent, respectively. There were also apparent differences in ripeness as indicated by ease of picking from the different source trees.

Prior to planting, some acorns in every size class began to germinate in cold storage, and these were separated out. The remaining ungerminated acorns were placed on moist vermiculite in germination boxes at lab room temperature of 15-23°C. Once germinated, as defined by an emerging radicle .5 cm or longer, they were returned to the cooler with those previously germinated until planting.

Table 1—*Ranges in acorn fresh weight (gm) for each tree-size combination*

Parent Tree	Acorn Size / Class			Average Weight
	Small	Medium	Large	
Tree 1, Small Acorn Tree	1.00—2.50	2.51—3.50	3.51—5.00	2.9
Tree 2, Medium Acorn Tree	2.00—3.50	3.51—4.50	4.51—6.00	4.0
Tree 3, Large Acorn Tree	4.00—6.00	6.01—7.50	7.51—9.50	6.8

The field plot was on a northeast facing 15 percent slope, in Sobrante-Las Posas, very rocky loam. Competing vegetation had been glyphosate treated in early fall and the dead plant cover and top few centimeters of soil carefully scalped off by tractor blade. A uniform planting area was thus created, with 720 planting spots arranged in eight blocks of nine rows each, a randomized complete block design. Each row had 10 planting spots on 30-cm centers; the rows were 60 cm apart. Rows were randomly assigned to acorns from the nine different tree source-acorn size classes. Acorns were planted over a 3 week period beginning December 20, 1988. All but 80 acorns were planted in the first week; 40 from Tree 1 and 40 from Tree 3 were slower to germinate in the germination boxes and were planted two weeks later than the rest. All were planted on their sides at 2-3 cm depth with radicles pointing in natural downward position. Only acorns with radicles less than 2 cm were planted.

Beginning in March and continuing throughout the summer the plot was evaluated twice weekly for seedling emergence, which was defined as first visible sign of the shoot. The plot was hand weeded on occasion, but competing vegetation was very slow to return. No irrigation was provided. Year-end survival and height measurements were taken, and the plot was similarly monitored the following year.

Growth Box

A selection of acorns from Tree 2, the medium sized acorn tree, was reserved for planting in two plywood growth boxes. Each box measured 50 cm by 90 cm by 100 cm deep. The boxes were each partitioned into ten compartments 8 cm wide using polyethylene covered sliding partitions. Each compartment was filled with soil from the field plot site, sifted through a 1.3 cm screen, and compacted by thoroughly watering to promote settling. The planting design was a split plot, so that each removable compartment contained four replications of randomly assigned small, medium, or large pre-germinated acorns. All acorns were planted on December 19, 1988, with points up and then covered with 2-3 cm soil. This planting position was necessary to fit in all the acorns, with 2-3 cm spaces between them. It differed from the on-side position of our field plantings. Extra acorns were planted on outside planting spots to serve as buffers and were not included in the data. The outermost compartments, which corresponded to the first and last harvest dates, were also considered buffers. The boxes were kept outdoors except for a brief period (two nights) of sub-freezing temperatures when they were moved to an unheated warehouse.

It was possible to harvest the acorns in each compartment by removing the entire compartment and either carefully excavating the acorn and its root system (early stages only), or gently removing all soil with a fine water spray. Roots were thus recovered in very clean condition, nearly 100 percent intact. We measured and calculated acorn fresh weight prior to planting, dry weight at harvest to fresh weight ratio (an index of nutrient depletion), total length of root system, number of branched roots vs. tap root configuration, dry weight of root in 20 cm segments, numbers of laterals emanating from the first segment, length of longest lateral, length and weight of shoot, and date of shoot emergence. The first compartment was harvested one month after planting. So little growth had occurred that the next harvest occurred one month later on February 21, 1989, and every two weeks thereafter until June 13.

Data were analyzed by ANOVA and, when significant differences ($P \leq 5.05$) were detected, by a Fisher's Protected LSD test. Harvest dates were treated as random variables, but by necessity the compartments had to be harvested in a serial, non-random fashion. We believe this not to have been a serious violation of the design since the differences measured between harvest dates were in all cases very great.

RESULTS

Field Trial

In the field, the timing of acorn emergence was unusual. Generally, the emergence pattern was not typical of our experience for this site. The main emergence period was April 1- June 1(fig. 1). Fast germinating species like blue oak typically show emergence curves considerably steeper in slope and much earlier in the year after late fall planting (McCreary 1990). Furthermore, the 64 percent emergence for the first year was somewhat low, although not unusually low from the experience of others for this site. Unusual weather patterns could account for these results. We would have expected greatest emergence during February - March. During these two months, the Field Station recorded minimum temperatures for several days as low as -10 and -5°C; and February's mean low was 1.7°C, compared to the 20 year norm of 5°C. Precipitation in March 1989 was in excess of 30 cm, compared to the norm of 9 cm. McClaran (1986) observed poor emergence under wetter conditions, and Matsuda and McBride (1989) noted delayed shoot development associated with decreasing temperatures of higher elevations. What was noteworthy in our study was a very delayed emer-

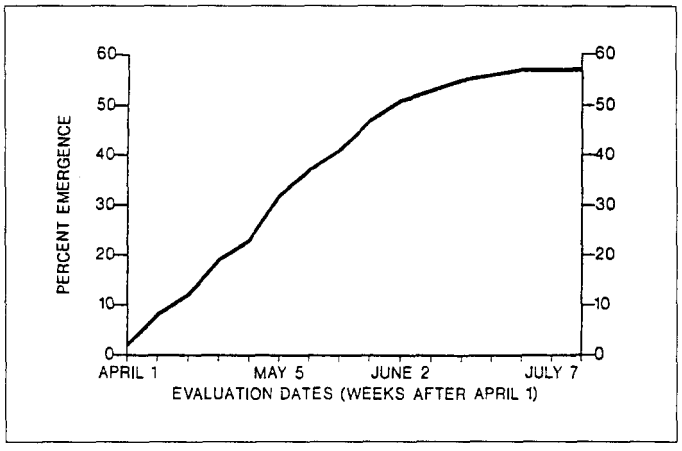


Figure 1—Cumulative emergence of acorns in 1989.

gence of 14 percent of the acorns. Four percent of the acorns emerged in the fall after an unseasonably wet September. The following spring and summer 10 percent (70 acorns) more emerged for the first time, bringing our total plot emergence to 74 percent. We are not aware of reports of such extensive delayed emergence in the literature.

Table 2 summarizes results for different sized acorns, disregarding parent tree. For 1989, significantly more seedlings from the largest acorns emerged. A greater proportion of these seedlings also survived than did those from the smallest acorn size class. While the largest acorns also had the highest percent survival in 1990, the differences were not statistically significant. Larger acorns also produced taller seedlings, and this relationship lasted into the second year of growth, with an increasing magnitude of height difference between large-acorn seedlings and small-acorn seedlings. The incremental growth differences from 1989-90, while greatest for the largest acorns, were not significant at the P≤05 level (ANOVA).

Table 3 summarizes our data for acorn size differences in relation to their parent trees. While there are trends toward increasing emergence, survival, and height depending on parent tree, the significance of these differences do not present a clear pattern, and there were no significant differences between the parent trees with regard to shoot emergence date or seedling height. Since large acorn size was found to make a difference in emergence and survival, we expected to observe significant differences between the small acorn tree and the large acorn tree, because the small acorn tree's acorns weighed 1.0-5.0 gms, while the large acorn tree's weighed 4.0-9.5 gms. This was not the case. While the large acorn tree tended to have greater emergence, survival, and height growth, the only significant patterns for parent tree were for survival in 1990 (table 3). The 1990 survival analysis also showed a tree by acorn size interaction that complicates the parent tree significance for this variable. But when we examined the parent tree by acorn size class combinations, we found that the large acorn tree in all cases had the highest survival. We would, thus, still accept parent tree effect as significant for survival.

Acorns which emerged for the first time in the second year were distributed throughout the plot in a spotty fashion. There were too many missing values for whole rows to do a valid ANOVA analysis. However, table 4 summarizes our findings for this interesting phenomena. There seems to be a trend for greater year-end height related to acorn size. Parent tree seems also to be important, as seen in table 5, with the large acorn tree producing most of the new emergers.

Growth Box

Table 6 summarizes the result of our analysis. The most interesting finding was that total root weight was significantly related to acorn size. The average weights of roots from large acorns were almost double those of the small acorns. This relationship was also true for the first 20 cm root segment, which merely indicates that this was where most of the root mass was located. Over the course of this study, 72 percent of the total root weight was, on average, accounted for by this root segment. Root weights, regardless of acorn size, increased in a somewhat similar manner over time (fig. 2), the differences in magnitude

Table 2—*Field plot average for different sized acorns, regardless of parent tree - 1989-90*[1]

	Pct emergence	Pct year end ---- survival ----		Year end -----height (cm) ---		Average emergence
Acorn Sizes	1989	1989	1990	1989	1990[2]	date (1989)
Small	59[a]	57[a]	67	5.2[a]	19.3[a]	May 4
Medium	63[b]	62[ab]	68	5.1[a]	17.4[a]	May 8
Large	71[b]	70[b]	76	7.1[b]	24.5[b]	May 5

[1]Values for each variable are not significantly different (P ≤ 0.05), Fisher's LSD test, if they are followed by the same letter or none.

[2]Data for this variable tracks those seedlings emerged in 1989 only.

Table 3—*Field plot averages of all acorn size classes from different parent trees*

	Pct emergence	Pct year end - survival -------		Year end ---height (cm)----		Average emergence
Parent Tree	1989	1989	1990	1989	1990[1]	date (1989)
Small Acorn tree	67[a]	65[ab]	70[a]	5.2	17.9	May 4
Medium Acorn tree	57[b]	55[a]	61[b]	5.6	20.8	May 5
Large Acorn tree	70[a]	69[b]	80[c]	6.5	22.5	May 9

[1]Data for this variable tracks those seedlings emerged in 1989 only.

Table 4—*Averages of acorns newly emerged in second year by size class*

Acorn sizes	Number emerged	Pct vacant spots w/new emergers	Emergence date	Year end height
Small	29	29	April 20	3.4
Medium	22	25	April 14	6.0
Large	19	28	April 12	6.4

Table 5—*Averages of acorns newly emerged in second year by parent tree*

Parent Tree	Number emerged	Pct vacant spots w/new emergers	Emergence date	Year end height
Small Acorn tree	21	26	April 12	4.6
Medium Acorn Tree	16	15	April 16	5.1
Large Acorn Tree	33	46	April 18	6.1

Table 6—*Averages for variables measured in growth box trial for 8 harvest dates*[1]

Variable	Acorn Size Small	Medium	Large
Total Root Weight (g)	.278a	.376b	.498c
First 20 cm segment of root (g)	.203a	.268b	.359c
Root Length (cm)	47.5	49.6	51.2
Shoot Weight (g)	.119a	.184b	.196b
Shoot Length (cm)	5.09	6.61	6.43
Length of Lateral Root Zone (cm)	56.0	57.2	59.3
No. of Laterals >1 cm in 1st Root Sgmt	38.9	44.8	50.3
Length of Longest Lateral (cm)	6.8a	8.7ab	11.3c
Acorn Fresh Weight (g)	2.98a	3.94b	5.09c
Acorn Dry Weight (g)	1.03a	1.36b	1.81c
Ratio Dry Weight/Fresh Weight	.35	.35	.36

[1]Values for each variable are not significantly different (P≤0.05), Fisher's LSD test, if they are followed by the same letter or none.

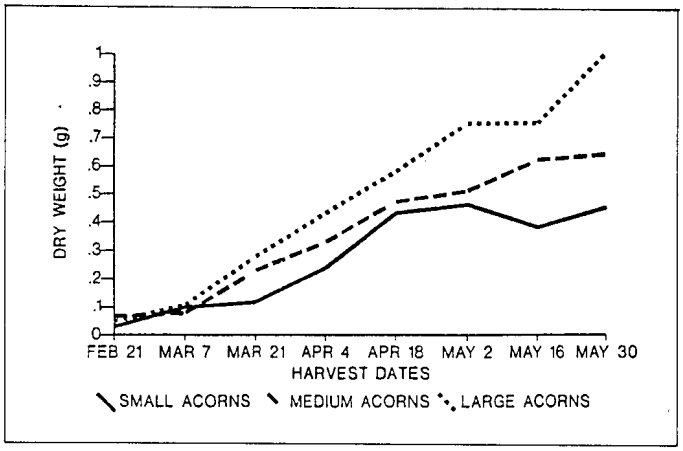


Figure 2—Average root weights for 3 sizes of acorns harvested on different dates.

increasing, especially after the tenth week when most above ground shoot growth commenced. Root lengths, on the other hand (fig. 3), were very similar for all acorn sizes and increased at a similar rate. There were no significant differences for average root lengths.

A similar pattern was observed for shoot weight and shoot length; large and medium sized acorns produced significantly heavier shoots than did small acorns, while shoot lengths were not significantly different.

There were no significant differences between acorn size classes as regards the length of the lateral root zone or the number of laterals in the first root segment. However, the subjective impression that large acorn roots were "bushier" was supported by the significant difference between the longest laterals of the large and small acorns.

When we consider the index of depletion of the acorn's cotyledon reserves as measured by the ratio of acorn dry weight at harvest over initial fresh weight (fig. 4), it is clear that these reserves are utilized similarly over time independent of acorn size. There were no significant differences and ratios were almost identical.

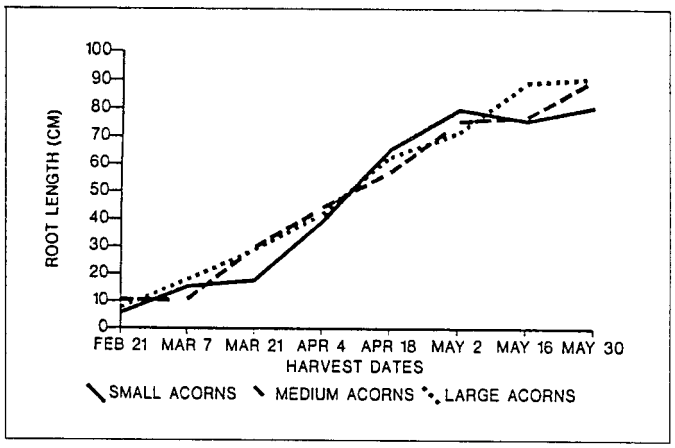


Figure 3—Average root lengths for 3 sizes of acorns harvested on different dates.

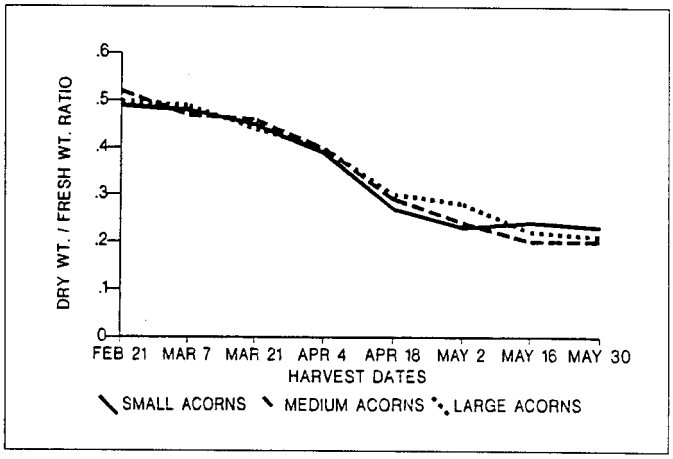


Figure 4—Average acorn dry weight/fresh weight ratio for 3 sizes of acorns harvested on different dates.

DISCUSSION

The data indicate that acorn size in blue oaks is significantly related to initial seedling growth. The field trial demonstrated that larger acorns convey an advantage to seedlings which is reflected especially in the ability to produce taller seedlings. Larger acorns also produced heavier and more developed root systems in the box trial. It was somewhat surprising that root length was not affected by acorn size in our growth box. We had initially reasoned that larger acorn size would be advantageous since larger acorns could rapidly grow deeper root systems, thus accessing soil moisture unavailable at shallower depths. The simulated field conditions of our box data did not support this hypothesis. However, the growth box limited our investigation to depths <100 cm, and differences might have been detected had we been able to track root growth for a longer period to greater depths. Still, the greater mass and branching of root systems produced by larger acorns would seem to promote uptake of both moisture and nutrients and account for the greater seedling heights observed.

The growth box component of this study was intended to shed light on the below ground development which might be occurring in the field plots. We did not expect such rapid root growth. When the last compartment was harvested on June 13, roots had already reached beyond the one meter depth of our box. Most of this growth began after January 19. Extensive root development preceded shoot emergence, and we were unable to obtain shoot growth comparable to that in our field plot because our seedlings outgrew the box depth, terminating observation. Root growth was not affected by the low temperatures we experienced, which was to be expected from the findings of Matsuda and McBride (1986). Average root lengths for February and March,1989 (fig. 3), for instance, when air temperatures were especially low, increased in roughly the same manner as for periods when temperatures were much higher.

The average emergence date for the box can only be considered an estimate- since compartments were destructively harvested over time and any acorn that hadn't emerged by harvest date was therefore not recorded for emergence. However, if we consider the last six harvest dates, where emergence was nearly complete in all compartments, average emergence date was April 1. This compares to April 20 for the field plot. Twenty-nine out of a total 144 acorns in these last six harvest compartments failed to emerge but were still alive. Of these non-emergers, 59 percent had a multi-branched root system rather than a normal tap root system, compared to 24 percent occurrence of such root systems among those which emerged. Multi-branched systems result from damage to the radicle early in development and can be artificially induced by simulated injury (Carpenter and Guard 1954). It is therefore probable that the delayed emergence observed in both box and field plot was related to early radicle injury.

It would appear that the root system serves an important storage function as a reserve for seedling resprouting. Blue oak seedlings readily resprout (Griffin 1971) and have an enormous potential to remain alive for long periods without photosynthetic support or other above ground functions. After complete stem clipping of seedlings, for example, an entire year may pass before above ground functions resume (Welker and Menke, in press). This could be seen as an adaptation to herbivory, fire, and xeric or other harsh environmental conditions. Our results indicate that this ability is established before the seedling ever receives any photosynthetic support. The rapid translocation of nutrients to below ground storage in blue oaks may even give an acorn a two growing season potential for successful shoot emergence under favorable environmental conditions as we observed in our field plot. Large acorn size would logically be an advantage in this regard, and while we have indications that this might be the case, we cannot say with certainty that acorn size provides a significant advantage for such delayed emergence or resprouting. The potential for delayed emergence of acorns also suggests caution in interpreting survival or emergence results from a one-year study.

The large volume of the first 20 cm segment of our seedling root systems in the growth box, coupled with its significant relationship to acorn size for all harvest dates of our box study, point to this root segment as the principal storage region or recipient of translocated nutrients from the acorn. The segment resides in the most competitive part of the soil profile, has the least amount of active root growth, and the most suberization, and would appear to be most favorably situated for a more passive storage function.

CONCLUSION

The results of these trials suggest that increased growth and survival may be obtained by selecting acorns from trees that produce large acorns, as well as by selecting the largest acorns within single tree collections. Large acorns tended to produce taller seedlings with roots of greater mass. However, there was considerable variation in field performance between the three trees tested. For the medium acorn tree, greater acorn size resulted in a clear pattern of increased survival. For the other two trees, however, there was relatively little difference between acorn size classes. This suggests that the benefits in artificial regeneration of selecting larger acorns within single tree collections could vary greatly depending upon the parent tree. In general, the height gains from increased acorn size, while not great in the first year, do show significant persistence. Only further tracking of our field plot will reveal how persistent these advantages may be, and at this time, based on the limited evidence, we would not recommend selecting large acorns as a regeneration prescription. However, researchers should be aware of possible acorn size effect when conducting comparisons of seedlings to ascertain various treatment effects on planted acorns.

Finally, it should be noted that other considerations may influence decisions concerning which acorns to select for plant-

ing. Even if larger acorns are deemed superior from a growth and survival standpoint, smaller acorns may be preferred to meet other objectives, such as the use of local seed sources and maintaining adequate genetic diversity by planting acorns from a large number of parents.

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Soil Water Effects on Blue Oak Seedling Establishment[1]

Doria R. Gordon Kevin J. Rice Jeffrey M. Welker[2]

Abstract: A field experiment was conducted to examine the effects of soil water availability on blue oak (*Quercus douglasii*) seedling establishment. Acorns were planted either into cleared plots of 0, 10, 20, or 40 cm diameter. The cleared plots were located in two grazed and one ungrazed site. Half of the plots received drip irrigation in a split plot design. Soil water and plot size, depending on the site, and initial acorn weight and parent tree all influenced oak seedling growth. Survival and height in subsequent growing seasons was dependent on early growth. Soil water availability in the first growing season, therefore, influences both oak seedling establishment and growth in subsequent years.

Earlier work (Gordon and others 1989, Gordon and Rice 1990, Rice and others these proceedings) indicates that blue oak (*Quercus douglasii* Hook. & Am.) seedling establishment, water relations, and growth depend on the rate of soil water depletion. Further, this rate has been demonstrated to depend on the composition of the herbaceous neighborhood in which a blue oak seedling is planted. In addition to the effects of the competitive environment, seedling growth varies with tree of acorn origin and initial acorn weight (Rice and others these proceedings). Thus, maternal or genetic differences in source material interact with the competitive characteristics of the environment to influence the probability of oak seedling establishment and survival.

The above experiments were all conducted in containers. This paper describes a field experiment in which soil water availability and proximity of herbaceous competitors were varied around establishing blue oak seedlings to examine the questions: 1) Are seedling emergence and growth in the field reduced under rapidly drying soil water conditions? 2) Do parent tree and initial acorn weight interact to influence seedling response to environmental conditions? 3) Does seedling growth in the first growing season influence survival and growth in subsequent years?

METHODS

The experiment was conducted at the University of California Sierra Foothill Range Field Station (SFRFS) in Yuba Co., California. A 1 ha area encompassing grazed land and adjacent land which had not been grazed since 1972 was fenced to exclude both livestock and deer. Soils are derived from metamorphic parent materials and consist of reddish Alfisols and brownish Ochrepts. Annual precipitation averages 740 mm; temperature extremes range from -2 to 40°C.

This experiment examined the growth, water status, and survival of oak seedlings in cleared circular plots of 1, 10, 20, and 40 cm diameter, with or without irrigation in the spring. The watering treatment was established as the main plot in a split-plot design, with plot size as a subplot treatment. Ten blocks were established in each of three sites: grazed with oak canopy removed, grazed open, and ungrazed low canopy sites. The canopy-removed site was established so that the effects of canopy-influenced soil could be examined without a confounding reduction in light availability.

The surface 1-2 cm of soil and litter were removed from the plots in fall, 1986. Plots were weeded as necessary during the first 2 years of the experiment. Blue oak acorns, collected from four trees at the SFRFS, were planted in the center of each subplot in winter, 1987. All acorns showed healthy radicle development of up to 10 mm when planted. Parent tree and initial acorn weight in 0.5 g classes were recorded for use as covariates in the analysis. Tree and weight were randomly distributed among the subplots. To reduce herbivory on seedlings, each subplot was caged with aluminum screening.

Soil water content was increased for 2 months with drip irrigation tubing in one main plot of each block. Each watered plot received about 7 liters of water weekly starting April 23. Soil water potential at 40 cm depth was measured biweekly with calibrated screen-cage thermocouple psychrometers (J.D. Merrill Specialty Equip.) placed in 2 replicates each of the 0, 20, and 40 cm unwatered plots and in the 20 cm watered plots.

Shoot emergence, stem height, leaf number, and estimated leaf area of oak seedlings were measured weekly. Mid-day leaf conductance and transpiration rates (Licor null-balance porometer) were also taken weekly. Initial and final seedling height in 1988, and final height in 1989 and 1990 were also recorded to determine the relationship between initial seedling growth and subsequent survival.

BMDP logistic regression (Dixon 1985) was used to examine the effects of watering treatment and plot size on oak

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seedling emergence in 1987 and 1988. Chi-square analysis examined the influence of parent tree and acorn weight class on emergence. The general SAS linear model analysis of split plot designs (Freund and others 1985) was used to compare oak growth responses to treatments. Acorn weight and parent tree identity were included as covariates in these analyses. Parameters measured over time were tested in ANCOVA models through an orthogonal polynomial decomposition of the time effect. Main and interactive effects and Tukey tests were thus tested against specified nested Type I error terms (Gordon and Rice 1990). Correlations of seedling growth within and among seasons were also examined. Continuous variables were log-transformed while count variables were square root-transformed to increase consistency with linear model assumptions.

RESULTS

The watering treatment maintained the water potential above -1.5 MPa at the 40 cm depth in cleared plots during most of June (fig. 1). Plot size did not affect the rate of soil water decrease through the season at any of the sites (fig. 1). Average water potential tended to increase with plot diameter, but significant differences were not detected.

By early April, 23, 4, and 0 percent of the acorns had produced shoots in the grazed canopy-removed, ungrazed, and grazed open sites, respectively. In mid-May, 48, 33, and 36 percent had emerged in the three sites. However, between the second and third weeks of May, 94 percent of the new shoots emerging were in irrigated plots. Actual numbers of plots with acorns were lower than the percentages indicate, however, because of shoot mortality and disappearance from several plots. Gopher activity (focussed on irrigated plots) appeared to be the major cause of this loss. Overall, only about 40 percent of the acorns planted produced shoots in the plots.

Logistic regression of block, plot size, and water treatment effects on seedling emergence within each of the three sites revealed significant effects of watering in the grazed open ($F=3.88$, $p=.05$) and the grazed canopy-removed ($F=4.3\ 1$, $p<.05$) sites. These effects were most dramatic in the grazed open site, where 30 percent of the unwatered and 59 percent of the watered acorns showed shoot growth (fig. 2). Conversely, the main and interactive effects of block and plot size significantly influenced emergence in the ungrazed site ($F=6.48$, $p<.0001$); emergence was significantly lower than expected in the 10 cm ($p<.005$) and higher than expected in the 20 cm ($p<.004$) diameter plots.

Interactions between planting site and acorn weight ($F=2.97$, $p=.05$) and site and parent tree ($F=3.81$, $p<.0005$) influenced the probability of oak shoot emergence. Smaller acorns from three of the four parent trees emerged later than did larger acorns; the opposite relationship between size and emergence date existed for the remaining tree (fig. 3). When sites were evaluated separately, emergence was positively dependent on acorn size

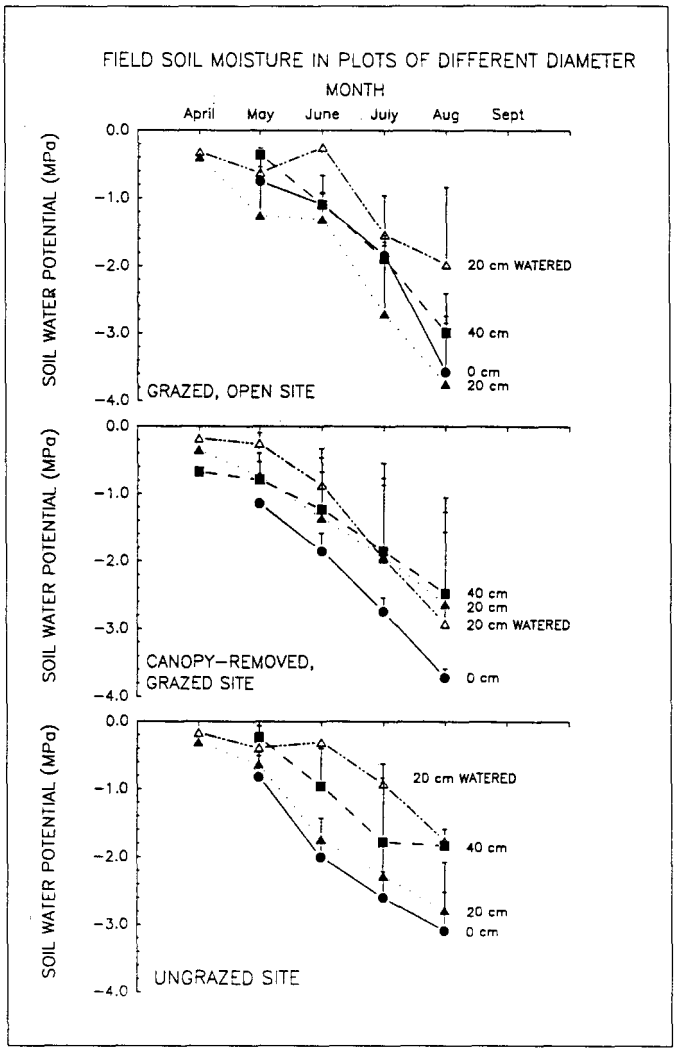


Figure 1—Soil water potential (mean and 1 s.e.) at 40 cm depth in cleared plots by site, plot size, and irrigation treatment.

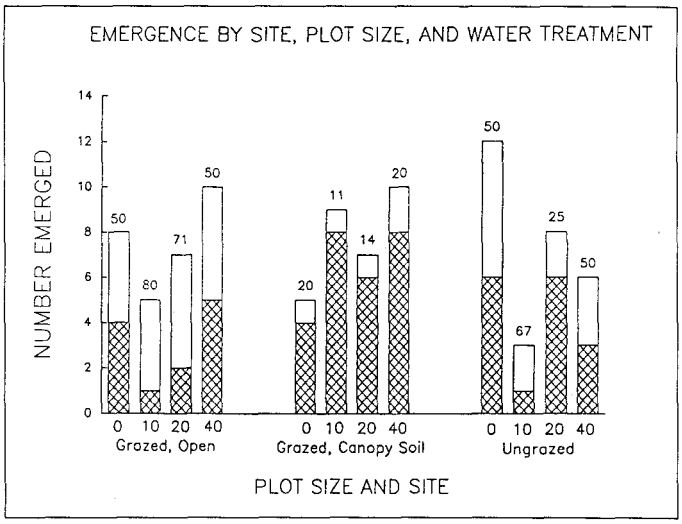


Figure 2—Number of shoots which emerged from acorns planted in plots of different size in each of three sites. Open bars are total number emerged; hatched bars show the number which emerged prior to irrigation. The numbers above the bars are the percent emergence following irrigation.

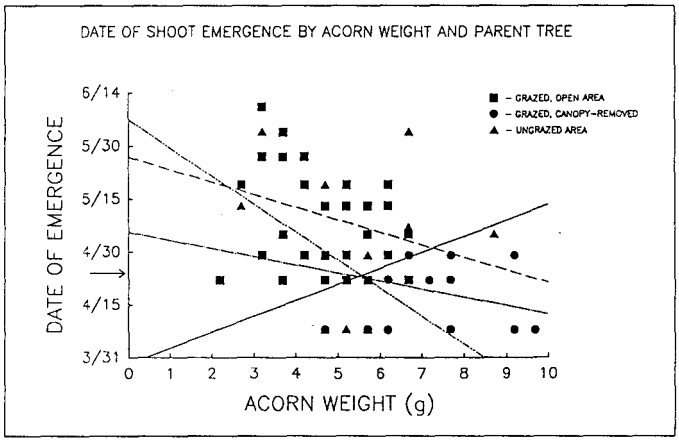


Figure 3—Emergence dates of seedlings from acorns of different weights by parent tree. Planting sites are designated by symbol. The arrow on the y- axis indicates the date on which irrigation started.

only in the ungrazed site: 73 percent of the seedlings emerged from acorns larger than the mean sowing weight. Parent tree identity significantly (X^2=9.49, p<.025) influenced the probability of shoot growth only in the open grazed site. Following emergence, however, neither acorn weight nor parent tree had further effects on height or leaf growth.

All seedling growth and gas exchange responses measured were significantly dependent on soil water potential over time (table 1). Seedlings in irrigated plots were larger than were those in non-irrigated plots. Plot size had significant but inconsistent effects on seedling growth (table 1). Leaf number, for example, was higher (p<.05) in 0 and 20 cm irrigated plots than in 0 or 10 cm non-irrigated plots. Seedlings in irrigated 40 cm plots had more leaves than did those in 0, 10 or 20 cm non- irrigated, or 10 cm irrigated plots. Final height was correlated with the number of leaves (r=.90, p<.0001).

About 60 percent of the 1987 seedlings showed further growth in 1988, with the probability of regrowth being dependent only on emergence in 1987 (F=46.18, p<.0001) across all sites and treatments. An additional 7 percent of the acorns in the grazed open site, and 2 percent in the ungrazed site which had not grown in 1987 showed shoot growth in 1988. These delayed emergences were independent of plot size or watering treatment.

Excavation of those plots from which no shoots emerged in either 1987 or 1988 revealed that acorns in 56 percent of the plots had either been eaten or attacked by fungi and showed no evidence of root growth. Acorns were missing from 27 percent of the plots. Only 8 percent of the plots had acorns present which showed root development prior to death. More acorns were missing from the ungrazed site relative to the 2 grazed sites.

Seedling height and leaf number were significantly correlated in both 1987 and 1988 (r=.90, p<.0001 and r=.96, p<.0001, respectively). Final height in 1988 was correlated with that in 1987 (i-.56, p..0001), although neither the length of the 1987 growing season nor the experimental treatment influenced 1988 growth. Height in 1989 was also correlated with that in 1988

Table 1—*Summary of ANCOVA results of the dependence of blue oak seedling growth and stomatal conductance on soil water potential over time. Seedlings were grown in cleared plots of various size (plot), in the Sierra Nevada foothills.*

	Stem Height (cm)	Number of Leaves	Leaf Area (cm^2)	Stomatal Conductance (mmol $m^{-2}s^{-1}$)
Overall model F	9.07	14.34	12.21	9.09
p	.0001	.0001	.0001	.0001
Block*	0.58	0.39	0.59	1.35
	.80	.92	.78	.33
Soil Water Potential*	62.51	48.55	70.56	4.83
	.0001	.0001	.0001	.06
Tree*	0.01	0.14	3.62	3.34
	.94	.73	.09	.10
Acorn Weight*	0.46	0.55	0.14	0.53
	.52	.48	.72	.48
Plot(block)	2.73	5.41	3.21	6.37
	.005	.0001	.001	.0001
Date	0.29	1.25	1.54	17.94
	.59	.26	.23	.0001
Water Potential x Date	5.04	6.39	4.90	1.66
	.02	.01	.03	.20

*tested against the Type I error term Plot(block)

(r=.86, p<.0001). Only those seedlings which emerged in 1987 were included in these analyses.

Seedlings senesced their leaves earlier in the grazed canopy-removed and the ungrazed sites than in the grazed open site in 1988. Close to 50 percent of the seedlings in the two former sites had no remaining green tissue in early October, 1988, while 75 percent of the seedlings from the grazed open site retained green leaves.

Chi-square analysis revealed that the probability of surviving through 4 growing seasons was independent of height at the end of the first growing season across all sites. However, individuals greater than 8 cm in height by the end of 1987 tended to survive through 1990 at greater than expected frequency than did those below that height (fig. 4). Small sample sizes preclude confident evaluation of these data. Seedlings which were taller than 7.5 cm after their first growing season had a significantly higher probability of surviving through 3 growing seasons in another field experiment (Gordon unpub. data).

DISCUSSION

Results from this experiment support the hypothesis that water availability significantly affects blue oak seedling recruitment in the field. Shoot emergence of the pre-germinated acorns

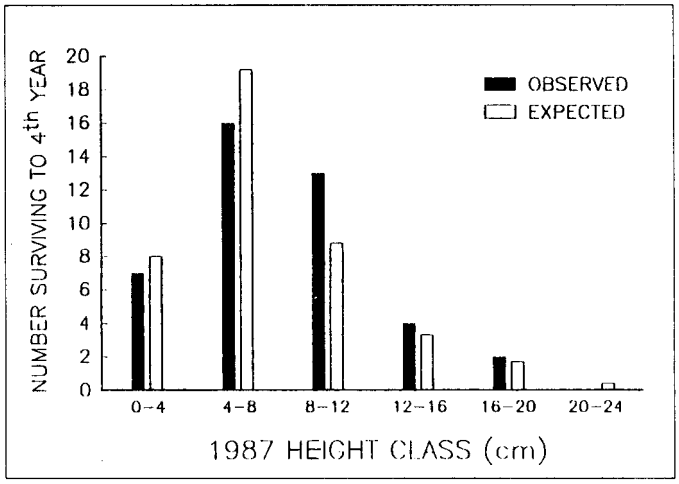


Figure 4—Expected and observed number of seedlings surviving through the 1990 growing season by height class at the end of the first growing season (1987).

was significantly enhanced by late season water availability in grazed areas. The reduced response of seedlings in cleared plots in the ungrazed area may be partially explained by gopher depredation of watered plots in that site.

Plot size effects, though significant, were secondary to those of irrigation. These results are explained by the insignificant effect of plot size, or proximity of competitors for soil water, on the resource. Plot size appeared to have the greatest influence in the ungrazed site, where plant densities were already the lowest (unpub. data) and where soil water tended to be highest. Root encroachment into the plots may have reduced plot size treatment effects.

Following emergence, water potentials continue to determine the extent of growth and stomatal conductance in oak seedlings. These results are consistent with others for both blue oak (Borchert and others 1989, Gordon and others 1989, Gordon and Rice unpublished draft, Welker and Menke 1990) and for valley oak (*Q. lobata*) (Danielsen 1990) in California. Further, influences of soil water potential on growth in the first growing season continue to influence seedling growth in subsequent seasons. Griffin (1971) also reported enhanced blue oak survivorship when competing grasses were experimentally removed.

The results from the blue oak experiments discussed here and elsewhere (Gordon and Rice 1990, Rice and others these proceedings) also suggest that blue oak sensitivity to competition for soil water has a genetic component. Acorns were collected from trees ranging in elevation and aspect at the SFRFS. Both the distribution of acorn weights and the responses of acorns to the environment varied among these parent trees: acorn weight and parent tree interacted with site conditions to influence seedling emergence and growth. Significant variation in acorn size distributions and influence of acorn weight and parent tree on seedling establishment have been documented for *Q. petraea* (Jarvis 1963), *Q. kelloggii* and *Q. agrifolia* (Hunter and van Doren 1982), and *Q. rubra* (Kolb and Steiner 1989). Thus, potential genetic influence on such characters as leaf number holds implications both for survival and growth over several growing seasons, and for regrowth following browsing because axillary buds for lateral branches are formed at the base of the petiole.

These data indicate that the interaction between maternal characters and the water environment surrounding establishing blue oaks may influence the success of establishment. A more gradual decline of soil water when the oak understory was dominated by perennial rather than annual grasses (White 1967, Welker and Menke 1990) would allow higher oak growth rates for longer into the summer drought. The larger seedlings developed would be better able both to exploit soil resources not available to the herbaceous understory and to survive into subsequent growing seasons. This scenario may partially explain why reduced recruitment in oak populations coincides with the conversion of the oak woodland understory to annual grassland.

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Intraspecific Phenotypic Variation and Ecological Genetics of Blue Oak *(Quercus douglasii* Hook. & Arn.)[1]

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Abstract: We examined potential variation in water use efficiency (WUE) in both mature trees and seedlings of blue oak by measuring the carbon isotope composition of plant tissue collected from populations arrayed along a latitudinal rainfall gradient. We also conducted common garden studies to determine the potential genetic basis for phenotypic variation in seedling WUE, growth and phenology. We planted acorns from both xeric and mesic populations into herbaceous neighborhoods characterized by different rates of soil water depletion.

Acorns from the mesic site were significantly smaller. While the probability of emergence increased with acorn size in the xeric population, there was no effect of acorn size on emergence in the mesic population. Seedling WUE was influenced significantly by herbaceous neighborhood composition. Average leaf size and stem weight increased with acorn size in the mesic population. Differences among maternal families in the mesic population suggested significant within-population genetic variation for seedling traits. Further, leaf weight responded differently among families to variation in neighborhood composition, suggesting genetic variation for plasticity in leaf morphology.

Conservation concerns about California's blue oak (*Quercus douglasii* Hook. & Arn.) woodlands focus on the recent documentation of low seedling survival over the entire range of blue oak (Muick and Bartolome 1987, McClaren and Bartolome 1989). Although seedlings are relatively common, successful recruitment to sapling age classes (common before the mid-1800's), now appears rare. Concern about this apparent lack of recruitment is heightened by the fact that the woodland community created by blue oak populations has decreased in area by over 43,000 ha since 1973 and is currently being lost to human development at a rate of over 4,000 ha/yr (Bolsinger 1988). These woodlands are extremely important as wildlife habitat (Verner 1987); for example, among Mediterranean ecosystems world-wide, blue oak woodlands have the highest diversity of bird species (Cody 1986). In addition, the importance of the nutrient cycling role of blue oaks in maintaining the productivity of oak woodland and oak-savanna ecosystems has been documented (Holland 1973, Holland 1979, Kay 1987).

Given the obvious importance of conserving blue oak woodlands and the general recognition that consideration of genetic diversity is critical in any conservation effort (Schoenwald-Cox and others 1983), we have initiated a research program on the ecological genetics of blue oak. The study reported here used both a regional survey and a common garden approach to examine how phenotypic expression in several seedling traits is influenced by the interaction of acorn source and competitive environment.

METHODS

Regional Variation in Blue Oak Water Use Efficiency (WUE)

Leaf and stem material produced during the 1987 growing season was collected from three adult blue oak trees in each of four regional sites in September, 1987. Samples of approximately 50 gm fresh weight were taken from four branches in the lower canopy of each tree and pooled by tree. Samples were collected from the 1ower tree canopy to minimize the differences in atmospheric moisture conditions experienced by trees and seedlings. Simultaneously, three blue oak seedlings under each tree were collected and pooled.

The collection sites were chosen along a latitudinal rainfall gradient that is based on both total rainfall accumulation during 1986-1987 and differences in 30 year rainfall averages. The most northern, mesic site (University of California Hopland Field Station, Mendocino County) is located 20 km inland from the north-central California coast and receives an average of 90.4 cm of rainfall each year (71.2 cm in 1987). The most southern, xeric collection site (San Joaquin Experimental Range, Madera County) receives an annual average of 48.0 cm of rainfall (28.3 cm in 1987). The two intermediate sites were the Hastings Reserve (Monterey County) located 21 km inland from the Pacific Ocean in the Carmel Valley (average annual rainfall of 53.8 cm; 38.1 cm in 1987), and the Sierra Foothill Range Field Station (Yuba County) located along the western foothills of the Sierra Nevada mountains (average annual rainfall of 73.1 cm; 46.0 cm in 1987). Although rainfall accumulation at all sites during 1986-1987 was lower than the 30 year average, the two extreme sites (Hopland and San Joaquin) still differed by 50 pct.

Plant material was dried at 65 °C for 48 hours, ground through a 60 mesh screen and analyzed for $^{13}C/^{12}C$ ratios (Ehleringer and others 1987). Carbon isotope analysis consists

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of sample combustion with a catalyst to generate the CO_2 gas which is then analyzed for isotopic differences with an isotope-mass_ spectrometer. The carbon isotope ratio of the sample is then compared to the ratio in a standard and a $\delta^{13}C$ value is calculated (Farquhar and others 1989). This ^{13}C value is expressed as parts per thousand or "per mil"; as this value becomes less negative, reduced discrimination against ^{13}C is indicated. In turn, a lower degree of isotope discrimination is an indication of higher plant WUE (Farquhar and others 1988).

The $\delta^{13}C$ values for stem and leaf material in tree and seedling samples were analyzed separately using linear regression analysis. An average $\delta^{13}C$ value per tree or composite seedling sample was used as an indication of whole plant physiological performance. The power of non-significant ($p>0.05$) statistical tests was calculated using tables provided in Cohen (1988).

Common Garden Study

Potential genetic variation on local and regional scales in blue oak seedlings were examined in a common garden experiment by collecting acorns from oak populations occupying the southern, xeric site (San Joaquin Experimental Range, Madera County) and the northern, mesic site (Hopland Field Station, Mendocino County). Seedlings germinated from these collections were grown outdoors at University of California Davis in 12 specially designed large volume containers, each having one slanted glass side for root growth observations. The containers were 1 m in height, 48 by 24 cm at the top and 48 by 12 cm at the base. The potential for maternal tree effects as manifested by differences in acorn size were assessed by weighing each acorn before planting. Acorns were planted into three types of herbaceous neighborhoods: an introduced annual grass, *Bromus diandrus* Roth.; an introduced annual dicot, *Erodium botrys* Cav.; and a native perennial grass, *Stipa pulchra* Hitchc. These different neighborhoods induce different rates of soil water depletion; soil moisture is exhausted more rapidly by the introduced annual species (Gordon and Rice, unpublished data). We examined the potential influence of the local soil water regime on phenotypic expression of population differences in seedling WUE, morphology, growth, and survival. Relative estimates of seedling WUE were obtained by measuring the ratio of ^{13}C to ^{12}C in leaf and stem material (Farquhar and others 1988).

Contingency table analysis was used to detect differences between populations in the relationship between acorn weight and emergence probability. The General Linear Model (GLM) procedure of the SAS statistical package (Freund and others 1986) was used to calculate linear correlations between acorn weight and various seedling traits. Analysis of variance procedures within the GLM were used to examine the interactive influence of germplasm (population or family) and competitive environment on phenotypic variation in seedling traits. If necessary, data were appropriately transformed to conform with the assumptions of the analyses within the parametric GLM procedure.

RESULTS

Regional Variation in Blue Oak WUE

Regression analysis indicated that the $\delta^{13}C$ values of leaves and stems of adult blue oak trees were significantly related to annual rainfall ($p=0.018$, $r^2=0.44$). Along the decreasing rainfall gradient from Hopland in the north to San Joaquin in the south, carbon isotope discrimination in adult plants decreased. This strong pattern across regional boundaries suggests higher WUE in trees from dry habitats and lower WUE in trees from more mesic sites.

In contrast, there was not a significant relationship between blue oak seedling tissue $\delta^{13}C$ and rainfall ($p=0.23$, $r^2=0.13$). The power to detect a significant relationship for seedlings was low (i.e. for $r^2 = 0.13$, power = .22); however if the relationship between seedling tissue $\delta^{13}C$ and rainfall had been as strong as that found for adult trees, the power to detect this relationship would have been relatively high (power = .72).

Common Garden Study

On average, acorns were smaller in size in the mesic population and the acorn size distribution within this population was heavily skewed to the right (fig. 1). Probability of seedling emergence increased with acorn size in the xeric population, but was independent of acorn size (contingency table analysis; $p > 0.50$) in the mesic population (fig. 1). There were significant differences between populations in the relationship between acorn size and seedling morphology and growth. In the mesic population, both average leaf size ($r = 0.68$) and final stem weight ($r = 0.79$) increased with acorn size, while in the xeric population these seedling traits were not significantly correlated with acorn size. There was no detectable difference in seedling WUE between the two populations ($p>0.50$). However, herbaceous neighborhood composition had a significant effect on WUE; in the native *Stipa* neighborhood, where soil water is depleted more slowly, the seedlings exhibited significantly lower WUE ($p<0.05$)than in the annual neighborhoods.

Within the mesic population there were significant differences in acorn size among families ($p<0.001$); family averages ranged in size from a high of 8.4 to a low of 2.7 gins. Analogous to the results reported for between-population variation, the effect of within-family variation in acorn size varied among maternal families. Significant differences among trees in the direction and magnitude of the linear correlation between acorn size and seedling average leaf size and stem weight are indicated by a significant family by acorn weight interaction (ANOVA; $p < 0.02$) and the interaction plots for both seedling traits (fig. 2A and 2B). Thus, the relative importance of acorn size on seedling morphology and growth differs significantly among families within this population. Significant interaction (ANOVA; $p <$

0.01) of maternal family and neighborhood composition in average leaf weight (fig. 3) indicates that the magnitude and direction of phenotypic response in seedling leaf weight to changes in herbaceous neighborhood varies from one tree to the next.

DISCUSSION

The higher $\delta^{13}C$ values for blue oak tree populations in the drier regions suggests greater WUE because of greater regulation of diurnal and seasonal stomatal conductance. Phenotypic variation in gas exchange characteristics that regulate water use may result from either genetic differentiation or acclimation. The possibility of genetic differentiation among blue oak populations in water use characteristics is supported by recent reports of heritable variation for carbon discrimination and WUE in agronomic species (Farquhar and others 1989).

In contrast to the strong linear relationship between tree WUE and rainfall, we were unable to detect a comparable relationship for seedlings. This difference in response to the rainfall gradient may result from differences in growth phenology between trees and seedlings. In blue oak seedlings, stomatal conductance and growth are very sensitive to reductions in soil water potential (Gordon and others 1989). Seedling conductance and growth are minimal at the pre-dawn water potentials of $\geq$ -3.0 MPa that have been observed in the field by late May and early June (Welker 1988, Gordon and others 1989). As a result, seedlings avoid drought by actively growing only during the spring when both temperature and moisture are favorable. In contrast, adult blue oak trees continue to transpire and grow well into the summer drought (Elliott 1958, Griffin 1973, Baker and others 1981). During late summer when soil water potentials exceed -5.0 MPa at the xeric sites, higher WUE may significantly improve drought tolerance in adult oaks (Levitt 1980).

The common garden study represents an initial attempt to examine the interactive effects of germplasm, maternal effects (e.g. acorn size), and local competitive environment on phenotypic variation in blue oak seedlings. The importance of germplasm source or phenotypic plasticity, or both, in shaping oak seedling phenotypes appears to be trait-dependent. For example, seedling WUE is characterized by a plastic response to drought induced by different herbaceous neighborhoods and does not appear significantly affected by acorn source. In contrast, probability of emergence is determined by an interaction of regional acorn source, maternal effects (i.e. acorn size), and competitive environment (Gordon and others 1989).

These differences between the regional acorn sources suggest that significant racial or subspecific variation may exist in blue oak. These results for quantitative traits contrast with the results obtained by Millar and others (1990) for electrophoretic variation in blue oak. Although their results indicate that there is no geographic pattern in blue oak allozyme variation, they point out that electrophoretic variation may be a poor indication of genetic variation in quantitative traits (Gottlieb 1981, Hamrick 1983) and suggest that common garden studies are needed to fully understand the role of genetic variation in blue oak adaptation.

In addition to significant variation between populations, differences among trees within the mesic population in both acorn size and seedling growth and morphology suggest that there may be significant within-population genetic variation for traits of potential adaptive significance. This within- population variation provides the genetic raw material for selection to act upon; it represents, in a sense, the evolutionary potential of a population to respond to selective challenges in the future. Evidence for genetic variation in phenotypic plasticity is also indicated by the differential response among families in leaf weight to changes in the competitive neighborhood. If this variation has a significant additive genetic component, selection for plastic responses in seedling leaf traits may also be possible in this population (Via and Lande 1985, Schlichting 1986).

Conservation and restoration biologists are in general agreement on placing high priority on the conservation of critical or keystone species within ecosystems (Wilcox and Murphy 1985, Terborgh 1986). As noted by Thomas and Salwasser (1989), the conservation of keystone species such as blue oak that occur in multiple-use lands represents one of greatest challenges but also one of the greatest opportunities for maintaining biological diversity. The challenge is to conserve diversity in a manner compatible with multiple-use demands; the opportunity arises from the fact that conservation practices developed within multiple-use arenas can be applied to a wide range of public lands. However, the conservation of species and habitats requires understanding of the determinants of phenotypic expression. Common garden studies are helpful in partitioning the relative influences of genetic variation and environment on phenotypic development. Whether the apparent genetic variation detected between and within populations of blue oaks is adaptive remains to be tested; to this end we have initiated a series of reciprocal transplant experiments to detect spatial scales of local adaptation, if it exists. Because the importance of acorn size in phenotypic expression was demonstrated for several traits in this study, a series of reciprocal grafting studies are also currently planned to help evaluate the influence of genotype and environment on adult blue oak traits such as acorn size and WUE.

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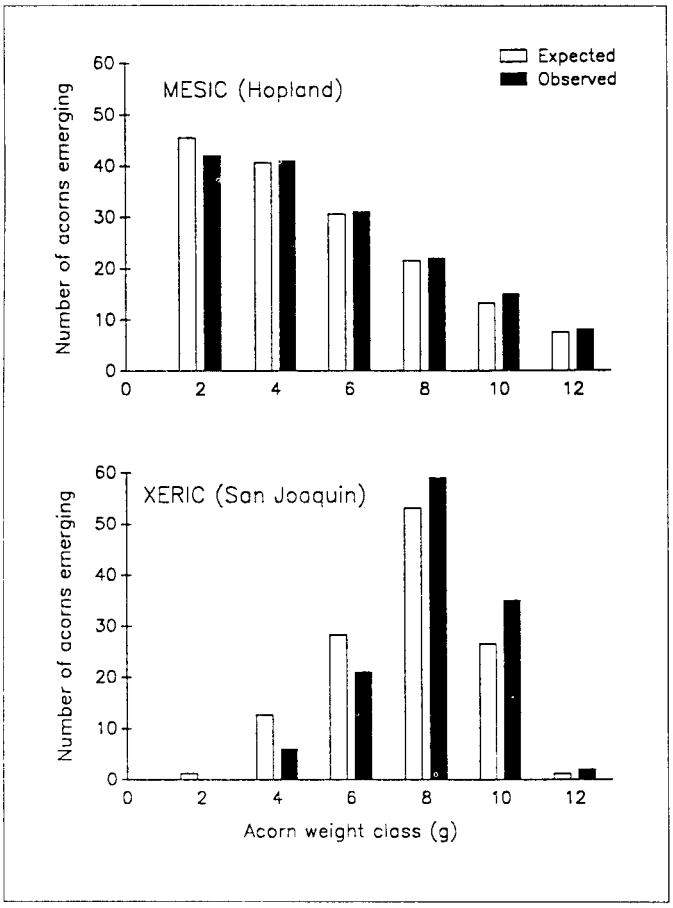


Figure 1—Between-population differences in the effect of acorn size on emergence.

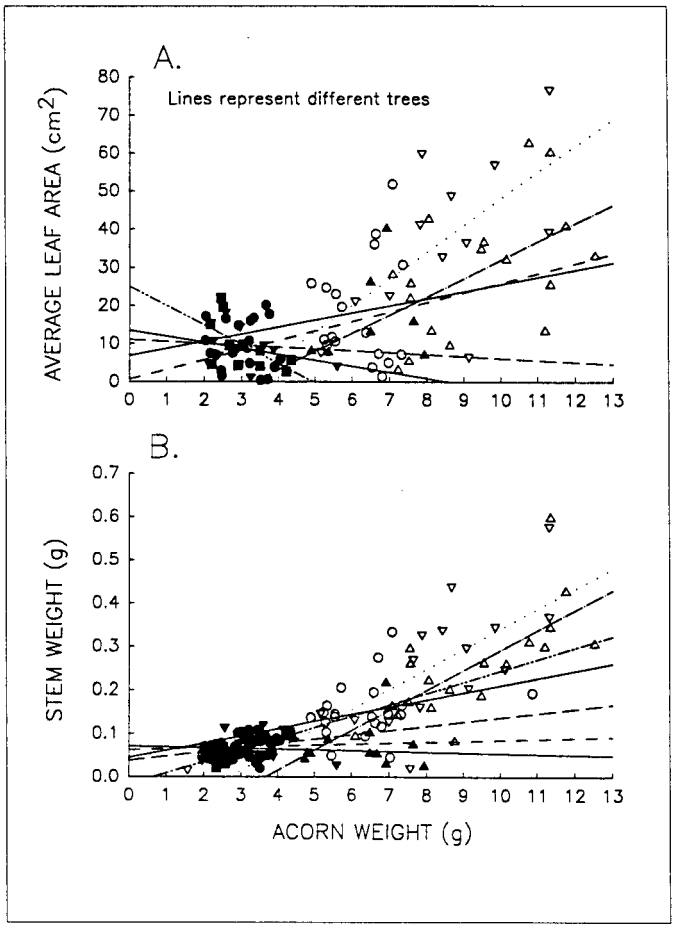


Figure 2—Within-population (among tree) variation in the effect of acorn size on A) seedling leaf size and B) shoot growth.

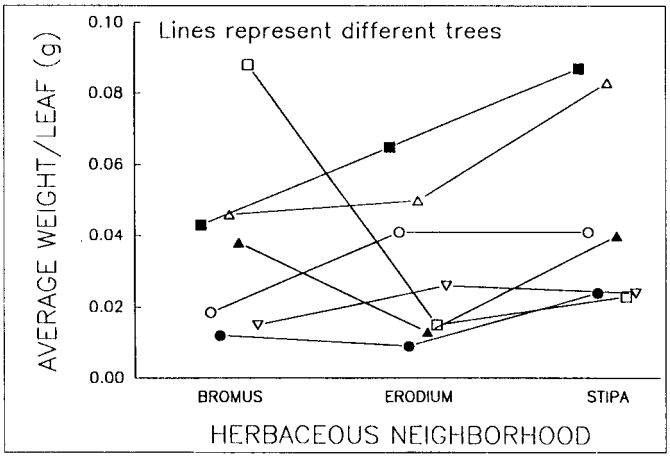


Figure 3—Within-population variation for plasticity in leaf weight in response to competitive neighborhood.

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Stump Sprouting of Blue Oaks in California[1]

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Abstract: A study was conducted at five sites in California to determine the sprouting response of blue oak (*Quercus douglasii* Hook. & Am.) to varying harvest dates, stump heights, and fencing treatments. First- and second-year results indicated that harvest date had relatively little influence on sprouting, while stump height had a great impact. Nearly twice as many 90-cm stumps sprouted as did ground-cut stumps. Site also had a large influence. The average percent of stumps with live sprouts after two years ranged from 76 percent at one site to 37 percent at another, and average shoot length ranged from over a meter to less than 40 cm. While fencing had relatively little effect on the percent of stumps that sprouted, it greatly reduced browsing injury and increased sprout length. These results suggest that sprouting by blue oak will result in the reestablishment of many harvested trees, but that a number of factors can influence sprouting success.

Recent inventories of California oaks indicate that blue oaks are not regenerating well in portions of the state (Bolsinger 1988; Muick and Bartolome 1987). A variety of factors are known to limit natural regeneration, including predation of acorns, browsing of seedlings, clipping of roots, and drought-induced mortality caused by dense, competing vegetation. In some of the areas where recruitment by seedlings is apparently limited, it is believed that many of the existing blue oaks have originated from sprouts following fire or cutting (McClaran 1986). For a variety of reasons, stump sprouts are thought to have a competitive advantage over seedlings. First, since no acorns are involved, there is less risk of losses to insects, birds, or rodents. Second, since the root systems of established trees are massive in comparison to those of newly germinated acorns, they have a greater ability to tap soil moisture and maintain a more favorable water balance during the hot, dry summers that characterize the blue oak region. Finally, the initial growth rate of sprouts is likely to be greater than that of seedlings since stored carbohydrates in the roots provide an abundant food reserve unavailable to small seedlings. Rapid initial growth may be critical to successful establishment since it allows plants to grow above the level where they are susceptible to clipping or repeated browsing. Trees originating from stumps are also obviously located in areas suitable for growing blue oaks.

Previous research indicates that sprouts grow much faster than seedlings. Zahner and Myers (1984) found that sprout origin oak stands grew rapidly even on poor sites. A study of four species of oaks in the South reported that seedling growth was only 12 percent of sprout growth ten years after clearcutting (McQuilkin 1975). And Johnson (1978:p. 115) stated that "probably the most important silvicultural trait of stump and root sprouts is their rapid early growth".

While oaks are known for their ability to sprout (Hannah 1987), there has been very little research on sprouting of California species including blue oak. The following study was initiated to evaluate the effects of harvest date, site, stump height and protection from browsing on sprouting of this species.

METHODS

In 1987, 1-hectare study sites were selected at five locations (fig. 1) in dense (about 500 stems per ha) blue oaks stands representing a range of site conditions (table 1). At each study site, four plots were established. Each plot ranged in size from 0.15 to 0.30 ha and contained at least 96 trees. Two of the four plots were enclosed within 1.8-m tall fences to exclude deer and livestock. All study sites were grazed by either cattle or sheep.

Within each plot, 96 blue oak trees ranging in size from 7- to 40-cm DBH (Diameter Breast Height) were marked with numbered aluminum tags. On each of four dates (July, October 1987, January, April 1988) 12 trees were harvested per plot. Of these 12, six were cut at or near ground level (basal stump), and six were cut approximately 90 cm from the ground. Trees selected for harvest were chosen randomly. At the time of harvest, tree DBH and height were recorded. After felling, tags were nailed to the tops of stumps for permanent identification.

At the end of the 1988 and 1989 growing seasons (late September or early October), the number of sprouts, length of the longest sprout and browsing damage were recorded for each stump. A stump was given a positive browse rating if there was evidence of browsing or clipping on any of the living sprouts. Unfortunately, it was usually not possible to determine the animals responsible for injury.

Data were evaluated using analysis of variance for a doubly nested randomized block design, with sites as the main plots, fences as the sub-plots, and combinations of harvest dates and stump heights as the sub-sub plots. Where we found significant

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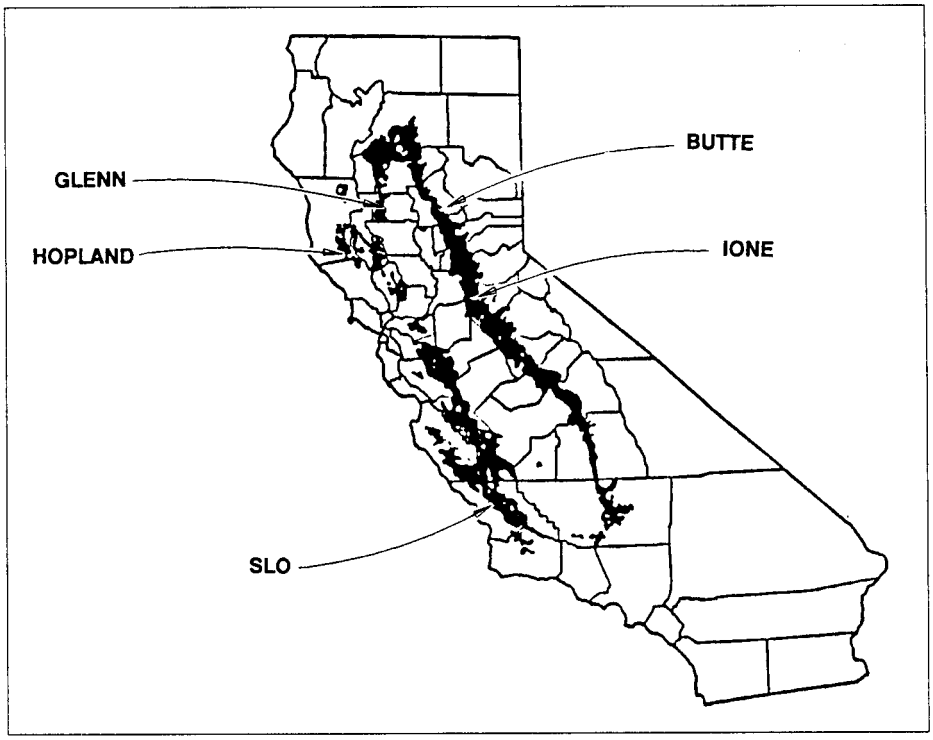


Figure 1—Location of the study sites. Shaded areas show the distribution of blue oak in California.

Table 1 — ***Characteristics of blue oak study sites***[1]

	Site				
Site Characteristics	Hopland	Glenn	Butte	Ione	SLO
Elevation (m)	490	240	170	82	550
Density (stems/ha)	483	518	464	470	485
Basal area (m2/ha)	17	9	15	12	11
Annual precipitation (cm)[1]	93	55	52	46	55
Soil:					
Depth (cm)	60	70	45	100	42
Texture	silt loam	clay loam	clay loam	grav.loam	grav.loam
Series	Laughlin	Sehorn	Auburn	Red Bluff	Millsholm
Subgroup	Ultic Haploxeroll	Entic Chromoxerert	Lithic Xerochrept	Ultic Palexeralf	Lithic Xerochrept

[1] Precipitation data are from the nearest NOAA weather station. Soils information is from U.S. Soil Conservation Service reports for Glenn, Butte, Amador (Ione), San Luis Obispo (SLO) and Mendocino (Hopland) Counties.

differences ($P < 0.05$), individual treatment means were compared using a Fisher's protected LSD test. In addition, average diameter and height of trees whose stumps sprouted were compared with those that did not sprout using t-tests. Finally, regression analysis was used to determine if there were significant relationships between preharvest tree measurements and sprout growth.

RESULTS

Percent of Stumps Sprouting

In both 1988 and 1989 more than half of the stumps sprouted at all study sites except Glenn (table 2). In 1988, sprouting ranged from a high of 73 percent at San Luis Obispo (SLO) to a low of 34 percent at Glenn. By 1989, overall sprouting percent increased at each site and ranged from 76 to 37 percent. Sprouting at the Glenn site was significantly lower than sprouting at all

Table 2 —*The average values of sprouting variables for different sites and evaluation years*[1]

	--- Sprout Percent ---		---Sprout Number ---		---- Sprout (cm) ---	
Stand Location	1988	1989	1988	1989	1988	1989
Hopland	62a	72a	25.3	54.1	36.7c	52.6c
Glenn	34b	37b	26.5	22.0	37.3c	41.6d
Butte	63a	65a	34.0	30.1	74.7a	107.2a
lone	59a	65a	21.2	20.2	51.6b	77.8b
San Luis Obispo	73a	76a	24.7	25.0	29.8c	39.9d
Totals	58	63	26.5	30.6	46.5	64.8

[1]Values within a column are significantly different (P<0.05) if they are followed by a different letter (Fisher's protected LSD test).

other sites, which were not significantly different from one another.

The most striking difference in the percent of stumps sprouting resulted from stump height (fig. 2). Nearly twice as many 90-cm stumps sprouted both years. While tall stumps had greater sprouting than basal stumps at all sites, the proportion in these two groups varied by site, resulting in a significant site by stump height interaction for 1988.

Although there was no significant difference the first year, in 1989 a significantly greater percent of protected stumps sprouted compared to unprotected stumps (67 versus 59 percent). There were no significant differences in sprouting percent either year for dates of harvest. These percentages ranged from 55 to 63 percent in 1988, and from 60 to 65 percent in 1989 (fig. 3).

Number of Sprouts

In contrast to the sprouting percent, the number of sprouts per stump was not significantly affected by site (table 2). It was also not affected by harvest date in 1989, but it was in 1988. In the first year, there were significantly fewer sprouts on stumps from the last harvest date (April 1988) than from any of the other harvest dates.

There were also significant differences in the number of sprouts growing on tall and short stumps both years, with a greater number of sprouts growing on the 90-cm stumps (36 versus 15 in 1988, and 33 versus 28 in 1989). However, there was no consistent pattern in number of sprouts inside or outside the fences; in 1988 there were significantly more sprouts inside while in 1989 there were more outside. In 1989 there were several significant interactions for the number of sprouts. These were due primarily to one basal stump at Hopland which had 600 sprouts! - more than double the number of any other tree in the study.

Length of the Longest Sprouts

For both years there were significant differences among study sites in the average lengths of the longest sprouts (table 2). In 1989, average sprout lengths varied from 75 cm at Butte to 30 cm at SLO. For 1989, average sprout lengths at these respective sites were 107 cm and 40 cm. There were also significant differences in sprout lengths inside and outside the fences (fig. 4). In 1988, average length inside was 59 cm, compared to 33 cm outside. In 1989, these averages were 85 cm and 42 cm.

Date of harvest also influenced sprout lengths. For both years, stumps from the April harvest produced significantly shorter sprouts than those from the other harvest dates. There were no significant differences in sprout lengths between stump heights.

There was also a significant fence by site interaction for

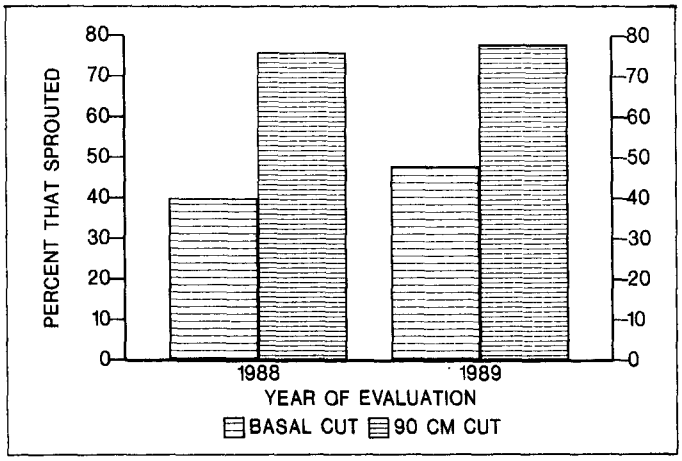


Figure 2 —The percent of stumps from each stump height that sprouted in both 1988 and 1989.

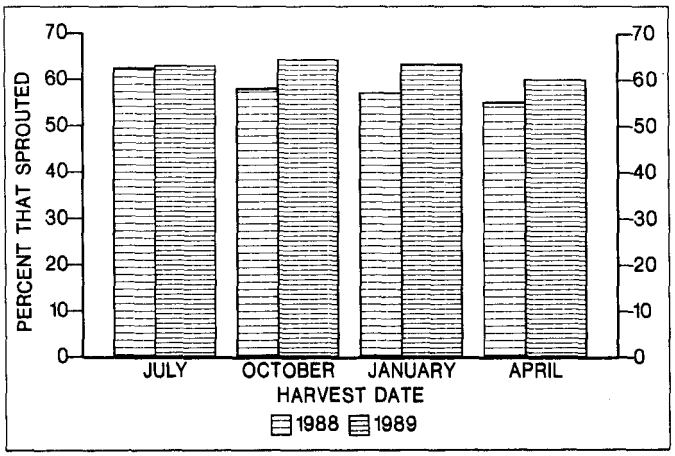


Figure 3—The percent of stumps from each harvest date that sprouted in both 1988 and 1989.

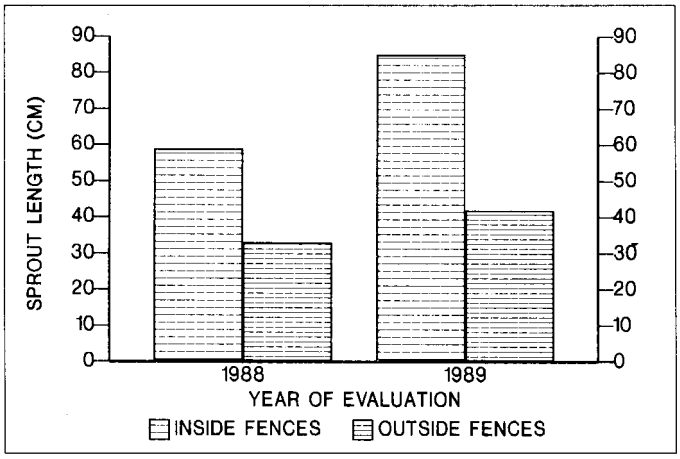


Figure 4 — The average length of the longest sprout per stump in 1988 and 1989, both inside and outside fenced exclosures.

sprout length, primarily because at Hopland both years the lengths inside fences were more than 10 times those outside due to unusually heavy browsing. At the other sites, however, lengths inside were generally less than double those outside.

Browse Damage

The only significant difference in browse damage in either year was between protected and unprotected stumps. Eighty-two percent of stumps outside fences were browsed in 1988 compared to 18 percent inside. For 1989 these figures were 88 and 14 percent, respectively. It appeared that mice and/or rabbits browsed or clipped the sprouts inside the fences, while deer and livestock were primarily responsible outside.

Relationship between Tree Size and Sprouting

For both 1988 and 1989 trees that sprouted were significantly smaller, averaging 15.5 cm in diameter. Non-sprouting trees averaged 17.8 cm both years. While these differences were fairly small and there were trees of all size classes in each group, there was a clear trend for small trees to sprout more than large trees. For instance, for trees less than 13-cm DBH, 71 percent sprouted in 1988 while, for trees greater than 26-cm DBH, only 41 percent sprouted. However, there were no significant differences in initial tree height between sprouting and non-sprouting trees.

We also tried to find out if initial tree diameter affected subsequent sprouting characteristics by correlating the DBH of trees that sprouted with the number of sprouts and length of the longest sprout that were produced each year. There was a significant positive correlation for all of these combinations, except for DBH and number of sprouts in 1988. These results indicate that, of the trees that did sprout, larger initial diameter promoted the growth of more sprouts and longer sprouts.

DISCUSSION

A dramatic result from this study was the tremendous influence of stump height on sprouting. More 90-cm stumps from each harvest date at each site sprouted than did basal stumps, although stump height did not have a consistent effect on sprout number or length. The reasons for the greater sprouting of the 90-cm stumps are unclear but are probably related to the fact that tall stumps have more dormant buds than short stumps, as well as more stored carbohydrates in their stumps.

This finding contradicts research on oaks by Roth and Hepting (1943:p.29) who reported that "the height at which stumps are cut has little effect upon the sprouting capacity, because the great majority of sprouts arise about the root collar." In this study, sprouts on the 90-cm stumps often originated up and down the stump, but few came from the roots.

Even though tall stumps may produce more sprouts than basal stumps, Hannah (1987) asserted that oak sprouts originating high on stumps are inferior to those growing from the root crown or low on the stump. He concluded that the best sprouts originated from buds at or below the ground line and, consequently, recommended cutting stumps low. The common perception is that sprouts originating high on stumps are at greater risk from decay which moves from the decaying stump to the new. sprouts. Shigo (1986), however, argued that decay does not move freely from an old wound into the new sprouts since the heartwood core of the stump and the heartwood of the sprout are not connected. He pointed out that sprouts originating at all locations on the stump and roots can still be killed from below by root rots taking advantage of the weakened host, or from above through wounds resulting from the death of low-vigor sprouts or branches. He also noted that stool sprouts - those originating from buds along the cambial zone on the surface of the cut stump - are inherently weak and generally do not last long. We will continue to monitor the stumps and evaluate the differences in sprouting of high and low-cut stumps over time to determine if there are differential rates of survival, growth and decay.

One surprising result of this study was that harvest date had very little influence on sprouting. Previous research on the relationship between season of harvest and sprouting has been mixed, with both positive (Buell 1940; Roth and Hepting 1943), and neutral (Johnson 1977) results reported. For blue oak, the only previous study found a seasonal pattern of sprouting with more sprouting of trees harvested during the winter months (Longhurst 1956), although seasonal effects on sprouting tended to decrease over time.

Our finding that tree diameter was inversely related to degree of sprouting has been reported by others. Johnson (1977) found that the probability of sprouting decreased with increasing stump diameter, and Roth and Hepting (1943) reported that very large stumps would not sprout at all. That blue oak DBH is correlated with the number and length of sprouts is similar to

Johnson's (1975) finding for northern red oak that DBH was positively correlated with the percent of stumps with long sprouts.

While the overall level of sprouting varied considerably among sites, we found no correlations between sprouting and obvious site factors, including annual rainfall. In fact, the site with the highest percentage of sprouting was San Luis Obispo which had average rainfall (55 cm per year). We suspect hybridization between blue oak and desert scrub oak (*Quercus turbinella* Greene subsp. *californica* Tucker) at this site may have contributed to the high degree of sprouting. Hybrids of these two species are known to occur in the general area (Benson and others 1967) and would likely demonstrate a greater tendency to sprout. While the plot trees appeared to have predominantly blue oak traits, a preliminary analysis of trichomes on the undersides of some sample leaves indicated that some hybridization was occurring.

Another factor which varied greatly by site was the degree of browsing. Trees outside fences were subject to some browsing at all sites, but at Hopland browsing was so severe that sprouts on all unprotected stumps were chewed back almost completely. This intense browsing pressure at Hopland was attributed primarily to a high resident black-tailed deer (*Odocoileus hemiomus*) population, and secondarily to sheep. Where such high populations of browsing animals are present, sprouts apparently need protection in order to produce new trees. Even at the sites where browsing pressures are less, it appears that the differences between protected and unprotected sprouts are increasing with time.

Our results also indicate that blue oak sprouts generally grow much more rapidly than seedlings. After two years, average length of the longest sprout per stump was over 64 cm, even though half of the stumps were repeatedly browsed. This growth is far greater than would normally be expected from natural seedlings or even from artificial plantings, unless intensive planting and maintenance procedures were followed. In addition, many of the fastest growing sprouts originated high on the 90-cm stumps which means that after two years they were well on their way out of the browse zone. Such rapid growth has important implications for regeneration programs. Much of the land where blue oak grows is in private ownership where the principal use of the land is livestock grazing. If landowners choose to cut some trees for firewood, or to thin dense stands to produce increased forage, encouraging and protecting sprouts would likely lead to new trees more rapidly than the planting of seedlings.

As indicated in this discussion, while there were marked differences in sprouting due to different treatments, for the study as a whole the level of sprouting was high and the growth of sprouts vigorous. This is somewhat surprising since blue oak is often labeled a poor sprouter or non- sprouter. Clearly this is not the case at many sites in California. It must be recognized, however, that results from a two-year trial do not translate into long-term management options. Long-term monitoring is required to determine if stump sprouts will survive to become mature trees. The results from this study are also not applicable to other native oak species in California which vary greatly in their sprouting abilities.

CONCLUSIONS

Contrary to common belief, blue oak sprouts well after harvesting. Of 960 trees cut at five separate sites, over 60 percent had living sprouts at the end of two years and average length of the longest sprout was over 64 cm. Stump height had the greatest influence on sprouting, with approximately twice the sprouting for 90-cm stumps compared to ground-cut stumps. Season of cutting, on the other hand, had little influence, suggesting trees can be harvested at any time of the year and still sprout. Larger diameter trees were less likely to sprout than small ones, but DBH and sprout growth were positively correlated. Unprotected sprouts were damaged by browsing. Damage was especially great where there were large populations of browsing animals present. Where sprouts were protected, however, they grew quite rapidly. These results suggest that stump sprouting can help offset losses from tree harvesting by replacing a sizeable percent of the trees which are removed.

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Factors Limiting the Establishment of a Chaparral Oak, *Quercus durata* Jeps., in Grassland[1]

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Abstract: We studied factors that restrict colonization of grassland by *Quercus durata* Jeps., an oak commonly found in chaparral on serpentine soils. The study site contained a chaparral/grassland border that had been stable for at least 50 years. Monitoring of acorns planted in the chaparral understory and grassland revealed that, although initial seedling emergence was similar in the different sites, seedling survival was much higher in the chaparral. No seedling in the open grassland survived beyond the third year of the study, while 25 percent in the chaparral understory were still alive at the end of 6 years. The differences in survival could not be explained by differences in animal activity and herbivory. Rather, the high solar radiation load on seedlings in the grassland appeared to play a major role in mortality. Experimental shading of seedlings in the grassland with light shade cloth increased seedling survival.

Little successful oak seedling establishment has been observed in California grasslands and savannas in recent decades (Griffin 1977, White 1966). Over historical time, oak cover has been reduced and oak woodland has been converted to grassland in many areas (Holmes 1990). Because of this, concern has focused on the ability of oaks to establish in grasslands. Studies addressing this problem have identified several bottlenecks to seedling establishment. Acorns suffer high levels of predation by a wide variety of mammals, rodents and birds (Griffin 1980, Borchert and others 1989, McCreary 1989). In addition, germination of acorns may be reduced by heating and drying, conditions often encountered at the soil surface after acorn drop (Griffin 1971, Keeley 1987, McCreary 1989). Despite these pre-germination obstacles, seedlings often emerge (Griffin 1971). Seedlings rarely survive, however, and browsing of seedlings (above- and belowground) has been identified as a major factor preventing oak establishment (Griffin 1976).

In addition to animal damage, physical characteristics of the grassland environment may be hostile to oak seedling survival. In the mediterranean-type climate of California, high radiation loads, high soil surface temperatures and drought coincide in grasslands during the summer. While the grassland annuals escape these conditions by dying, the oak seedlings must survive them. There are some indications that mesic sites, such as those provided by tree cover and north-facing aspects, are more conducive to oak seedling survival in some areas of California (Griffin 1971, Muick and Bartolome 1987). This study was implemented to determine whether simple shading could increase oak seedling survival in a grassland setting.

We studied the survival of seedlings of *Quercus durata* Jeps. at Stanford University's Jasper Ridge Biological Preserve, San Mateo County, California. *Quercus durata is* a shrubby oak, commonly occurring in stands of chaparral on serpentine soil. Our site had serpentine soil with a stand of chaparral adjacent to an area of grassland. Aerial photographs revealed that the chaparral/grassland boundary had not moved in at least 50 years (Davis and Mooney 1985). Cattle grazing, which may have prevented invasion of the grassland by oak, was removed from the site in 1960. Acorns reach the grassland and germinate, as evidenced by small scattered *Quercus durata* seedlings found several meters from the edge of the chaparral during the course of this study. The stability of the chaparral/grassland boundary suggests, however, that survival of these seedlings is nil. We planted acorns across this boundary and compared the survival of seedlings in the chaparral understory, in the bare zone adjacent to the chaparral, in the grassland, and in the grassland with artificial shading.

METHODS

Acorns were collected from *Quercus durata* shrubs at our site in October of 1984, during the time of natural seed dispersal, and planted in plots along four transects: one through the chaparral understory, one along the bare zone and two parallel to the bare zone in the grassland. Acorns were planted approximately 2-3 cm deep and at least 25 cm apart (234-240 acorns per transect). During the summer months, 40-percent shade cloth was erected over half of each grassland transect.

Planting locations (located with a grid) were examined every 2-4 weeks. Initial emergence of a shoot from the soil surface was noted and the presence or absence of a live shoot was subsequently monitored. Condition of the shoot (browning leaves, herbivory) was also noted. A live shoot was defined as one having some green leaf area. After the first summer, it became obvious that oak seedlings did not resprout during the summer drought. Therefore, only plants with previously live shoots were monitored during the summer. Seedlings were monitored for six years (1985-1990). Because the seedlings often resprouted following shoot loss, a seedling was only

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considered dead if it did not resprout the following year. Differences among treatments and sites in the fraction of acorns producing aboveground shoots (percent emergence) and in the fraction of seedlings surviving six years were compared using G-tests.

Because of the patchiness of shade within the chaparral understory, planting locations were scored for degree of shadiness. At four times during one sunny day in July of 1986, planting locations were visually scored to estimate their daily interception of direct sunlight. A score of 1 to 4 was assigned depending on whether direct sunlight impinged on >95, 50-95, 5-50, or <5 percent of the soil surface. Summation of these scores over the day yielded an arbitrary ranking of shadiness for the locations in which acorns were planted. The association of plant survival with shade was examined by using a Mann-Whitney two sample test to compare the shade score distribu-tions of sites in which seedlings emerged and sites in which they survived.

To compare the degree of shading imposed by the shade cloth with that produced by other, natural sources of shade, daily courses of photosynthetically active radiation (PAR) were measured (1) in full sun, (2) under shade cloth, (3) under the edge of the chaparral canopy, and (4) under small, isolated shrubs in the grassland at Jasper Ridge. Measurements were collected on a clear midsummer day (4 July 1990) using gallium-arsenide sensors (PH 201 A, NEC, Tokyo, Japan) monitored by Campbell 21x data loggers (Campbell Scientific, Logan, UT).

RESULTS

Plant emergence (the percent of acorns producing aboveground shoots) ranged from 65 percent in the unshaded grassland to 76 percent in the bare zone. While emergence was statistically higher in the shaded grassland and bare zone than in the unshaded grassland, high numbers of seedlings emerged in all sites.

Site	Percent emergence[1]
Grassland	65[a]
Shaded grassland	73 [b]
Bare zone	76[b]
Chaparral	69 [ab]

[1] Values superscripted by the same letter are not significantly different, G-test, $p<0.05$.

Experimental shading increased the survival of oak seedlings in the grassland (fig. 1). In the natural, unshaded grassland, no seedling survived past the third year. Six percent of the seedlings in both the bare zone and shaded grassland were alive at the end of six years. Seedlings in the chaparral understory had the highest survival at the end of six years (25 percent). Survival in the chaparral understory was significantly higher than that in any other treatment (G-test, $p<0.01$). Survival in shaded grassland was significantly higher than that in natural, unshaded grassland (G-test, $p<0.01$).

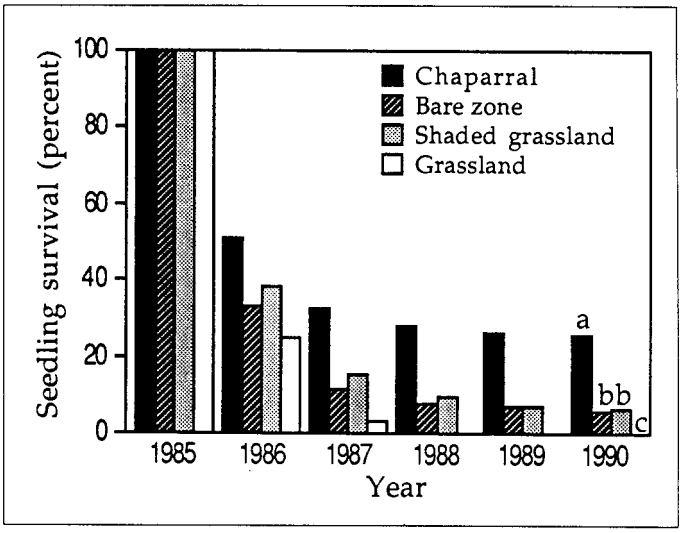


Figure 1—Seedlings alive each year in different treatments and sites. Numbers are percentages of those seedlings alive the first year: 133 in the open grassland, 158 in the shaded grassland, 161 in the bare zone and 143 in the chaparral understory. (Because some seedlings were destructively harvested the first year, these numbers are lower than the number of seedlings that emerged.) Letters indicate statistical differences among treatments and sites for final (1990) survival. Values superscripted by the same letter are not significantly different, G-test, $p<0.05$.

The shade provided by the shade cloth in the grassland was much less than that cast by either the chaparral canopy or small isolated shrubs in the grassland. The shade cloth transmitted approximately 55 percent of the photosynthetically active radiation (fig. 2). The scatter in the data was due to the small sensors detecting shadows cast by the weave of the shade cloth. Light levels under a small, 40 cm tall poison oak in the grassland (fig. 2) were only 5-6 percent of full sunlight during much of the day. The light regime in the chaparral understory was extremely

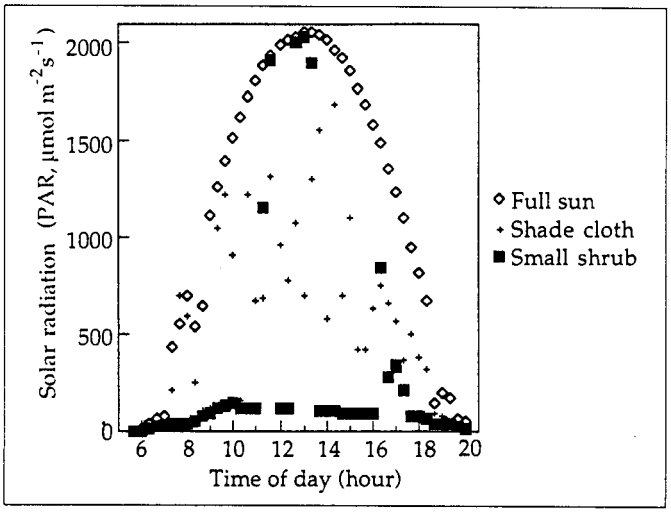


Figure 2—Photosynthetically active radiation (µmol $m^{-2}s^{-1}$) in full sun, under the shade cloth and under a small shrub in the grassland.

variable. Light levels in full shade (no direct sunlight) were also approximately 6 percent of full sun (data not shown).

Within the chaparral understory, seedling survival was higher in the shadier microsites (fig. 3). Comparing the distribution of shade among sites in which seedlings emerged and sites in which they survived revealed that survival was higher in the shadier sites (Mann-Whitney two sample test, $p<0.01$).

The higher seedling survival in the chaparral did not appear to be related to a lower incidence of animal damage. On the contrary, levels of animal damage appeared higher in the chaparral than in other sites and treatments. A greater proportion of the plants that died in the chaparral died with evidence of severe animal damage (severe browsing or evidence of gopher damage), compared to plants that died in any other site (G-test, $p<0.01$) (fig. 4). Root damage to seedlings was difficult to assess, but gopher disturbance was observed in all sites (grassland, bare zone and chaparral understory).

DISCUSSION

Artificial shading of seedlings in the grassland increased survival, but final survival (at the end of six years) was still low. It is uncertain how many of these seedlings will ultimately survive to adulthood. At the end of six years, the tallest seedling in any site was only 15 cm tall. The fact that seedling mortality was very low for the past three years, however, suggests that the remaining seedlings may be well established and have a high probability of continued survival.

The association of high seedling survival with shady microsites within the chaparral understory is consistent with the hypothesis that shade increases seedling survivorship, but is not conclusive. The canopies of the adult shrubs may coincide with some feature of the underlying rock and soil that actually controls shrub distribution. However, such possible associations were not factors in the grassland shading experiment, and shading increased seedling survivorship in both grassland transects.

The mechanism by which shading increased seedling survival is not clear. Shading may reduce leaf temperatures of the seedlings or improve their water status by reducing the transpiration rate of both the oak seedlings and the competing grassland annuals. Additionally, some interaction of high light, high temperature and water stress, all of which may be reduced by shading, may have a negative impact on seedling metabolism. Some evidence exists that water stress in some California grasslands contributes to poor performance of oak seedlings. Gordon and others (1989) showed that competition from grassland annuals for soil moisture reduced emergence and growth rates of blue oak seedlings (*Quercus douglasii* Hook. & Arn.). Griffin (1971, 1980) found that clearing competing grassland vegetation decreased rates of mortality in seedlings of several oak species, but a study on *Quercus lobata* Née (Griffin 1976) showed little effect of grass interference on seedling survival. Snow (1973) observed that, while seedlings of *Quercus agrifolia* Née experienced lower water potentials when competing with herbaceous vegetation, visible injury (browning of leaves) was associated with whether or not the seedling was shaded rather than its degree of water stress. Thus, while alleviation of water stress may improve oak seedling performance, other factors associated with shading may interact with seedling water status to affect survival.

The difference in seedling survival between the bare zone and the grassland in this study may have resulted partly from improved soil water status in the bare zone and partly from shading by the adjacent chaparral. The soil moisture regimes in the grassland, bare zone and chaparral at our study site are quite different. Davis and Mooney (1985) showed that, below approximately 60 cm, soil was driest in the chaparral during the summer. At shallower depths soil dried most rapidly in the grassland, presumably due to water depletion by the grassland

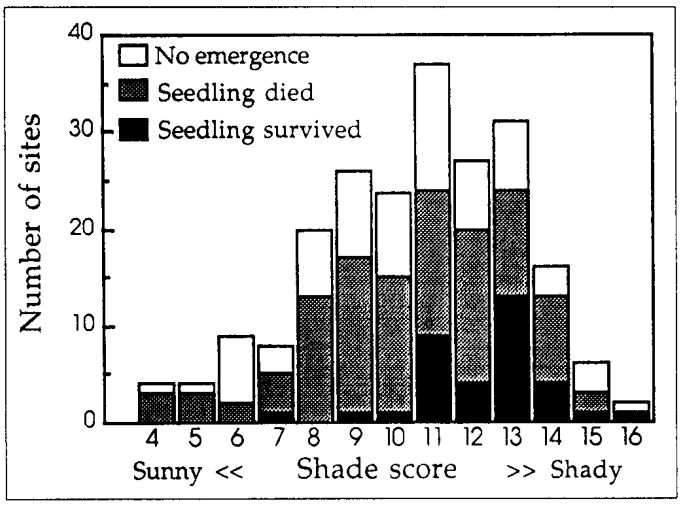


Figure 3—Distribution of shade among planting sites in the chaparral understory. Graph indicates sites in which seedling emergence occurred and sites in which seedlings survived six years.

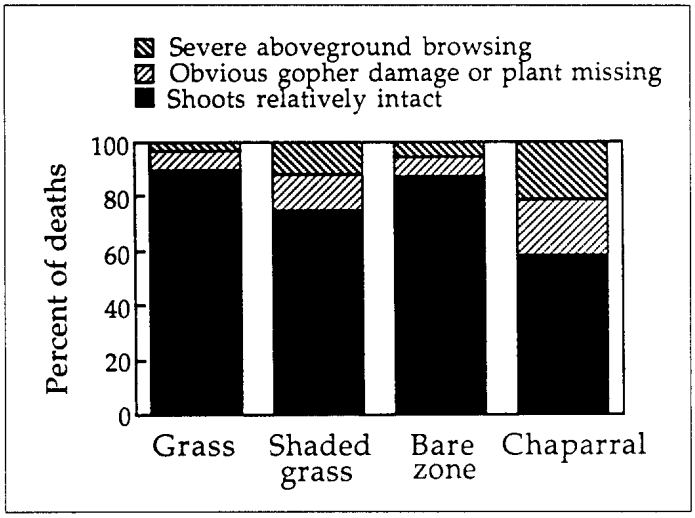


Figure 4—Final symptoms or fates of plants that died in the different sites and treatments.

annuals. Soil water potential in the bare zone was higher than that in the grassland during a large part of the summer drought. The higher soil water potentials in the bare zone, as well as partial afternoon shading of some seedlings by adjacent chaparral, may have increased seedling survival in the bare zone over that in the grassland.

Our main conclusion is that high summer radiation loads in the grassland contribute to the lack of oak seedling survival there. The shade provided by the mature chaparral canopy increases seedling survival in the chaparral. Other factors may vary between the chaparral and grassland, contributing to the difference in seedling survival between habitats. These factors, however, are not obvious. The soil in the grassland was similar to that in the chaparral (Davis and Mooney 1985) and evidence of animal damage to seedlings (this study) actually indicated a higher incidence of animal damage in the chaparral. Despite the possible existence of other factors restricting the establishment of oak seedlings in the grassland, artificial shading in the grassland did increase seedling survival. Furthermore, the artificial shading imposed was unnaturally light. The numbers of seedlings surviving under the shade cloth may have increased with a heavier shade treatment that more realistically imitated the shade cast by the chaparral canopy or by isolated shrubs in the grassland.

The results of this study are consistent with the observations of other investigators, noting increased seedling survival in shade for various California oak species (Griffin 1980, Griggs 1987, Muick and Bartolome 1987, Snow 1973). Increased survival of oak seedlings has been associated with shade, not only in California, but also in the central Rocky Mountain region, where seedlings of *Quercus gambelii* Nutt. were shown to survive much better under canopy protection (Neilson and Wullstein 1983). Observations such as this, combined with the results of this study, suggest that, in and open habitats, shading can improve oak seedling survival. Although artificial shading may be unrealistic as a large-scale management practice, the use of nurse plants to provide shade in grassland settings for fostering oak seedling establishment may prove profitable.

ACKNOWLEDGMENTS

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Artificial Regeneration of Blue and Coast Live Oaks in the Central Coast[1]

Tim R. Plumb Bennie Hannah[2]

Abstract: The primary goal of this study was to find economical and effective planting techniques that will ensure the establishment and early survival of coast live oak (*Quercus agrifolia* Née) and blue oak (*Q. douglasii* H. and A.) in the Central Coast region of California. Eight treatments were evaluated ranging from unprotected seed spots to those protected by 1/4-inch hardware cloth exclosures. Planting was repeated for two years. Seedling establishment varied significantly among study sites and between planting years. Poor germination and survival was attributed to below normal rainfall before and during the study. Seedling survival was enhanced with the use of animal exclosures and somewhat by shade. Blue oak establishment was somewhat better than that for coast live oak.

Lack of adequate regeneration of several woodland oak species is a major hardwood problem in California (Bartolome and others 1987; Bolsinger 1988; Griffen 1976; Johnson 1985). Many factors either individually or together impact acorns and the seedlings that develop from them. Acorns are a primary food for many animals including cattle, deer, turkeys, pigs, and assorted rodents. Birds and insects are extremely important factors in acorn utilization and seedling mortality (Griffin 1980; Brown 1980). Grazing by domestic livestock has been identified as the most persistent pressure on oak reproduction since the introduction of livestock by the Spanish in the late 18th century (Rossi 1980). However, excluding livestock from an area has not guaranteed seedling establishment (Griffin 1980). Where cattle and deer are excluded, small rodents, especially gophers, mice, and ground squirrels seem to be the major cause of seedling mortality (Griffen 1976; Borchert and others 1989; Adams and others 1987). The increase in small mammal populations is likely due to an abundance of annual grass seeds and roots and a reduction of predators.

Competition from annual grasses and herbaceous weeds for moisture, light, and nutrients also affects the survival of oak seedlings (Adams and others 1987; McCreary 1989). Moisture stress is believed to be an extremely important cause of seedling death, especially on marginal sites and during years of low rainfall. Blue oak (*Quercus douglasii* H. and A.) establishment has been found to be positively associated with increasing canopy cover and more mesic sites (Borchert and others 1989). On north-facing sites or partial shade, seedlings are able to survive in a grass cover even in dry years (Griffin 1980). Weed control in late winter or spring will decrease soil moisture loss due to transpiration. Weed control will also reduce the impact of pocket gophers and insects by removing their food source near the planting sites.

The overall objective of this study was to determine practical and economical methods of successfully establishing blue oak and coast live oak (*Q. agrifolia* Née) regeneration. Factors evaluated include three types of animal exclosures, light exposure (open versus canopy shade), and weed control to reduce moisture stress. The study was carried out on four planting sites in the Central Coast of California for two consecutive years to account for climatic variation.

STUDY AREAS

Blythe Ranch

The Blythe Ranch site is about 8 miles northwest of Paso Robles; descriptive characteristics are listed in table 1. The predominant vegetation is a woodland mixture of individual trees and small stands of coast live oak and blue oak with an occasional valley oak (*Q. lobata* Née) and it is interspersed with small areas of chaparral and open grassland. The soil under the two oak species is distinctly different even when the trees are in close proximity of each other with the coast live oak soil being decidedly more sandy than the blue oak soil.

A resident herd of about 20 cattle grazed the site continuously during the study. Wildlife typical of the coastal area is abundant including mule deer (*Odocoileus hemionus*), pocket gopher (*Thromomys bottae*), ground squirrels (*Spermophilus beecheyi*), and several flocks of wild turkeys (*Meleagris gallopavo*).

U.C. Hastings Reservation

The vegetation at Hastings Reservation is similar to that at Blythe Ranch with individual trees and small stands of coast live oak and blue oak, but with a greater component of valley oak. Wildlife species are abundant; there were no cattle or other livestock on this area.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

[2]Professor and Graduate Student, Natural Resources Management Department, California Polytechnic State University, San Luis Obispo, Calif.

Table 1—*Name, location, and physical characteristics of the four oak regeneration planting sites*

Name	Location	Elevation (ft.)	Soil	Rainfall (in.)[1]	Species	Cattle	Aspect and Slope
Blythe Ranch	8 miles NW of Paso Robles	725	Sandy loam (CLO) to Clay loam (BO)	24 (10-34)	Coast live oak Blue oak	Yes	SE 10-40%
U.C. Hastings Reservation	26 miles SE of Carmel	2,200	Sandy loam with clay hardpan	20 (12-40)	Coast live oak	No	SE 10-40%
Agua Escondido (USFS)	20 miles SE of San Luis Obispo	2,490	Clay loam	— (11-16)	Blue oak	Yes	SE 15-20%
Benedict Ranch	10 miles W of Buellton	820	Santa Lucia series mixed with small rocks	14 (9-16)	Coastal live oak	Yes	N 10-15%

[1] Rainfall data collected locally at the Blythe Ranch and U.C. Hastings Reservation; data for other sites taken from nearest official weather station. First number is long-time average; numbers in parenthesis are for 1985-1989.

Agua Escondido

Agua Escondido is the most xeric of the test sites. Blue oak is the dominant tree species forming a small wooded savanna in a sea of chamise chaparral. Various Mediterranean herbaceous plants form a continuous ground cover. The area was grazed in 1987-88 by a herd of Brahman cattle.

Benedict Ranch

Coast live oak is the predominant tree species intermixed with small areas of grass and coastal sage. Over forty head of cattle grazed the area for a few months during the 1988 growing season, and a few horses had been pastured in the area during most of the study.

METHODS

Treatments

The eight planting treatments compared in this study (table 2) fall into the following three general categories: unprotected seed spots (Treatments 1-3), weed control-mulch (Treatment 4), and three types of animal exclosures (Treatments 5-8). All of the treatments were established in full sunlight at all sites or in the shade as noted in table 2.

Treatment 1 is a basic "control" planting without site preparation or weed control, and it simulates natural seedling establishment. Treatments 2 and 3 are the controls for the different levels of site preparation used in Treatments 5 to 8. Weed control was obtained either by scalping (scraping away herbaceous vegetation) or with black, 2-foot-square woven plastic sheets pinned in place with U-clips.

Three levels of predator exclusion were evaluated. In Treatment 5, only cattle were excluded from 40-foot-square barbed wire exclosures. Treatment 6 involved the use of 3-foot-high by 2-foot-diameter hog wire exclosures that were designed to keep out all large mammals. Treatments 7 and 8 involved the use of 1/4-inch hardware cloth exclosures that were 4 inches in

Table 2—*Study design and number of seed spots per treatment by test site and exposure for a single species*

	Test Area[2]				Total
	---------- I ---------		---II,III, IV-----		Seed
Treatment[1]	Open	Shade	Open	Shade	Spots[3]
1. Unprotected control, not predug or scalped	25	25	25	25	200
2. Unprotected, not scalped	25	25	25	25	200
3. Unprotected	100	100	25	25	350
4. Weed mats, unprotected	25	25	25	—	125
5. Cattle excluded	100	100	—	—	200
6. Large mammals excluded	25	25	25	—	125
7. Small and large mammals excluded	25	25	25	—	125
8. Small and large mammals excluded, mechanical clipping	25	25	25	—	125
Total seed spots:	350	350	175	75	1450

[1] Unless otherwise noted, all treatments include predigging and scalping.
[2] Test Area I = Blythe Ranch; Area II = Hastings Natural History Reservation; Area III = Benedict Ranch (coast live oak); Area IV = USFS site at Agua Escondido (blue oak).
[3] There were 1,450 see spots/species/year for a grand total of 5,800 for the study.

diameter and extended 12 inches above and 12 inches below the ground level. All animals are excluded except small insects. Mechanical clipping, Treatment 8, is a technique that is used to simulate animal browsing when there is no way to control the wildlife population. The above ground part of a seedling was cut back to ground level in late spring.

Planting Technique

The location of each seed spot was preselected and marked with a 2-foot-long 1/4-inch iron rebar stake. Except for Treatment 1, each seed spot was predug with a 4-inch power auger to a depth of 18 inches. Where required, a hardware cloth exclosure was installed and the soil refilled. Three acorns were planted at each seed spot between December, 1987, and January 1989. For the first year's planting, the acorns were placed straight down, point first, with the basal one-third of the acorn exposed. The second year, the acorns were pregerminated (Schettler and Smith 1980) and planted sideways 1 to 2 inches below ground.

Seed Collection and Storage

Acorns were collected directly from trees in October and November as close to each planting site as possible. An ample supply of blue oak acorns was available on each test site each year of planting. However, almost no coast live oak acorns were available at the Blythe and Hastings sites in 1987 and 1988.

The acorns collected in 1987 and 1988 were air-dried for several days and were then stored in plastic bags at about 38°F. Excess acorns were refrigerated until May, 1990, when a germination test was run to determine if the acorns were still viable.

Design and Analysis

An overall picture of the study design can be obtained from table 2 which lists the number of seed spots per treatment for each test site. Five 40-foot-square cattle exclosures were built on the north side of an individual tree with two-thirds of the exclosure in the open and one-third under the canopy. All the treatments for both planting dates were then randomly assigned to pre-selected seed spots. Logistic linear regression analysis was used to evaluate test results. Planting success was rated on the basis of at least one live seedling per seed spot. Sampling was done during late spring, after the first year's planting and again in late summer, 1988, and again in 1989. Germination for the second year's planting was evaluated in late summer, 1989.

Treatment Cost

An estimate of the cost for construction and setup of the animal exclosures and time required to predig a seed spot are listed in table 3. A fairly wide range in labor requirements is provided. Time for a specific job varied considerably depending on site conditions (e.g., loose versus hard soil), equipment availability, worker experience, etc. These figures should give a "ball-park" estimate of labor requirements and material cost.

Table 3—*Approximate labor requirements and material costs needed to fabricate and install the various items listed. The times and cost do not include site selection, supervision, travel time, etc.*

Item	Labor Requirements	Material Costs per unit[1]
Cattle exclosure 5-strand barbed wire 40 foot-square	[2]10-13 hours	$148.68
Large mammal exclosure hog wire	8-15 minutes	$2.07
Small mammal exclosure 1/4" hardware cloth	8-17 minutes	$0.87
Weed mats	1.5-2.5 minutes	$0.48
Pre-digging seed spots.	0.5-2.0 minutes	none

[1] Does not include the cost of equipment to manufacture or set up an item.
[2] Involved two workers plus an operator and tractor fitted with a 9-inch auger.

RESULTS AND DISCUSSION

Test Location

There was a considerable amount of variation in seedling survival among the four planting locations (figures 1-5) with the year of planting a confounding factor. Seedling establishment ranged up to 100 percent at Blythe in 1987-88 to less than 20 percent for both years of planting at the Benedict location.

Blythe Ranch

By far, the best initial seedling establishment obtained with the first year's planting was at Blythe. Percent seedling survival in May, about 5 months after planting, ranged from 52 to 96 percent for blue oak and from 48 to 100 percent for coast live oak (figure 1). Seedling survival dropped dramatically by the end of the first summer, especially for the coast live oak seed spots in the open where survival ranged from 0 to about 32 percent, except for the small mammal exclosures where over 80 percent of the seedlings were still alive. Overall, blue oak had less decline in survival over the summer than coast live oak, and the best establishment was obtained with the small mammal exclosures.

One explanation for the higher seedling survival at Blythe, compared to the other study locations, is that it was planted

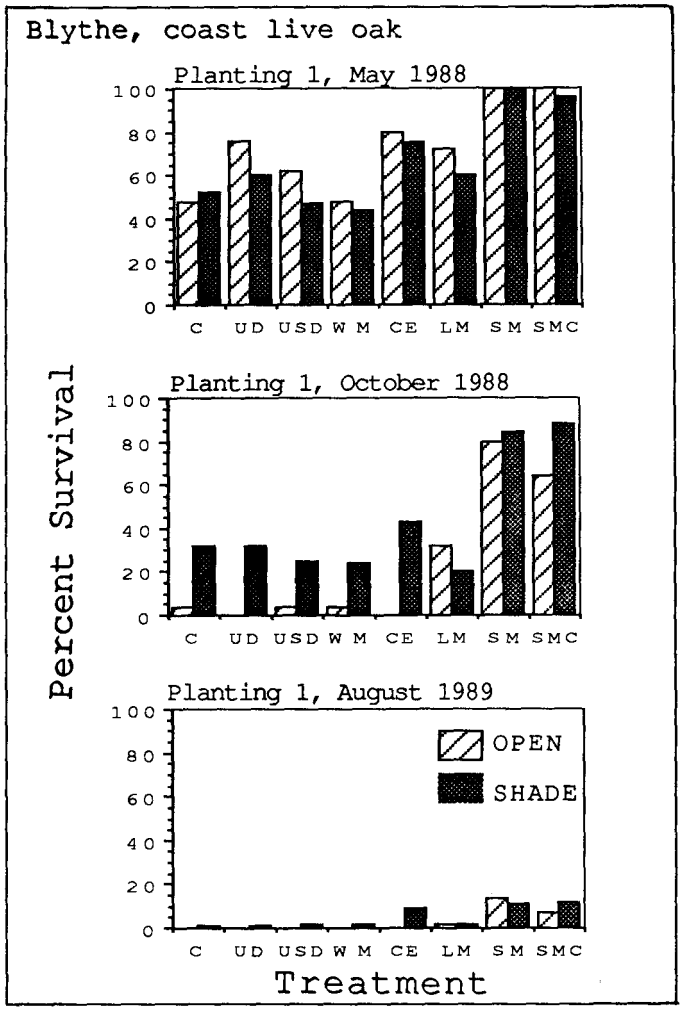


Figure 1—Percent survival of coast live oak seedlings over a 2-year period at the Blythe test site near Paso Robles. Planting 1 was done in December 1987. Treatments are as follows:

C .....Control, not scalped or predug
UD.....Unprotected, not scalped
USD .....Unprotected
WM .....Weedmats
CE .....Cattle excluded
LM .....Large mammals excluded
SM .....Small mammals excluded
SMC .....SM and clipped

Note: unless other wise stated, all treatments were predug and scalped.

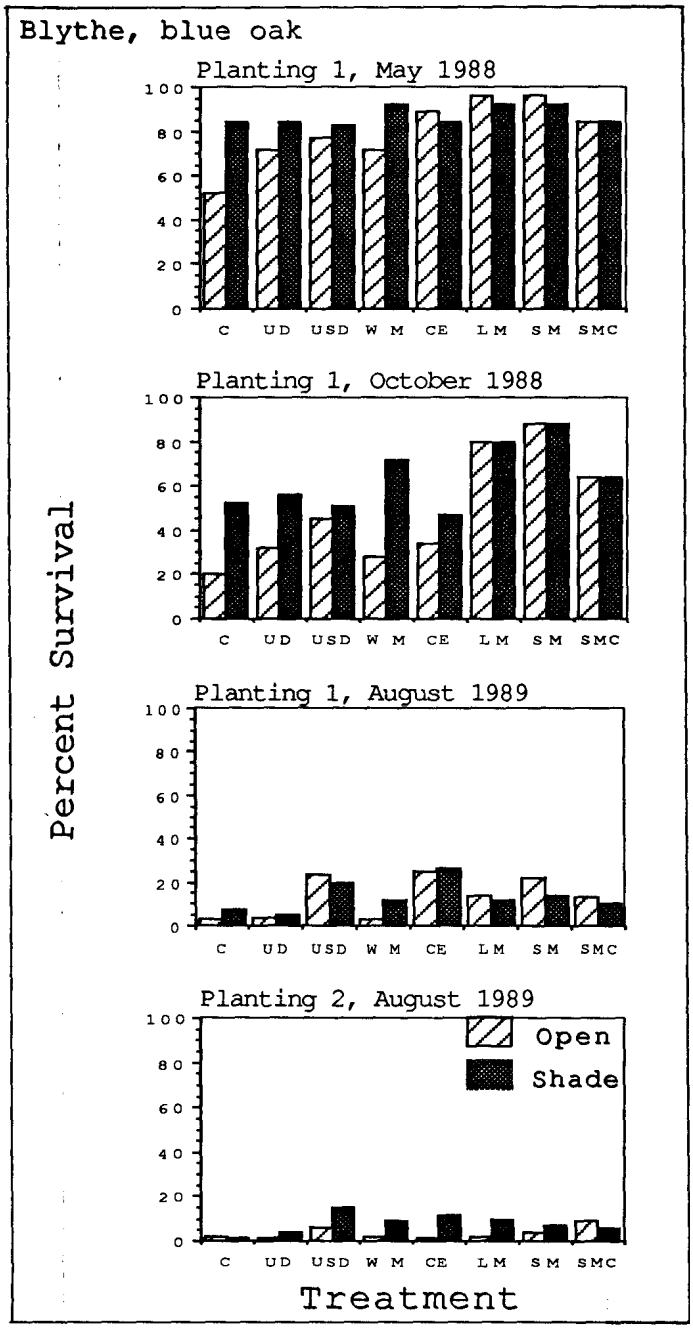


Figure 2—Percent survival of blue oak seedlings over a 1- or 2-year period at the Blythe test site near Paso Robles. Planting 1 was done in December 1987 and Planting 2 in January 1989. See Figure 1 for treatment description.

almost a month earlier. Early germination and root development would better prepare these seedlings for the dry months that followed than the acorns that were planted a month later and had less time to become established.

Results of the second year's planting at Blythe were very disappointing. Almost no coast live oak became established and blue oak establishment was not much better (figures 1 and 2). As in the previous 2 years, less than normal rain fell after December. Acorn predation began within a couple of weeks after planting. Several of the unprotected coast live oak seed spots were partially excavated to a depth of 1 to 2 inches. However, no predation of blue oak seed spots was observed at any time. The fact that almost no coast live oak acorns had developed at the study site during the first 3 years of this test may account for its selective predation. Within 4 weeks after planting, all of the remaining unprotected coast live oak acorns were removed by a flock of resident wild turkeys. The few seedlings that were established that year were mostly those protected by small mammal exclosures.

U.C. Hastings Reservation

Initial establishment of coast live oak seedlings at Hastings was fairly high for the protected seed spots with almost 55-65

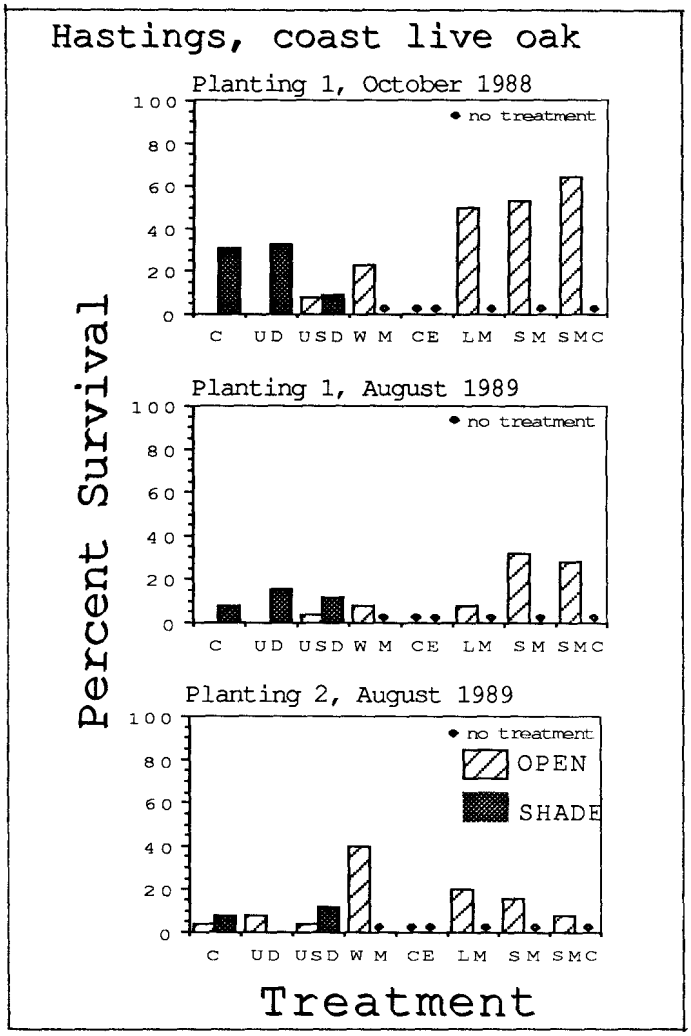


Figure 3—Percent survival of coast live oak seedlings over a 1- or 2-year period at the Hastings test site. Planting 1 was done in December 1987 and Planting 2 in January 1989. See Figure 1 for treatment description.

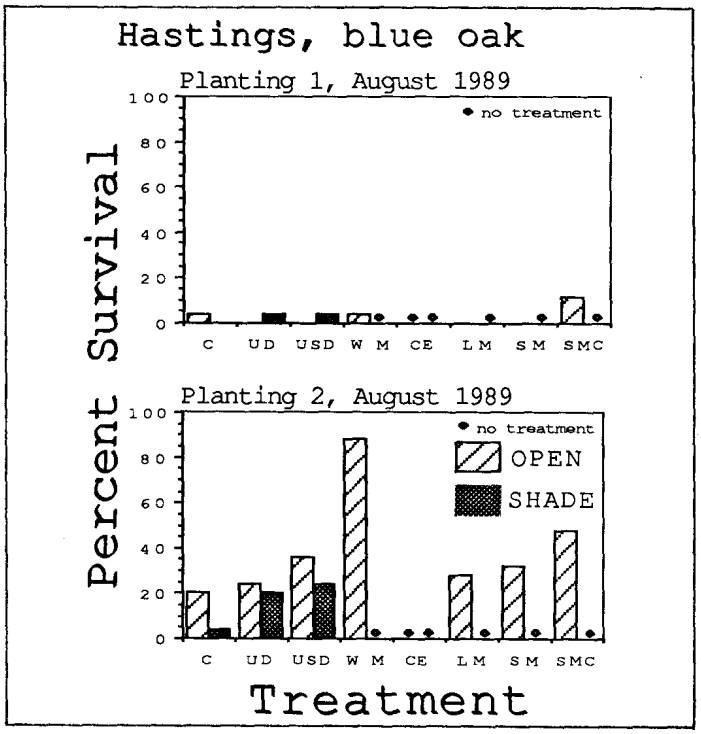


Figure 4—Percent survival of blue oak seedlings over a 1- or 2-year period at the Hastings test site. Planting 1 was done in December 1987 and Planting 2 in January 1989. See Figure 1 for treatment description.

percent of the plants still alive after the first summer (figure 3). By the end of the second summer, 30 percent of the seedlings protected by the small mammal exclosures were still alive, a slightly higher percentage of seedling survival than at Blythe, but not significantly higher. On the contrary, coast live oak germination for the second year's planting was low, apparently the victim of the continuing drought. The best survival was obtained with weed mats; they had little or no positive effect on the first year's planting survival.

Blue oak seedling establishment with the first year's planting was extremely low with only a few percent of the acorns germinating (figure 4). It was not apparent why it was less successful than coast live oak in getting established the first year. Blue oak survival was considerably better with the second planting, especially with weed mats which resulted in over 85 percent survival (figure 4).

Agua Escondido

Seedling establishment at Agua Escondido was low the first year except for seedlings protected by small mammal exclosures (up to 50 percent survival at the end of the first summer, figure 5). However, seedling survival with the second year's planting was much higher for all treatments, ranging from 35 to 65 percent. There were no obvious reasons for the higher germination and survival the second year. Planting the first year was in December followed by 8.6 inches of rain between January and June. Planting the second year was in January with only 3.9 inches of rain until June. Based on just the amount of rainfall after planting, seedling establishment should have been extremely low instead of better.

Benedict Ranch

Coast live oak establishment for both years at the Benedict site was extremely low, less than 10 percent for both years of planting. Many of the acorns did not even germinate. The rocky soil, with its large air spaces, was not a favorable environment for satisfactory germination and development, especially when rainfall was below normal.

Species

Blue oak survival was significantly higher than coast live oak's for both years of planting and at all sampling dates with the exception at Hastings when only a few blue oak became established from the first year of planting, regardless of treatment (figure 4).

Because blue oak grows on more xeric sites and it better adapted to drought conditions than coast live oak (Matsuda and

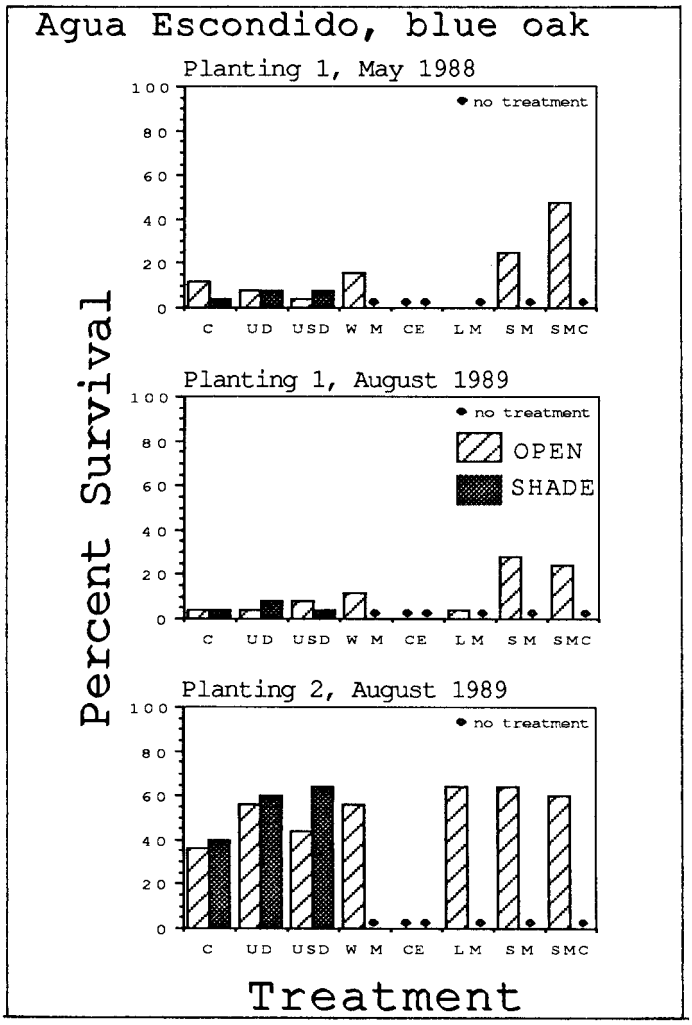


Figure 5—Percent survival of blue oak seedlings over a 1- or 2-year period at the Agua Escondido test site. Planting 1 was done in December 1987 and Planting 2 in January 1989. See Figure 1 for treatment description.

McBride 1986), it might be expected to have a higher survival rate than coast live oak during low rainfall years. The data from this study appear to substantiate this. However, even though blue oak performed better than coast live oak in this study, both numerically and statistically, its percent survival one year after planting was not high enough for the planting operation to be considered successful.

Light Exposure

In general, shade improved the odds for survival at the end of the summer for both years of planting. These results confirm other reports that oak regeneration is usually greater under tree canopy than it is in the open (Griffin 1971, Griggs 1987). More specifically, Bartolome and others (1987) indicate that it was more common to find oak saplings at the canopy edges than under the canopy or in the open. However, by the end of the second summer after planting (figures 1-2), seedling survival had dropped to such a low value that canopy effect was no longer of practical importance.

Treatments

Unprotected Controls (Treatments 1-3)

There was no significant difference in seedling establishment and survival among the three treatments involving unprotected seed spots. Compared to Treatment 1, which had no site preparation and amounted to simply planting acorns directly into the ground, there was no apparent advantage gained by predigging the seed spots or scalping the soil around a seed spot. Consequently, these cultural activities should not have had any effect on the other treatments.

Weed Mats (Treatment 4)

The weed mats effectively kept weeds away from the seed spots, but there appeared to be little positive effect on seedling survival for the first year of planting. In fact, they actually seemed to have a negative effect. This was unexpected because of the drought conditions during the study. Any treatment that reduced moisture stress should have been somewhat beneficial. The black mats may have caused elevated soil temperatures that were detrimental to the seedlings. At any rate, the weed mats had a strong positive effect on seedling survival at Hastings with the second year of blue oak planting (figure 4) and to a lesser extent with coast live oak (figure 3). There was no obvious reason for such a positive effect the second year and only at one location.

Animal Exclosures (Treatments 5-8)

Cattle alone had no significant impact on seedling survival, but where both cattle and deer were excluded (Treatment 5, large mammal exclosures), survival was significantly increased. Although this suggests that deer alone or in combination with cattle were responsible for seedling losses, there was no obvious field evidence for this conclusion.

The small mammal exclosures significantly improved the odds of seedling survival, at least until the first fall season after planting. However, percent seedling survival a year later had dropped from about 80 percent to only about 10 percent at Blythe (figures 1 and 2). This decline in survival was most likely due to the effect of moisture stress and points out the need to wait at least two years after planting to realistically evaluate seedling survival.

Live seedlings in the small mammal exclosures (Treatment 8) were clipped off at ground level by hand in the spring of 1988 to simulate animal browsing. Clipping appeared to have little effect on seedling survival and was not carried out with the second planting.

The 1/4-inch hardware cloth exclosures may be too durable for practical field use. If left in the ground, there is concern that they will severely restrict root growth as a seedling gets older. Removing an enclosure after a seedling is well established is not practical because almost the whole enclosure has to be dug up to get it out of the ground. This would be time consuming and a bit traumatic for the seedling. Also, at a cost of at least $1.00 per

seed spot, including materials, construction, and installation, the hardware cloth exclosures would be too expensive for large field plantings.

Acorn Storage

There has been considerable debate about how long acorns can be stored and remain viable. White oak acorns are reported to be less durable than black oak acorns (Bonner 1979). Plumb and McDonald (1981) reported that scrub oak acorns, if air dried prior to cold storage, would remain viable for at least 15 months.

Results of a germination test, involving acorns collected for this regeneration study and acorns of other species stored during the same period, indicate that both white and black oak acorns will remain viable for at least 30 months. Percent germination for coast live oak and blue oak stored since October, 1987, were 30 and 46 percent, respectively. Coast live oak stored since October, 1988 and 1989, germinated at a rate of 40 and 100 percent, respectively. California black oak (*Q. kelloggii* Newb.) and canyon live oak (*Q. chrysolepis* Lieb.) were also viable after 2 years of storage (41 and 35 percent, respectively).

CONCLUSIONS

The results of this oak regeneration study varied from location to location and year to year at the same location, making it difficult to draw clearcut conclusions about the regeneration methods tested. There is little doubt that below normal rainfall during the 4 years of this study had an extremely negative effect on both acorn germination and subsequent seedling survival.

Even though some of the treatments resulted in statistically higher survival than obtained with the controls, the numerical results in terms of seedling survival were too low to have practical significance.

In summary, blue oak had a higher rate of survival than coast live oak. Planting in shaded sites increased the odds of seedling survival over planting in the open. Weed mats gave erratic results, but significantly increased seedling survival at a couple of sites in 1988. They need further testing. There was a clearcut advantage in using small, wire mesh cages to protect acorns and seedlings from animal depredation. Finally, cattle were not found to have any singular detrimental impact on oak survival.

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Factors Affecting Seedling Survivorship of Blue, Oak (*Quercus douglasii* H.& A.) in Central California

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Abstract: Blue oak seedling mortality was studied in relation to vertebrate predators, initial acorn planting position, slope and aspect, and oak canopy cover at two sites in the Central Coast Ranges of California. Seedling survival rates (Psd) were related to treatment variables using logistic regression analysis. Analysis of 2842 seedlings for 3 years following establishment indicated that site, rodents and acorn planting position were important variables explaining seedling losses. Seedling mortality was six times higher in the savanna site than the north-slope forest apparently because of unusually heavy competition between oak seedlings and annual grasses. Rodents were significant mortality agents at both sites. Overall, mortality was high during the first 3 years after seedling establishment with most losses occurring in the first year. Height growth of seedlings at both sites was very low. High seedling mortality coupled with slow growth rates and concomitant browsing apparently make the transition from seedling to small tree a rare event in this region.

In a previous paper we reported on acorn germination and seedling recruitment of blue oak in relation to postdispersal predators, planting depth, oak canopy cover, slope angle and aspect, and herb layer at two sites in the Central Coast Ranges of California (Borchert and others 1989). In the first phase of this multi-year study we sowed over 8000 acorns in a series of large and small predator exclosures to measure the significance of individual mortality factors affecting blue oak acorn germination and seedling recruitment. Results indicated that year, site, acorn planting position and rodents interacted strongly to affect seedling recruitment from acorns (table 1).

Although mortality was high in the seedling recruitment stage, several thousand seedlings managed to establish in the two stands (Borchert and others 1989). Several researchers (Griffin 1971, McClaran 1986) have suggested that mortality after establishment rather than limited seed and seedling production is responsible for the widespread absence of regeneration in blue oak. Nevertheless, few studies (Griffin 1971, Griffin 1980) have documented losses of seedlings and saplings for more than a few years. In this paper we examine the causes of blue oak seedling mortality over the first 3 years after establishment and compare them to mortality agents affecting seedling recruitment.

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METHODS

Site Description

We studied seedling mortality in blue oak forest at American Canyon (AC) and in blue oak savanna at Agua Escondido (AE), in the Coast Ranges of San Luis Obispo County, California (table 2). A more detailed description of each site is provided in Borchert and others (1989). AC was grazed by cattle continuously during the study, but AE was grazed only in 1986.

Average annual precipitation at Pozo, 9.5 km west of AC, is 527 mm. Precipitation in 1986 was 709 mm, well above the average. In 1987, 1988, and 1989, however, precipitation was 269, 453 and 328 mm, respectively, well below the average.

Exclosure Experiment

Beginning in 1984 at AC and 1985 at AE, we sowed acorns for 2 years in 38 each 2.4 by 2.4 m plots distributed over a 1.65 ha area that was divided into three adjacent 0.55 ha subareas: a cattle exclosure, a cattle/deer exclosure and an unfenced area. Six plots were distributed across the unfenced control area, half of the plots under oaks and the other half in the open. The remaining 32 plots were divided evenly between cattle and deer exclosures.

In each exclosure, 10 randomly selected plots received additional protection to prevent access by birds, mice and gophers, by birds and gophers, or by mice and gophers (table 3). These subexclosures were evenly distributed within each exclosure, with five plots placed under oaks and the other five placed in open areas. The remaining six plots in each exclosure received no additional protection and were located within 5 m of randomly selected subexclosures.

At AC, 30 surface and 30 buried acorns were sown in each plot in 1984 and 1985, and at AE in 1985. Because of a shortage of acorns at AE in 1986,28 surface and buried acorns were sown in the exclosures. A total of 8172 acorns were analyzed for seedling recruitment patterns (table 1). The sowing configuration is detailed in Borchert and others 1989. After establishment, seedling survival was monitored at both sites for an additional 4 years. In this paper we report on the survival of 2842 seedlings monitored from 1986 to 1988 at AC and 1987 to 1989 at AE.

Site	Year	Planting Position	Mice	Gophers	Sample Size	P_s
Both sites					8172	0.36
American Canyon					4500	0.38
	1985				2280	0.27
		Surface			1140	0.17
			+		660	0.11
			-		480	0.26
		Buried			1140	0.36
				+	540	0.30
				-	600	0.42
	1986				2220	0.50
		Surface			1140	0.36
			+		660	0.31
			-		480	0.50
		Buried			1080	0.62
				+	510	0.50
				-	570	0.73
Agua Escondido					3672	0.33
	1986				2040	0.45
		Surface			1020	0.30
				+	540	0.17
				-	480	0.44
		Buried			1020	0.61
	1987				1632	0.18
			+		1056	0.12
		Surface	+		528	0.07
		Buried	+		528	0.18
			-		576	0.29
		Surface	-		288	0.24
		Buried	-		288	0.34

Table 1—*Hierarchical classification of factors affecting seedling recruitment from acorns sown at American Canyon and Agua Escondido experimental sites, based on hierarchical logistic regression analysis. See Borchert et al. (1989) for details of data analysis. Sample* **size is** *the number of acorns sown in each treatment. P is the proportion of acorns that produced first year seedlings. For example, 38 percent of 2280 acorns* **sown** *at American Canyon produced seedlings (row 2); 11 percent of 660 acorns sown at American Canyon in 1985, on the surface, and accessible to mice produced seedlings (row* **5).**

Table 2—*Description of study sites.*

	American Canyon	Agua Escondido
Location	35°16'N, 120°16' W	35°1l' N, 123°13'W
Elevation (m)	540	798
Slope	5-15°	11°
Soil depth (cm)	122-167	61-76
Soil texture	clay loam	coarse sandy loam
Oak density (tree/ha)	316	104
Oak crown cover (pct)	65	15

Measurement of Other Variables

For each plot a northness index was calculated as:

100 x sin(slope) x cos(azimuth).

Oak canopy cover was measured with a concave gridded mirror (spherical densiometer).

In May 1990 herbaceous biomass and litter were measured at each site by harvesting all the material from 15 each 20 by 20 cm quadrats taken at random from subexclosures, exclosures and controls. Harvested material was separated into litter and herb biomass, dried at 38° C for 48 hours and weighed.

Table 3—*Description of protection treatments used in the exclosure experiments. Treatments are listed by the predators that had access to the plots. Numbers refer to the number of replicates in each exclosure. Numbers in parentheses are for Agua Escondido (AE), when different from American Canyon (AC) (Borchert and others 1989).*

	Exclosures			
Predator access	Deer	Cattle	Control	Description
No predators (NP)	2	2(3)	—	All predators were excluded using a 2.4 by 2.4 m subexclosure. Sides were 0.5-cm mesh hardware cloth buried to bedrock, 1 m high with a 25-cm border of galvanized flashing around the upper margin. 2.5-cm poultry netting was used to cover the top of the subexclosure.
Mice (M)	2(3)	2(1)	—	To allow mice to enter, 2.5-cm holes were placed at ground level around the perimeter of the subexclosures.
Birds (B)	6(5)	6(5)	—	Subexclosures were left uncovered in the cattle and deer exclosures.
B,M, Gophers (BMG)	6	—	—	Unprotected plots in the deer exclosure.
B,M,G, Deer (BMGD)	—	6	—	Unprotected plots in the cattle exclosure.
B,M,G,D, Cattle (BMGDC)	—	—	6	Unprotected plots in the control area.

In addition to counts, seedling heights were recorded for a random number of individuals in each plot for each year. We analyzed the heights of 4-year seedlings and pooled samples from B with the NP treatment and those from the BMG with the BMGD treatment to increase sample sizes (see table 3 for treatment codes). Seedling numbers from surface and buried acorns in the BMG and BMGD and BMGDC treatments at AE were too small for height analysis.

Data Analysis

Results from the exclosure studies were expressed as the seedling survival rate (Psd), i.e., probability of a seedling surviving from one year to the next for particular treatments. The dependence of Psd on predator treatments and environmental variables (site, planting position, northness and canopy cover) was estimated by fitting logistic regression models. Separate logistic models for nested subsets of the data were fitted using a dichotomous divisive classifier (Michaelsen and others 1987).

The choice of a variable for splitting the data at a branch of the hierarchical model and selection of variables to include in the logistic regression equations were based on the reduction in G2 (Sokal and Rohlf 1981), a measure of the strength of association between variables. Useful improvements in the model at each branch were tested by cross-validation which operates by dividing the data into groups, omitting each group in turn, estimating the model on the remaining groups, and testing it on the omitted group.

At each step, variables that produced the largest reduction in cross-validated G^2 were included in the logistic equations. The decision to stop splitting hierarchically was based on the small reduction in overall G^2 that resulted from further subdividing the data after the first three divisions.

One-way ANOVA and Sheffe's test were used to compare biomass and litter weights and seedling heights among the treatments. Mann-Whitney U test was used when sample sizes were <10.

Table 4—*Seedling survival at American Canyon. Data are given as absolute number of seedlings surviving after each year (above), and as the proportion of the total number of acorns sown (below).*

Planting position	Predator treatment[1]	Acorns sown in 1984					
		1984	1985	1986	1987	1988	1989
Surface	NP	120	34	10	8	7	5
			0.28	0.08	0.07	0.06	0.04
	BMGDC	180	22	7	5	4	4
			0.12	0.04	0.03	0.02	0.02
Buried	NP	120	51	37	30	30	21
			0.43	0.31	0.25	0.25	0.17
	BMGDC	180	51	17	11	8	6
			0.28	0.09	0.06	0.04	0.03

[1] *NP = no predators; BMGDC = birds, mice, gophers, deer, cattle.*

Table 5—*Seedling survival at Agua Escondido. Data are given as absolute number of seedlings surviving after each year (above), and as the proportion of the total number of acorns sown (below).*

Planting position	Predator treatment[1]	Acorns sown in 1985				
		1985	1986	1987	1988	1989
Surface	NP	120	62	18	7	4
			0.52	0.15	0.06	0.02
	BMGDC	180	28	3	1	1
			0.16	0.02	0.01	0.01
Buried	NP	120	75	33	4	4
			0.62	0.28	0.03	0.03
	BMGDC	180	107	35	12	11
			0.59	0.19	0.07	0.06

[1]***NP = no predators; BMGDC = birds, mice, gophers, deer, cattle.***

RESULTS

At AC, survival of seedlings from surface acorns after 5 years was similar (<5 percent) for the NP and BMGDC treatments (table 4). For seedlings from buried acorns, on the other hand, survival at the end of 5 years was five times higher in the NP than the BMGDC treatment.

At AE losses in the same two predator treatments were high regardless of planting position (table 5) with <5 percent of the seedlings still alive at the end of 5 years. At both sites seedling mortality was highest in the first year after establishment.

The hierarchical logistic regression tree for seedling survival (table 6) resulted in a 43.6 percent reduction of the total G^2 by division into 6 classes. An additional 1 percent reduction occurred by the fourth stratum but was not considered significant enough to include in the regression tree.

The first division of the data by site accounted for the largest GI reduction (29.5 percent). Psd was slightly more than six times higher at AC than at AE (table 6), a difference clearly reflected in the seedling survivorship (tables 4, 5).

At AC pocket gophers (*Thomomys bottae*) were the most important seedling predators; Psd was twice as high for protected seedlings (table 6). At AE, in contrast, mice (western harvest mouse, *Reithrodontomys megalotis,* and California pocket mouse, *Perognathus californicus*) were the most important seedling predators, although Psd was quite low (0.10) even in the absence of mice.

After gophers, Psd at AC was most influenced by planting position of the acorn. Seedlings from buried acorns had higher survival rates whether or not gophers were present. Still, the difference in Psd between surface and buried acorns was much greater in the presence of gophers (table 6).

Overall, seedlings were quite small at both sites, after 4 years averaging only 7 centimeters. Seedlings that originated from surface and buried acorns in the B/NP treatments did not differ in height between the two sites (table 7). At AC seedlings from buried acorns in the B/NP were significantly taller than those in the BMG/BMGD ($p<0.05$) or BMGDC ($p<0.001$) treatments, but seedling heights in the latter two treatments did not differ significantly. Surface-acorn seedlings did not differ in height between the B/NP and BMG/BMGD treatments at AC.

Herbaceous biomass of annuals at AE was significantly higher (4.5 times) in the exclosures than the control and was significantly higher (5.2 to 11.7 times) than biomass in all three

Site	Mice	Gophers	Planting Position	Sample Size	P_{sd}
Both sites				2842	0.24
American Canyon				1610	0.37
		+		543	0.22
			Surface	136	0.09
			Buried	407	0.27
		-		1067	0.44
			Surface	404	0.30
			Buried	663	0.53
Agua Escondido				1232	0.06
	+			669	0.03
	-			563	0.10

Table 6—*Hierarchical classification of factors affecting seedling establishment at American Canyon and Agua Escondido experimental sites, based on hierarchical logistic regression analysis. Sample size is the number of seedlings in the first year. P_{sd} is the proportion of seedlings that survived three years. Format is identical to that used in Table 1.*

Table 7—*Heights (cm) of 4 -year seedlings originating from surface and buried acorns in the BMG/BMGD, and BMGDC treatments at each site. Values are means and standard deviations with sample sizes in parentheses.*

	Treatments[1]					
	B/NP		BMG/BMGD		BMGDC	
Seedling origin[2]	Surface	Buried	Surface	Buried	Surface	Buried
Site						
AC	8.8±2.5a[3] (32)	9.3±2.5a (50)	8.0±1.9b (6)	6.8±2.6b (16)	—	5.4± 1.7b (28)
AE	7.7± 2.7a (8)	8.9± 3.3a (17)	—	—	—	—

[1]B = birds; G = gophers; M = mice; NP = no predators.
[2]AC = American Canyon; AE = Agua Escondido.
[3]Values in rows and columns not followed by the same letter are significantly different at least at p5 0.05.

Table 8—*Herbaceous biomass and litter weight (in grams) in the subexclosure, exclosure and control predator treatments at each site. Values are means and standard deviations for fifteen 20 by 20 cm plots.*

	AC[1]		AE[1]	
Treatment	Herbaceous biomass	Litter	Herbaceous biomass	Litter
Subexclosures	6.3±3.8a[2]	11.8±8.0a	75.0±33.9a	21.2±14.6a
Exclosures	14.2±14.1b	30.2±12.5b	73.7±16.5a	20.0±14.6a
Control	12.9±13.1b	18.6±10.5c	16.0±12.0b	12.9±9.2b

[1]Values in columns not followed by the same letter are significantly different at least at p5 0.05.
[2]AC = American Canyon; AE = Agua Escondido.

treatments at AC (table 8). The very high biomass production at AE was the result of rapid succession to ripgut brome (*Bromus diandrus)* after exclosure construction.

At AC, litter weight was significantly different among all the treatments (table 8). At AE litter weight was significantly higher in the subexclosures and exclosures than the control ($p<0.05$).

DISCUSSION

Compared to the seedling recruitment regression tree (table 1), the seedling survival regression tree is much less complex (table 6): it has fewer variables and strata, and there are fewer branches in the lower strata. In addition, the total G^2 reduction differs considerably between the two regression trees: 43.6 and 70 percent for the seedling survival and seedling recruitment trees, respectively. The lower G^2 reduction of the seedling survival tree suggests that variables useful for predicting seedling recruitment were less useful for predicting seedling survival. Unmeasured variables that may have played a role in seedling mortality include insect herbivory, drought, competition and soil microsite conditions (Griffin 1980).

Site was the most influential variable affecting both Ps and Psd. Compared to AC, Psd was much lower at AE even though initial rates of seedling recruitment were very similar (0.33 vs 0.38, table 1). We attribute these marked site differences in Psd to unusually heavy competition between *B. diandrus* and oak seedlings at AE. Gordon and others (1989) found that high densities of *B. diandrus* suppressed blue oak seedling emergence and root growth by reducing local water availability. They speculated that competition with annuals in combination with shoot suppression in drought years may result in a reduction in growth and ultimately the ability to resprout. Griffin (1971) also observed higher mortality of blue oak seedlings growing with annuals than those in cleared plots. At AE numerous seedlings were unable to resprout through the dense grass litter and thatch and those that did were tall and often etiolated. Many more never penetrated the thatch, and ultimately most died.

Rodents were the most important predators of both acorns and seedlings, but they were relatively more important as seedling predators. At AC gophers were the primary source of seedling losses. Griffin (1980) also noted heavy losses of valley oak (*Quercus lobata*) seedlings to gophers. Mice did, however, continue to consume seedlings at AC. Seedlings near runways were often dug up and the roots eaten but the stems left intact. At AE mouse herbivory was the most important mortality factor because dense grass at this site probably supported elevated densities of rodents. We noted, for example, that in some years mice stripped bark from previously browsed, low-growing oak saplings in the deer exclosure.

The year of acorn planting, an important variable in seedling recruitment, did not appear in the seedling survival tree. Acorn planting position, another significant variable in the recruitment stage, appeared only in the seedling survival tree at

AC, suggesting that seedlings from buried acorns may have developed more extensive root systems than seedlings from surface-sown acorns. Other variables that did not enter the model include northness, canopy cover, birds, deer and cattle.

Seedlings at both sites grew slowly during the first 5 years although growth almost certainly was reduced by successive years of below-average precipitation. If growth rates observed here are representative of blue oak seedlings in the study area, seedlings are likely exposed to an extended period of browsing before they can make the transition to larger size classes. Extensive stand surveys[3] indicate that shrubby, suppressed individuals <1 m are common in the region. These only rarely make the transition from shrubs to small trees (Harvey 1989). Combined high acorn and seedling mortality coupled with low growth rates and browsing severely limit the number of new trees recruited into these stands.

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Oak Tree Planting Project[1]

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Abstract: An Oak Tree Planting Project was conducted during 1989/90 in San Luis Obispo County by the Integrated Hardwood Range Management Program (IHRMP)/Central Coast. The local media and an IHRMP workshop were used to publicize the Planting Project and give information on the status of oaks (*Quercus* spp.) in California and oak planting techniques. Outreach efforts resulted in participation in the Oak Tree Planting Project by homeowners and ranchers as well as by 4-H, environmental, school, community, and homeowner-association groups: over 3,500 acorns were planted at about 1,200 sites (three acorns per site). The Oak Tree Planting Project provided a good opportunity for community awareness and involvement in helping ensure that oak trees will be around for future Californians to enjoy.

California has lost about one million acres of oak woodlands during the past 45 years to development and other causes of removal (Bolsinger 1988). In addition to this, several species of oaks are not regenerating well (Griffin 1971, 1976, Muick and Bartolome 1986). In response to these concerns the IHRMP was developed in 1986 to maintain and where possible increase the acreage of California's oak rangeland resource to provide wildlife habitat, recreational opportunities, wood and livestock products, high quality water supply, and aesthetic value. The IHRMP realizes the importance of involving and educating the public and that restoration of the oak woodlands can be accomplished in part through the use of educational programs and planting projects.

The Oak Tree Planting Project was an educational program conducted in San Luis Obispo County by the IHRMP/Central Coast. It was designed to use public participation to increase awareness of the importance of oak woodlands. It was felt that a hands-on experience would leave a valuable impression on the individuals participating in the project, as well as increase declining oak populations.

PROJECT DESCRIPTION AND IMPLEMENTATION

The objectives of the Oak Tree Planting Project were to (1) inform the people of San Luis Obispo county of the importance of having oak trees on and surrounding their property, (2) replace oak trees in some places where they were no longer growing, and (3) monitor growth and survival of the planted trees. The Oak Tree Planting Project was broken into four phases.

Phase One.—A workshop was held in September 1989 to generate interest in the project and to discuss the importance of oaks in our environment. This workshop provided information on the value of oaks, oak identification, collection and storage of acorns, oak planting and protection techniques, weed control, irrigation, and an example of a successful planting project on the central coast.

Phase Two.—The IHRMP/Central Coast collected acorns from the three common tree-sized oaks that occur in San Luis Obispo County: valley oak (*Quercus lobata*), blue oak (*Q. douglasii*), and coast live oak (*Q. agrifolia*). The acorns were stored for later planting by IHRMP and to give to homeowners, ranchers, and groups that needed acorns for planting.

Phase Three.—At the start of the oak-planting season in December 1989, a publicity campaign was launched (local newspapers, radio, and IHRMP newsletter) (fig. 1) to inform local residents of the Oak Planting Project and the availability of acorns and planting directions from the IHRMP. Also, a follow-up letter was sent to workshop participants to determine what assistance they might need for planting.

Phase Four.—Beginning in December 1989, acorns were planted. The IHRMP established two demonstration sites in San Luis Obispo County. Each demonstration site consisted of 40 planting sites, each cleared of weeds and protected with a wire exclosure. The IHRMP also coordinated planting activities of individuals and groups by providing acorns and helping to connect acorn planters with planting sites and available planting sites with planters.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

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Figure 1—The Oak Tree Planting Project and the availability of information on oak planting was advertised by newspaper, radio, and newsletter.

PROJECT RESULTS

About 70 people attended the workshop of which 15 signed up to participate in planting. The greatest response was generated from radio and newspaper publicity at the start of the planting season. Many individuals and several agencies and community groups participated in planting activities (fig. 2).

The California Conservation Corps (CCC) assisted with the demonstration sites. They dug holes, planted acorns, constructed and installed aluminum screen protection cages, and cleared competing weeds from around each planting site. Several San Luis Obispo County 4-H groups volunteered their time to individuals and community groups with large areas to plant (fig. 3). For example, the 4-H groups helped the San Luis Obispo County Recreation and Parks Department plant a site at the Lopez Lake Recreation Area, and assisted the Toucan Terrace

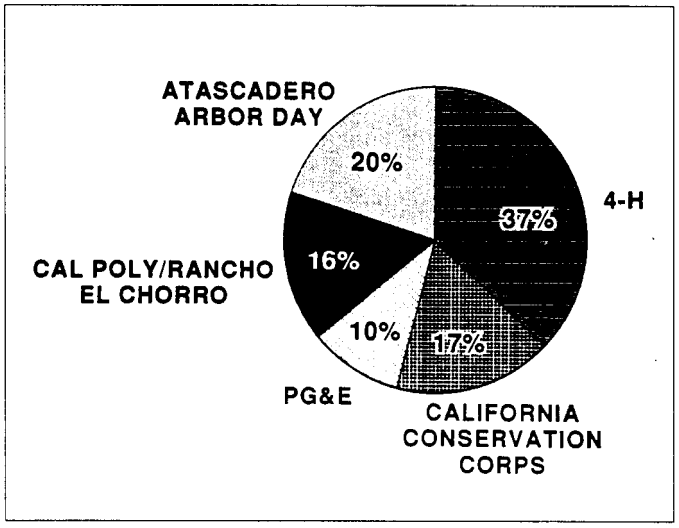


Figure 2—Newspapers, radio, and workshop publicity resulted in participation in the IHRMP Oak Tree Planting Project by individuals, several agencies, and community groups.



Figure 3—UCCE 4-H assisted community groups with planting.

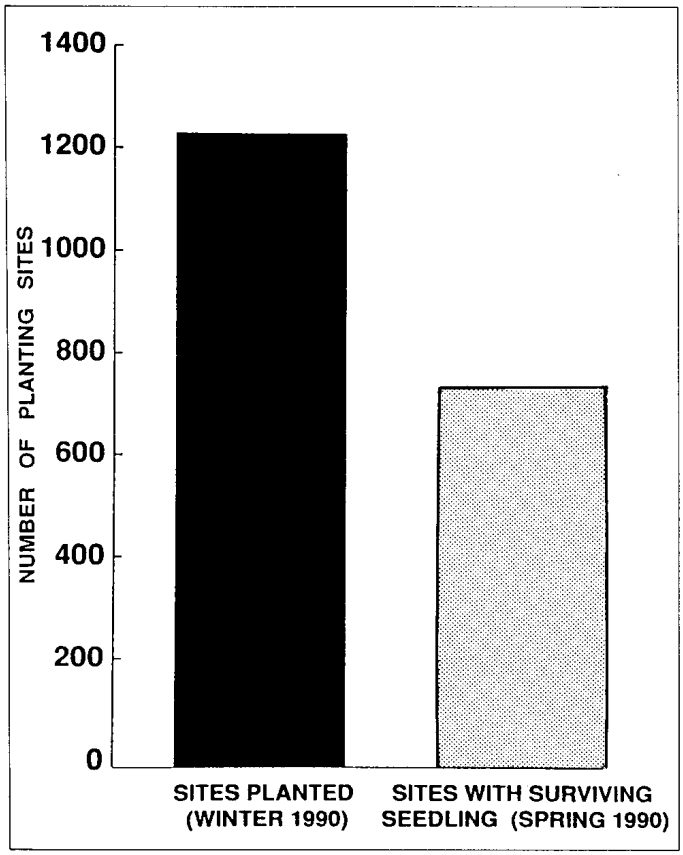


Figure 4—The participants in the Oak Tree Planting Project, planted and protected over 3,500 acorns at about 1,200 planting sites (three acorns per site) in winter 1989/90. Most plantings produced a healthy oak seedling.

Homeowners Association plant and protect 50 live oaks on 27 acres of "green space" along Highway 101 in Pismo Beach, California. PG&E sponsored a day of tree planting on the Santa Margarita Ranch just north of San Luis Obispo; approximately 10 volunteers planted 100 valley and blue oaks.

Several spin-offs were generated by the Oak Tree Planting Project. For example, Natural Resource Management (NRM) students from California Polytechnic State University, San Luis Obispo, explained the values of oaks and planting techniques to a class of 6th-grade students in San Luis Obispo County. The following week, the 6th graders and NRM students met at Rancho El Chorro Environmental Education Center in San Luis Obispo County and planted 80 coast live oaks. The 6th graders will help care for the seedlings and monitor survival and growth. The NRM students hope this becomes a long-term, on-going project between Cal Poly and Rancho El Chorro, with more planting and research.

In all, the IHRMP gave away over 3,500 acorns and about 1,200 sites (three acorns per site) were planted and protected (fig. 4). Of those sites planted, response to a mail questionnaire indicated that over half germinated and were doing well in June 1990.

FUTURE CONSIDERATIONS AND RECOMMENDATIONS

Our efforts in the Oak Tree Planting Project were very well rewarded. This type of project is an ideal opportunity for community awareness and involvement, as well as a method to increase oak populations. It was apparent that best results were achieved when careful instructions and on-site demonstrations of acorn planting and protection techniques were provided to participants. Furthermore, a long-term commitment to the protection and maintenance of the planting sites seems necessary for long-term survival of the planted oak trees.

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Oak Woodland Artificial Regeneration Correlating Soil Moisture to Seedling Survival[1]

Tim R. Plumb Karl Kraus[2]

Abstract: Broadleaf P4, an hydrogel soil amendment, was tested under field and greenhouse conditions to determine if it would increase the survival and growth of coast live oak (*Quercus agrifolia*) and blue oak (*Q. douglasii*) seedlings during periods of moisture stress. Broadleaf P4 had little positive effect on seedling survival in the field, and it actually appeared to reduce survival of blue oak. Low survival was not surprising, however, because of the unfavorable growing conditions during the late winter and spring 1989. Under greenhouse conditions, coast live oak grew twice as tall as blue oak. This growth differential was expected, and it is well documented in the literature. P4 enhanced coast live oak seedling height growth with biweekly and triweekly watering, but it inhibited blue oak at all levels.

A number of oak regeneration problems have been identified in California. Poor regeneration is attributed to factors ranging from poor acorn crops and unsatisfactory fall and winter weather conditions to predation by all sizes and types of wildlife and domestic animals, to summer drought (Griffin 1971; Plumb 1980; Plumb and McDonald 198 1). Poor oak seedling establishment and survival the last 4 years (1986-1990) can partly be attributed to inadequate rainfall.

Water-absorbing polymers, used as soil amendments, have been proposed to be an aid to plant growth under conditions of moisture stress (Johnson 1984; Johnson and Veltkamp 1985). Synthetic chemicals such as Broadleaf P4,[3] that can function as super absorbers, include polyvinylalcohols, starch co-polymers, and polyacrylamide compounds (Johnson 1984). Broadleaf P4 is a hydrogel soil amendment composed of polyacrylamide polymers. These gels have the capacity to absorb 200-400 times their weight in water (figure 1), and they can last 5-10 years in the soil. As the soil dries, the gel releases over 95 percent of the water back to the soil (Piper 1989). As the polymers absorb and release water, they expand and contract which improves soil structure and increases air spaces in the soil favoring root development, especially in fine-textured soils. Irrigation can be reduced, and a soil's increased water-holding capacity should help overcome periods of drought, especially with sandy soils that have low moisture-holding capacity.

The objective of this study was to enhance the survival and growth of coast live oak (*Quercus agrifolia*) and blue oak (*Q. douglasii*) by improving soil moisture conditions. Three concentrations of the soil amendment Broadleaf P4 were tested under field and greenhouse conditions. Increased seedling survival would be an important advance in the successful regeneration and survival of oaks on harsh sites or during dry years.

METHODS

Greenhouse Test

This test was conducted in the Natural Resources Management Greenhouse at Cal Poly, San Luis Obispo, California, in winter, 1989. Soil treatments included untreated controls and soils containing at the rates of 3.2, 4.0, and 5.8 g of P4 per 0.52 cubic foot of soil. The soils were collected from under coast live oak or blue oak trees on the Blythe Ranch near Paso Robles (Plumb and Hannah 1991). The soil-P4 mix was placed in 4 x 14-inch PVC pipes and seeded with pre-germinated coast live oak or blue oak acorns. Each P4 concentration was repeated forty-five times for a total of 360 plants. The plants were mist-watered until germination. After germination, 1/3 of the seedlings were watered weekly, 1/3 biweekly, and 1/3 triweekly. Seedling survival and height growth were monitored for several months. A small soil moisture trial was also run to determine how much water would remain in the different P4 soil mixes

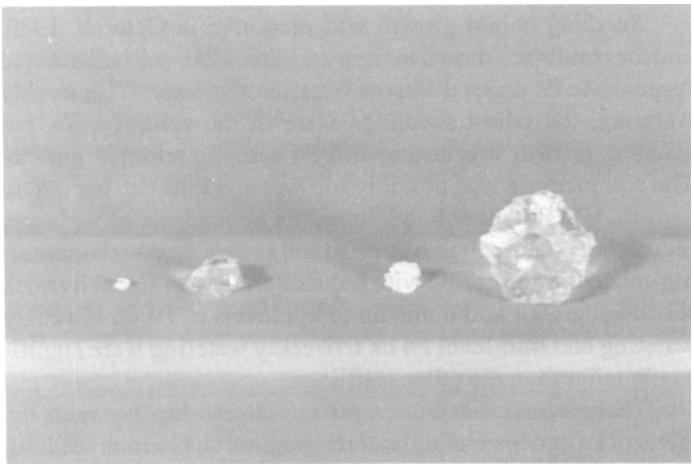


Figure 1—The massive water absorbing capacity of P4 is illustrated above with large and small granules of hydrated and unhydrated P4.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

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[3]Broadleaf P4 is a trade name for polyacrylamide co-polymer. Its name is mentioned for information and does not imply endorsement by the authors.

when no plants were present. Two to three planting tubes of coast live oak and blue oak soils containing the three concentrations of P4 were watered to saturation and then sampled at weekly intervals.

Field Study

The same concentrations of P4 were evaluated at the Blythe Ranch. The soil from each seed spot was removed with a 4-inch power auger, mixed with P4, and returned to the planting hole. Two acorns were planted horizontally below the soil surface at each seed spot during the period from February to March, 1989. The seed spots were protected with a 4-inch diameter small mammal exclosure made of 1/4-inch hardware cloth. The seed spots were then watered with a quart of water to ensure that the P-4 was hydrated. The seed spots were located both in the open and under the canopy of five coast live oak and five blue oak trees. The P4 treatments were replicated four times and randomly assigned to seed spots in a 4 by 4 grid for a total of 160 spots per species.

RESULTS AND DISCUSSION

Greenhouse Test

Several of the oak seedlings were excavated to determine the distribution of roots and P4 in the soil medium. Figure 2 illustrates a coast live oak seedling grown in the high concentration of P4. Both large and small roots readily grow through the globules of hydrated P4. The effect of P4 on soil moisture after three weeks of drying (figure 3) graphically illustrates the increased level of potentially available water with the increasing concentrations of P4. The coast live oak soils were sandier than those associated with blue oak and, therefore, had lower moisture holding capacity and should benefit the most from P4 water enhancement.

Seedling height growth was measured in October, 1989, and the results are shown in figure 4. Coast live oak had a mixed response to P4 under different watering regimes. With weekly watering, the tallest seedlings were in the control soils, but seedling growth was erratic and P4 actually retarded growth. The soil medium was possibly too wet and thus detrimental to growth. On the other hand, based on an analysis of variance, increasing plant growth was positively correlated with increasing concentrations of P4 with reduced watering. Coast live oak seedlings grown at the mid and high levels of P4 on biweekly watering and mid-level P4 on triweekly watering were significantly taller than the other seedlings.

There was a clearcut negative relationship between the effect of P4 and increasing watering regime on blue oak seedling growth. Because blue oak is generally believed to grow on more xeric sites than coast live oak (Matsuda and McBride 1986), it is possible that the P4 soils were too moist for satisfactory blue oak growth.

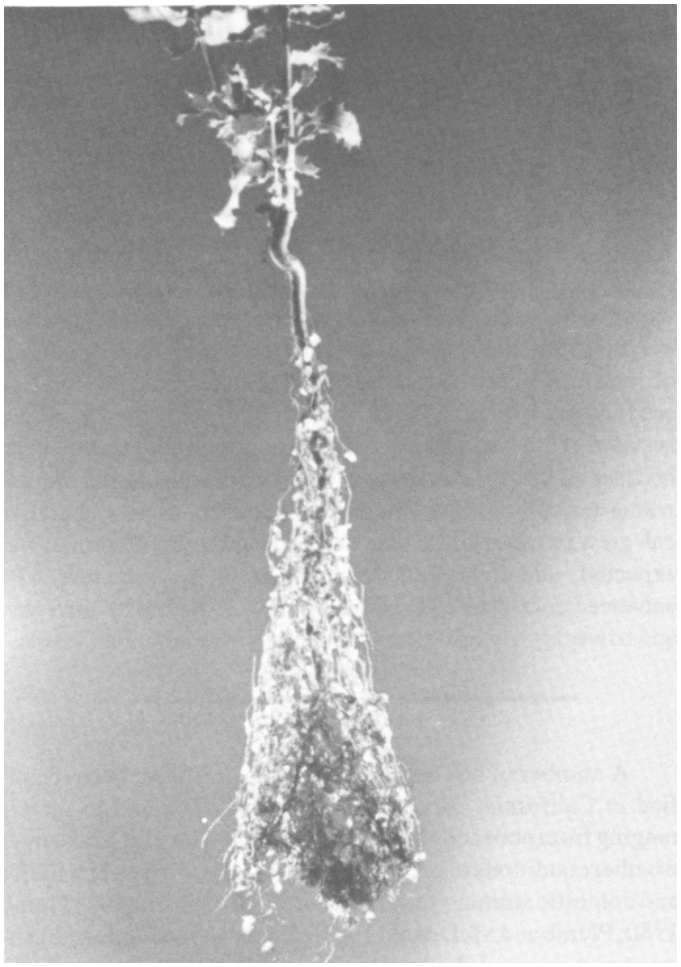


Figure 2—Both large and small roots readily grow through the globules of hydrated P4. This is illustrated here where the soil has been removed and only the gelatin-like P4 and roots remain.

Field Study

The results of P4 on seedling survival are shown in figure 5. There was no significant difference in seedling survival for any of the treatment variables including species, P4 concentration, and light exposure. If anything, P4 had somewhat of an inhibiting effect on survival. These results do not match the positive response that others have obtained. Also, they do not support the positive results obtained with coast live oak in the greenhouse test.

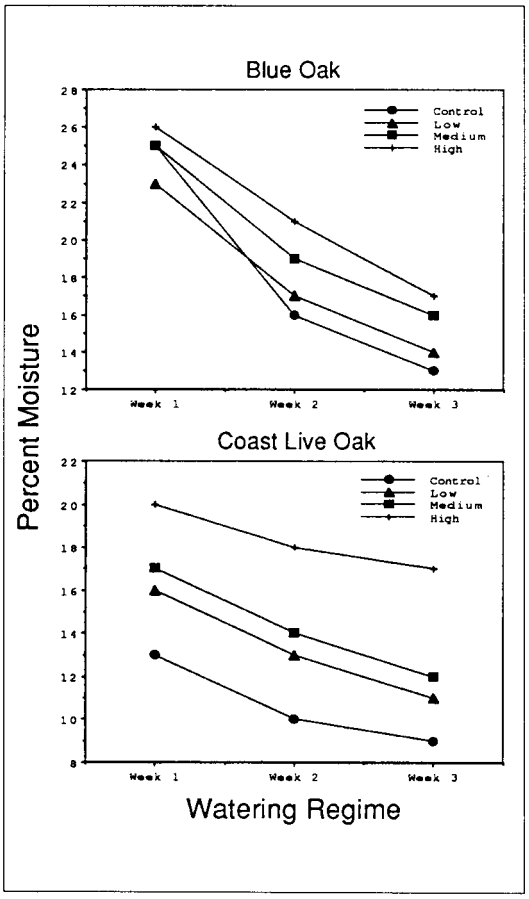


Figure 3—These graphs represent changes in percent soil moisture over a three week drying period for blue oak and coast live oak soils for different P4 concentrations.

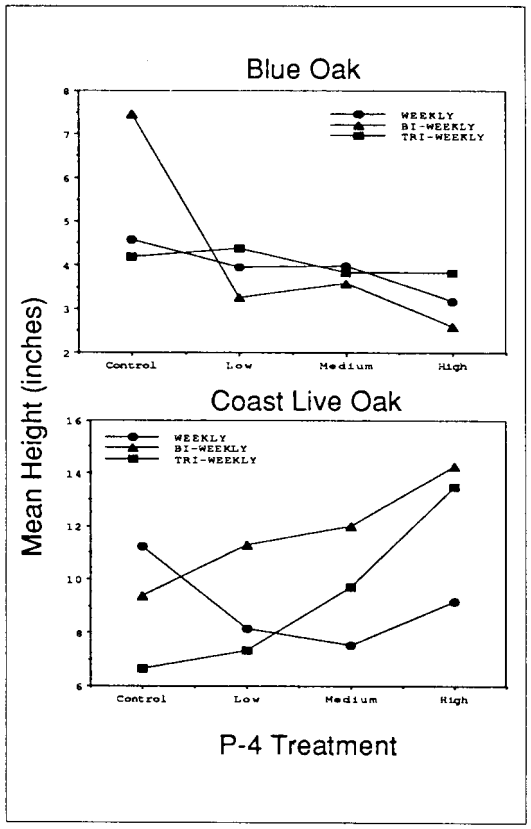


Figure 4—The effect of different concentrations of P4 on coast live oak and blue oak seedling height growth under three watering regimes are illustrated above. Coast live oak, but not blue oak, responses were significantly different, from the control treatment.

CONCLUSION

Although coast live oak responded favorably to P4 under greenhouse conditions, this positive effect did not carry over to the field study. The drought conditions in 1989 may have been too severe to have allowed any advantage of P4 to be demonstrated. More field testing should be done with coast live oak to further explore the effects of P4 on seedling survival. Some of the results of this work indicate that P4 may have kept the soil too moist for good blue oak growth; but this is contradicted by other results in this study where the available soil moisture was low, and there was still no positive effect of P4 on blue oak survival.

Finally, P4 shows enough promise that further testing should be done to determine if it can be used to enhance seedling survival.

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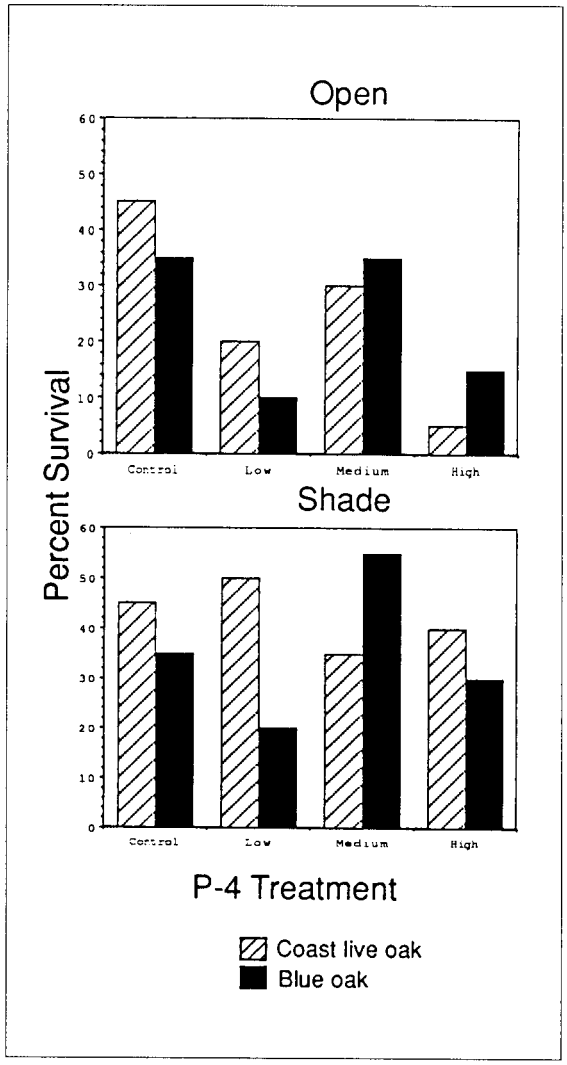
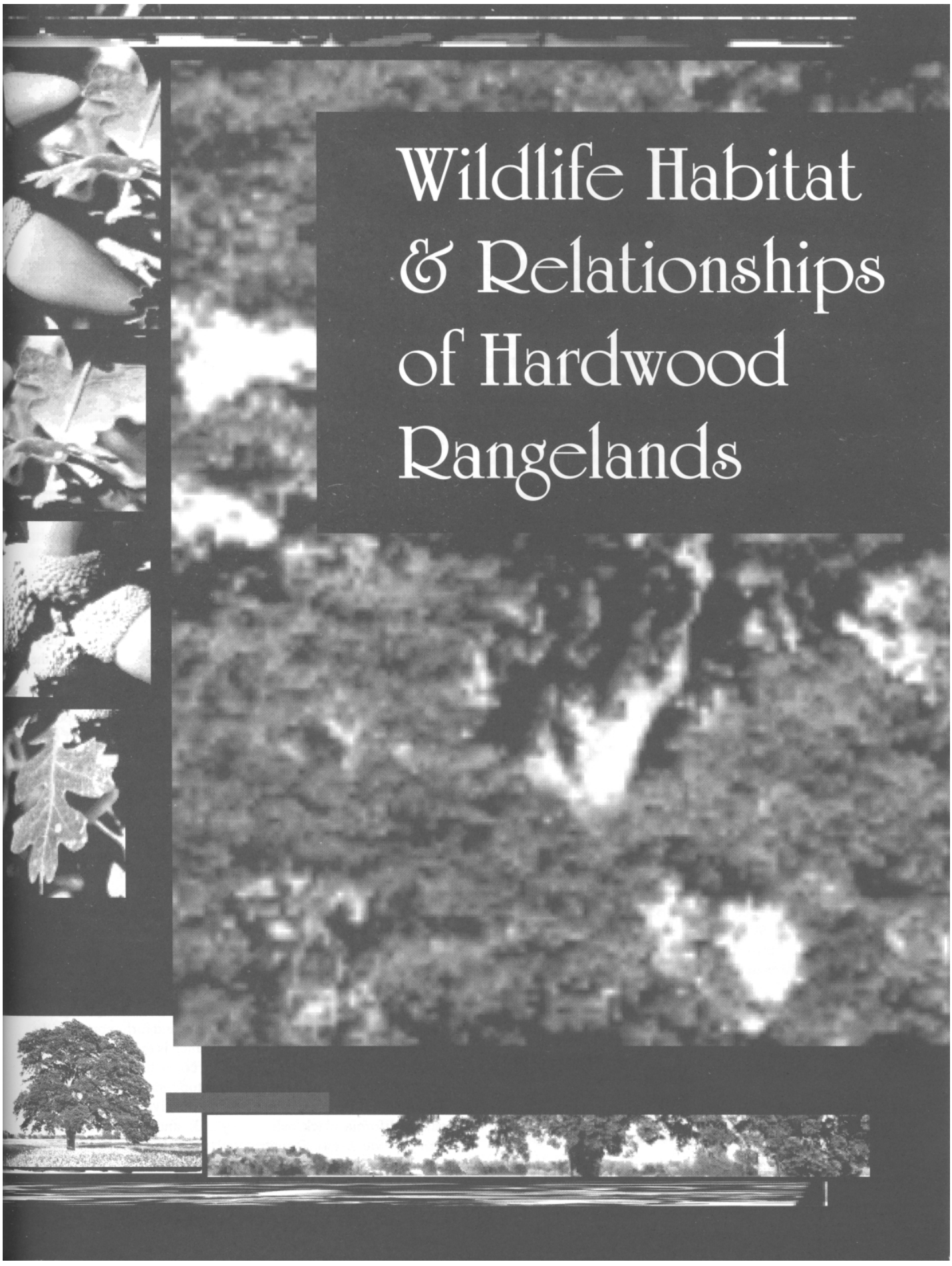


Figure 5—Blue oak and coast live oak pre-germinated acorns were planted in the ground in shaded and open areas. Seedling survival was determined for the first growing season. These graphs represent percent seedling survival for each Broadleaf P4 treatment in shaded and open exposures.

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Wildlife Habitat & Relationships of Hardwood Rangelands

Influence of Scale on the Management of Wildlife in California Oak Woodlands[1]

William M. Block Michael L. Morrison[2]

Abstract: Distributions, abundances, and patterns of resource use of amphibians, reptiles, birds, and small mammals varied spatially and temporally in California oak woodlands. Spatial variations occurred within stands, between stands of a similar type (e.g., canyon live oak [*Quercus chrysolepis*], blue oak [*Q. douglasii*], or valley oak [*Q. lobata*]), between stand types, and between geographic areas. Temporal variations occurred between seasons and years. Management of wildlife in oak woodlands should be based on research that details seasonal and temporal variations in habitat and resource use. Species that exhibit pronounced geographic variations in habitat use will require different management strategies, depending on location. Providing favorable conditions for breeding will not ensure that requirements for species occurring during nonbreeding periods will be met as well.

California oak woodlands extend from the northern to the southern boundaries of the state and encompass over 2.5 million hectares. Within this area exists a number of vegetation types distinguished by differences in the composition and structure of the woody vegetation (Allen 1990). This vegetative diversity provides a wide spectrum of conditions suitable for occupancy by many species of wildlife (Block and Morrison 1990, Block and others 1990). Actual occupancy of suitable habitat is further influenced by historic distributional patterns and modified by various biotic (e.g., food abundance and availability, density of the species, competition, predation) and abiotic (e.g., weather, fire, anthropogenic) processes.

Occupancy and specific resource-use patterns of wildlife are not static through time and space (Block 1989, Block and others 1988). With birds, for example, some species occur in a location throughout the year, whereas other species may be present only during breeding, winter, or migration. Resource-use patterns of many amphibians, reptiles, birds, and mammals shift within and between seasons (Block and Morrison 1990, Block and others 1988). These shifts may be responses to changing needs during different phases of species' life histories or responses to shifts in the quantity and quality of the resource base.

Knowledge of spatial and temporal variations in habitat use is needed to elucidate variations in populations, habitat associations, and community structure and to provide a basis for predicting effects of environmental perturbations on individual species and entire assemblages of species.

This paper examines spatial and temporal relationships of wildlife in oak woodlands. We draw upon three years of field data collected on population numbers and macrohabitat associations of amphibians, reptiles, birds, and small mammals from four study areas, three primary and one ancillary, representing a diversity of oak-woodland ecosystems. Our objectives are to categorize species according to general macrohabitat associations and to determine the spatial patterns in species distributions.

STUDY AREAS

The three primary study areas were: (1) San Joaquin Experimental Range, Madera County; (2) Sierra Foothill Range Field Station, Yuba County; and (3) Tejon Ranch, Kern County. Both San Joaquin and Sierra Foothill are in the foothills of the Sierra Nevada with Sierra Foothill lying northeast of Marysville and San Joaquin north of Fresno. Tejon Ranch is located in the Tehachapi Mountains east of the town of Lebec. The topography, and structure and composition of the vegetation of each study area differs from the others. San Joaquin is characterized by a relatively flat terrain with rolling hills on a general southwest-facing slope. The overstory is dominated by blue oak, interior live oak (*Q. wislizenii*), and gray pine (*Pinus sabiniana*) with buckbrush (*Ceanothus cuneatus),* chaparral whitethorn (*C. leucodermis*), redberry (*Rhamnus crocea*), coffeeberry (*R. californicus*), and poison oak (*Toxicodendron diversiloba*) comprising the woody understory. Annual grasses and forbs dominate the herbaceous layer. Topography is steeper at Sierra Foothill with moderate slopes facing in a general westerly direction. Dominant overstory trees include blue oak, interior live oak, gray pine, California black oak (*Q. kelloggii*), valley oak, and ponderosa pine (*P. ponderosa*). Major shrubs are buckbrush, coffeeberry, toyon (*Heteromeles arbutifolia*), and poison oak; annual and perennial grasses and forbs comprise the herbaceous layer. Terrain at Tejon Ranch is more mountainous than at Sierra Foothill or San Joaquin, consisting of steep slopes facing in all cardinal directions. This topography contributed to a more diverse flora as blue oak, interior live oak, canyon live oak, California black oak, valley oak, and Brewer's oak (*Q. garryana* var. *breweri*) contributed to the overstory. The woody

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2 1990, Davis, California.

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understory consisted of buckbrush, redberry, chamise (*Adenostoma fasciculatum*), big-berry manzanita (*Arctostaphylos glauca),* and mountain mahogany (*Cercocarpus betuloides*). Annual and perennial grasses and forbs comprised the herbaceous understory. More detailed descriptions of the study areas are given by Block (1989).

We also report additional data collected from a fourth site, Mad River, located in southern Humboldt County near the town of Dinsmore. Vegetation pattern was a mosaic consisting of stands of California black oak and Oregon white oak (*Quercus garryana*) interspersed among Douglas-fir (*Pseudotsuga menziesii*) forests.

METHODS

Sampling intensity for amphibians, reptiles, and small mammals described below was greater at Tejon Ranch than at San Joaquin or Sierra Foothill. Because San Joaquin and Sierra Foothill were relatively small in total area (1,800-2,200 ha), we were limited in the placement of spatially-independent sampling grids and surveys. In contrast, oak woodlands covered about 40,000 ha at Tejon Ranch, consequently we had a greater area to place more grids and conduct more surveys. Moreover, stands of major oak species at Tejon Ranch were often monotypic providing an opportunity to test for differences among these distinct stand types.

Time-constraint searches (Welsh 1987) were done at all four study areas to locate amphibians and reptiles during spring and fall. This method entailed searching randomly for animals under, on, or in logs, rocks, leaf litter, trees, and bare ground for 4-person hours. The amount of area covered during each search varied, depending on the abundance of suitable substrates. Once an animal was located, time was halted temporarily while the animal was identified and measured, and general characteristics of the macrohabitat were recorded. We conducted 28 time-constraint searches at Tejon Ranch, nine at Sierra Foothill, and seven each at Mad River and San Joaquin. Searches at Tejon Ranch were done within five distinct stand types: blue oak (four searches), valley oak (7), canyon live oak (7), interior live oak (5), and California black oak (5). Searches at the other study areas were done in a variety of stand types representative of the variations in vegetation that occurred there. Because the number of searches within all study areas but Tejon Ranch was relatively small (seven to nine), we did not separate stand types for statistical analyses. Searches conducted within these areas were pooled to provide a general description of the herpetofauna present. We first compared captures among stand types at Tejon Ranch to determine if species were closely associated with a specific vegetation type. We then pooled all searches from Tejon Ranch and compared captures among study areas. We compared capture frequencies among stand types at Tejon Ranch and among the four study areas using *G*-tests (Sokal and Rohlf 1969; p. 559).

Amphibians, reptiles, and small mammal populations were also sampled using pitfall traps. These traps consisted of 3.8-liter buckets that were sunk to ground level and covered with a square piece of plywood elevated 5-10 cm above the lip of the bucket (Block and others [1988] provide a more detailed discussion of the methods). Traps were in 6 x 6 grids with 20-meter spacing between buckets. We placed 13 grids at Tejon Ranch, and four each at Sierra Foothill and San Joaquin for a total of 740 traps. Traps were monitored at Tejon Ranch from 4 January to 20 May 1987, 10 December 1987 to 20 June 1988, and 10 November 1988 to 30 April 1989; traps were monitored at Sierra Foothill and San Joaquin from mid-January to mid-March 1988, and from 10 November 1988 to 15 January 1989. The total trapping effort included 98,592 trap days and nights. Traps were checked periodically for captured animals. Captures were identified and removed from the trapping grid. We used *G*-tests to compare frequencies of captures among study areas. To determine plant associations of individual species and of each major taxon (amphibian, reptile, and small mammal), we estimated cover by woody vegetation within each grid using the point-intercept method (Heady and others 1959) centered at each trapping station. We placed a 10-meter long intercept along a random bearing with 1-meter spacings between points. Percent cover by each major tree species (blue oak, interior live oak, canyon live oak, California black oak, valley oak, and gray pine) was calculated as the percentage of the points (360 per grid) covered by that species. We calculated product-moment correlations (Sokal and Rohlf 1969; p. 498-508) to measure associations of different species of amphibians, reptile, and small mammals and for each major taxon (amphibian, reptile, small mammal) to these tree species.

We also used Sherman live traps to sample small mammal populations. Traps were in 8 x 8 grids with 15-meter spacings between traps. Twelve grids were placed at Tejon Ranch and four each at San Joaquin and Sierra Foothill. We trapped small mammals at Tejon Ranch from July through December 1986; March, April, November, and December 1987; November and December 1988; and January through March 1989. Trapping was done at Sierra Foothill during April 1987, March 1988, and December 1988 and at San Joaquin during April 1987, December 1988, and from October 1989 through April 1990. Total trapping effort was 21,392 trap nights. Captures were identified, aged, measured, marked by toe clipping, and released. We measured vegetation using the same point-intercept method used in pitfall grids except that 640 points (10 points at 64 stations) were sampled within each grid. Analytic methods for live-trap data followed those described for pitfall traps.

Bird populations were sampled using a point-count procedure (Verner 1985). This method entailed an observer recording all birds detected by sight or sound within a 100-meter radius of the counting station. We sampled birds at 100 counting stations at each of the three study areas. More detailed descriptions of the methods for the establishment of stations and of the actual counting procedures are described in detail by Block (1989). Each point was sampled three times during each breeding season and five times during each nonbreeding season. We counted birds at Tejon Ranch during the 1986, 1987, and 1988 breeding

seasons and the 1986-87 and 1987-88 nonbreeding seasons. Counts were done at Sierra Foothill and San Joaquin during the 1987 and 1988 breeding and the 1987-88 nonbreeding seasons. A total of 4040 point counts were conducted over the duration of the study. To compare the rankings of total counts (i.e., numbers of detections) of species between study areas, years, and seasons, we calculated Spearman rank-correlation coefficients (Marascuilo and McSweeny 1977; p. 431-439). We restricted the species used in the analyses to those for which >100 total detections across all study areas were recorded. We so restricted our analyses because including uncommon and incidental species would have increased sample sizes and rendered the chance of observing significant correlations an artifact of sample size alone.

We also collected data pertaining to tree-species use by common species of birds found at each study area. We limited this analysis to common species to ensure adequate samples for statistical analysis (cf. Block and others 1987, Morrison 1988). We used log-linear analyses (Fienberg 1980; p. 13) to compare the frequency of use of major tree species by these birds among study areas, seasons, and years. Analyses done on birds present only during breeding or winter examined effects of study area, year, and their interaction.

RESULTS

Time-constraint Surveys

We located 428 individuals representing 17 species of herpetofauna during time-constraint searches including three salamanders, one frog, seven lizards, and six snakes (table 1). Significantly more salamanders were captured at Tejon Ranch (102) than at all of the other areas combined (21). These salamanders at Tejon Ranch occurred in association with canyon live oak, valley oak, and California black oak. Few salamanders were caught in association with blue oak or interior live oak at Tejon Ranch. Western fence lizards were the most frequently captured lizard at all study areas (table 1). Gilbert's skinks were captured frequently at Tejon Ranch and Sierra Foothill, whereas western skinks were captured at Sierra Foothill and Mad River (table 1). Southern alligator lizards were captured frequently at Sierra Foothill, whereas northern alligator lizards were common at Mad River. We found southern alligator lizards at Tejon Ranch, but caught none at San Joaquin even though they were observed at the field station during other times. Few snakes of any species were captured (table 1). Failure to capture snakes was a reflection of the inadequacy of this method to sample their populations.

Pitfall Traps

We captured 1,363 individuals representing 27 species during pitfall trapping including three salamanders, one newt, two frogs, two toads, seven lizards, one snake, and 11 small mammals (table 2). Western fence lizards, Gilbert's skinks, brush mice, deer mice, and pinyon mice were the most frequently captured animals accounting for about 73 percent of all captures. Relative frequencies of species captured differed significantly among grids within each study area (G-tests, $P < 0.01$). Relative frequencies of captures also differed significantly among the three study areas (G-test, $P < 0.01$). Amphibians were most closely associated with canyon live oak ($r = 0.67$, $P < 0.01$) and captures of mammals were significantly correlated with valley oaks (r=0.67, P<0.01). We found no significant associations of reptiles with stand type or species of tree. Black-bellied slender salamanders ($r = 0.66$) and yellow-blotched ensatinas (*Ensatina eschscholtzii croceater)* ($r = 0.69$) were both positively associated ($P < 0.01$) with canyon live oak. The California slender salamander (r=0.72) was positively associated ($P < 0.01$) with gray pine. Western fence lizards ($r = 0.69$) and western skinks (r= 0.59) were both positively associated *(P*<0.01) with blue oak. Brush mice ($r = 0.56$) and deer mice ($r = 0.82$) were positively associated ($P < 0.01$) with valley oak, and brush mice ($r = 0.59$) also showed a positive association ($P < 0.01$) to California black oak. The western harvest mouse was positively associated ($P < 0.01$) with blue oak. No other species was significantly associated or disassociated with tree species.

Live Traps

Live trapping resulted in 1,412 captures of 728 individuals representing 11 species of small mammals. Brush, pinyon, and deer mice, accounted for about 82 percent of all captures (table 3). Relative frequencies of captures differed among grids within and among study areas. Only two species were positively associated with a plant species: deer mice which were found in greater numbers in valley oak stands ($r = 0.74$, $P < 0.01$), and California pocket mice which appeared closely associated with gray pine ($r = 0.74$, $P < 0.01$). No other species exhibited a significant association ($P < 0.05$) with stand type.

Birds

Bird counts resulted in 33,798 detections of 124 species. Three general trends emerged from comparisons of rankings of species by numbers of detections (table 4). First, rankings were significantly correlated ($P < 0.05$) for 16 of 21 breeding season comparisons. The exceptions to this trend were for uncorrelated rankings of birds between Tejon Ranch and Sierra Foothill (table 4). Second, rankings of species were significantly correlated for all nonbreeding comparisons. Third, there was a general lack of concordance in rankings of bird species between seasons as no r_s was >0.41. The only significant correlations were between breeding birds at San Joaquin and nonbreeding birds at Tejon

Table 1—*Captures of amphibians and reptiles during time-constraint searches at four oak-woodland study areas in California from 1987 through 1990*

Species	Study area				Total
	Tejon Ranch	San Joaquin	Sierra Foothill	Mad River	
Amphibians					
Ensatina (*Ensatina eschscholtzii*)	76			6	82
Black-bellied slender salamander (*Batrachoseps nigriventris*)	26				26
California slender salamander (*Batrachoseps attenuatus*)		3	12		15
Pacific treefrog (*Hyla regilla*)			3	2	5
SUBTOTAL					128
Reptiles-lizards					
Side-blotched lizard (*Uta stansburiana*)		1			1
Western fence lizard (*Sceloporus occidentalis*)	49	30	49	57	185
Gilbert's skink (*Eumeces gilberti*)	25	16			41
Western skink (*Eumeces skiltonianus*)			7	11	18
Southern alligator lizard (*Elgaria multicarinata*)	5		22		27
Northern alligator lizard (*Elgaria coerulea*)				15	15
Legless lizard (*Anniella pulchra*)	3				3
SUBTOTAL					290
Reptiles-snakes			1	1	2
Racer (*Coluber constrictor*)					
California whipsnake (*Masticophis lateralis*)			1		1
Ringneck snake (*Diadophis punctatus*)			1	1	2
Gopher snake (*Pituophis melanoleucus*)	1	1		1	3
Sharp-tailed snake (*Contia tenuis*)				1	1
Western rattlesnake (*Crotalus viridis*)			1		1
SUBTOTAL					10
TOTAL	185	51	97	95	428
Number of searches	28	7	9	7	51
Number of search hours	112	28	36	28	204

Table 2—*Captures of amphibians, reptiles, and small mammals in pitfall traps at three oak-woodland study areas in California from 1987 through 1990*

Species	Study area			Total
	Tejon Ranch	San Joaquin	Sierra Foothill	
Amphibians				
California newt (*Taricha torosa*)		1		1
Ensatina	105			105
Black-bellied slender salamander	40			40
California salamander		13	2	15
Western spadefoot (*Scaphiopus hammondii*)		3		3
Western toad (*Bufo boreas*)	1	1		2
Foothill yellow-legged frog (*Rana boylii*)	1			1
Pacific treefrog	2			2
SUBTOTAL				169
Reptiles-lizards				
Side-blotched lizard		1		1
Western fence lizard	174	46	122	342
Gilbert's skink	117	56		173
Western skink			18	18
Southern alligator lizard	5		10	15
Legless lizard	1			1
Western whiptail (*Cnemidophorus tigris*)		46		46
SUBTOTAL				596
Reptiles-snakes				
Ringneck snake	1			1
Small mammals				
Ornate shrew (*Sores ornatus*)	30	2	8	40
Broad-footed mole (*Scapanus latimanus*)	1			1
California pocket mouse (*Perognathus californicus*)	11			11
San Joaquin pocket mouse (*Perognathus inornatus*)		1		1
Botta's pocket gopher (*Thomomys bottae*)	23	8	1	32
Western harvest mouse (*Reithrodontomys megalotis*)	7		9	16
Brush mouse (*Peromyscus boylei*)	234	13	16	263
Pinyon mouse (*Peromyscus truei*)	59	18	14	91
Deer mouse (*Peromyscus maniculatus*)	107	10	4	121
California mouse (*Peromyscus californicus*)	1			1
California vole (*Microtus californicus*)	12		9	21
SUBTOTAL				598
Total captures	931	219	213	1363
Total trapnights	65,850	17,280	15,462	98,592

Table 3—*Captures of small mammals in live traps at three oak-woodland study areas in California from 1987 through 1990. First number presented is the number of individuals; second number is total number of captures including recaptures*

Species	Study area			
	Tejon Ranch	San Joaquin	Sierra Foothill	Total
Ornate shrew			1/1	1/1
Beechey ground squirrel (*Spemophilos beecheyi*)		10/10		10/10
Merriam chipmunk (*Eutamias merriami*)		2/2		2/2
California pocket mouse	11/22	14/28		25/50
Heermann kangaroo rat (*Dipodomys heermanni*)	3/5	1/5		4/10
Brush mouse	118/242	97/195	66/127	281/564
Pinyon mouse	119/229	166/268	27/47	312/544
Deer mouse	58/161	8/21	7/11	73/193
California mouse	2/2			2/2
California vole	1/1	1/1		2/2
Dusky-footed woodrat (*Neotoma fuscipes*)	4/8	8/21	2/5	14/34
Total captures	318/670	307/551	103/191	728/1412
Trapnights	8,996	8,758	3,638	21,392

Table 4—*Spearman rank-order correlations comparing rankings of total counts of common birds found at three California oak woodlands—Tejon Ranch (TR), Kern County; San Joaquin Experimental Range (SJER), Madera County; and Sierra Foothill Range Field Station (SFRFS), Yuba County—between years (1986,1987,1988), seasons (B =breeding; N=nonbreeding), and study areas. For example, TRB86 vs. SJER/B87 compares 1986 breeding at TR with 1987 breeding at SJER*

	TR/ B86	TR/ B87	SJER/ B87	SFRFS/ B87	TR/ B88	SJER/ B88	SFRFS/ B88	TR/ N87	TR/ N88	SJER/ N88
TRB87	0.88 **									
SJERB87	0.65 **	0.64 **								
SFRFS/B87	0.27	0.29	0.54 **							
TRB88	0.89 **	0.94 **	0.69 **	0.28						
SJERB88	0.61 **	0.54 **	0.90 **	0.52 **	0.64 **					
SFRFS/B88	0.34 *	0.26	0.53 **	0.90 **	0.25	0.57 **				
TR/N87	0.12	0.27	0.37	-0.01	0.28 *	0.29	-0.06			
TR/N88	0.13	0.28	0.33 *	0.01	0.29	0.30 *	-0.02	0.91 **		
SJER/N88	0.06	0.13	0.41 **	0.10	0.16	0.35 *	0.09	0.74 **	0.79 **	
SFRFS/N88	0.04	0.02	0.21	0.22	0.04	0.20	0.24	0.42 *	0.48 **	0.53 **

[1] * r_s significant at $P < 0.05$ (n=44); ** r_s significant at $P < 0.01$ (n=44).

Table 5—*Summary from log-linear analyses of use of tree species by breeding and nonbreeding birds found in three California oak woodlands-Tejon Ranch, Kern County; San Joaquin Experimental Range, Madera County; and Sierra Foothill Range Field Station, Yuba County-from 1986 to 1988*

Species	Area	Year	Season	Area x Year	Area x Season	Year x Season	Area x Year x Season
Resident birds							
Acorn woodpeckers (*Melanerpes formicivorus*)	212.1 **[1]	8.6	9.1	1.4	5.1	4.8	0.0
Nuttall's woodpecker (*Picoides nuttalli*)	186.4 **	8.4	18.6 *	14.6	1.4	5.1	7.3
Scrub jay (*Aphelocoma coerulescens*)	124.2 **	21.2 **	11.7	6.6	6.4	8.5	1.8
Plain titmouse (*Parus inornatus*)	280.4 **	16.4 *	33.3 **	21.1	12.2	7.6	7.2
Bushtit (*Psaltriparus minimus*)	10.8 **	28.4 **	27.4	2.0	3.0	9.6	1.3
White-breasted nuthatch (*Sitta carolinensis*)	314.1 **	4.1	8.8	13.7	7.0	8.6	1.1
Bewick's Wren (*Thryomanes bewickii*)	37.0 **	12.0	12.3	5.5	5.2	6.4	7.5
Western bluebird (*Sialia mexicana*)	125.9 **	9.2	20.6 **	13.6	3.7	10.7	1.4
California towhee (*Pipilo fuscus*)	99.5 **	11.7	14.3	1.9	5.6	9.6	5.5
Hutton's vireo (*Vireo huttoni*)	—	14.9	7.8	—	—	7.6	—
Lesser goldfinch (*Carduelis psaltria*)	—	14.7	30.4 **	—	—	1.4	—
Wintering birds							
Ruby-crowned kinglet (*Regulus calendula*)	98.4 **	46.4 **	—	12.3	—	—	—
Yellow-rumped warbler (*Dendroica coronata*)	110.4 **	17.4 *	—	1.2	—	—	—
Rufous-sided towhee (*Pipilo erythrophthalmus*)	45.9 **	15.6 *	—	12.4	—	—	—
Dark-eyed junco (*Junco hyemalis*)	162.6 **	3.6	—	20.3	—	—	—
White-crowned sparrow (*Zonotrichia leucophrys*)	—	3.3	—	—	—	—	—
Golden-crowned sparrow (*Zonotrichia atricapilla*)	46.7 **	1.4	—	8.5	—	—	—
Breeding birds							
Western kingbird (*Tyrannus verticalis*)	26.0	6.9	—	3.7	—	—	—
Ash-throated flycatcher (*Myiarchus cinerascens*)	107.3 **	20.0	—	4.7	—	—	—
House wren (*Troglodytes aedon*)	105.2 **	7.7	—	5.3	—	—	—
Blue-gray gnatcatcher (*Polioptila caerulea*)	—	4.8	—	—	—	—	—
Orange-crowned warbler (*Vermivora celata*)	—	19.2	—	—	—	—	—
Wilson's warbler (*Wilsonia pusilla*)	—	11.8	—	—	—	—	—
Black-headed grosbeak (*Pheucticus melanocephalus*)	—	7.3	—	—	—	—	—
Northern oriole (*Icterus galbula*)	145.1 **	14.4	—	5.5	—	—	—

[1] * likelihood-ratio chi square significant at $P < 0.05$; ** likelihood ratio chi square significant at $P < 0.01$.

Ranch and San Joaquin, although the actual values of these correlations were relatively small; all rankings with Sierra Foothill birds were nonsignificant (table 4).

Spatial and temporal differences in tree-species use were attributable to main effects only (table 5). Of the birds occurring at more than 1 study area, all but the bushtit and western kingbird exhibited differences in tree-species use between or among study areas (table 5). Yearly differences in tree use were shown for the plain titmouse, scrub jay, bushtit, ash-throated flycatcher, ruby-crowned kinglet, rufous-sided towhee, and yellow-rumped warbler (table 5). Of the resident birds, the Nuttall's woodpecker, plain titmouse, western bluebird, bushtit, and lesser goldfinch showed seasonal differences in tree-species use (table 5). Detailed analyses of the specific trees used by each species at each study area and during each year and season are presented by Block (1989).

DISCUSSION

Distributions and habitat-use patterns of wildlife are not static in time or space and these phenomena are not peculiar to California oak woodlands. Variations in the types and relative abundances of wildlife are attributable to a number of factors. First, species have different historic distributional patterns as influenced by geologic events preceding human occupation of western North America (Landres and MacMahon 1983, Wright and Frey 1965). These patterns have been modified by humans and by continued changes in the natural environment during the Recent Epoch, resulting in an altered landscape. Local events resulting in both short- and long-term effects have further acted to influence the patterns that exist today.

We found that spatial variations occurred among (1) sampling points within a stand, (2) floristically- and structurally-similar stands, (3) different stand types, and (4) geographic locations. Differences within stands may have been attributed to local environmental conditions. For example, a fallen tree provides a large volume of downed dead woody debris, clearly an important habitat component for many amphibians and reptiles (Block and Morrison 1990, Welsh and Lind, in press). Even a slight change in slope or aspect can result in a measurably different microclimate and soil regime well-suited to a particular species of amphibian, reptile, or small mammal. Distributions of birds within a stand can depend on the presence of suitable nest sites or other special habitat components. For example, the presence of a suitable granary tree provides an activity center for a group of acorn woodpeckers (Koenig and Mumme 1987).

Our pitfall and livetrap data demonstrate some general relationships of taxa or species within a taxon to specific stand types. Salamanders were closely associated with canyon live oak. This oak generally occurs on mesic, north-facing slopes. The persistent humus layer created from its sclerophyllous leaves provides a favorable environment for these amphibians. Mammals, particularly deer mice, were closely associated with valley oak. The two most common reptiles in oak woodlands, western fence lizards and Gilbert's skinks, demonstrated an affinity for blue oak stands which often occur on xeric south-facing slopes. Thus, macrohabitat differences among stands provide conditions suitable for different species of wildlife.

Temporal variations in habitat use can occur with changing patterns of resource abundance and distribution or according to requirements unique to each period of a species' life history (e.g., breeding vs. wintering). Temporal variations in resource use occurred for all taxa we studied. For example, many salamanders are subterranean for a large portion of their annual cycle, surfacing only during the wet part of the year. Habitat use by small mammals often differs during dispersal of juveniles from the natal area from habitat-use patterns during other periods. Many species of birds are present only for a short period of the year such as the breeding season or during winter and migration. The general lack of concordance of avifaunas that we found between breeding and nonbreeding seasons demonstrates that different assemblages of species extract resources from oak woodlands during different times of the year. For example, many insectivorous birds are present during the spring when insect larvae are abundant and new insects are emerging. Seed-eating birds, such as sparrows and towhees, winter in oak woodlands to take advantage of the abundant seed crops. Birds that occur throughout the year often shift foraging patterns or habitats between seasons or years to take advantage of available resources. Such shifts may be differences in tree-species use or even more subtle changes in the use of foraging substrates. Nuttall's woodpeckers, for example, use blue oaks extensively during breeding and expand their use of trees to other species during nonbreeding. Western bluebirds take insects from the ground during most of the year, but eat berries from shrubs when ripe during the fall and winter (Block 1989).

The implications of our study demonstrate that management cannot be based on data restricted in time and space. Data representative of variations in distributions and resource use must provide the bases for management decisions. Failure to incorporate such variation will restrict management options. A worse-case scenario is that management based on a restricted data set not representative of the ecology of a species may ultimately be more detrimental than beneficial to the well-being of that species.

Thus, what is the appropriate scale of research and of management? Clearly, the answer to this question depends on the research and/or management objectives. Species-specific research must be scaled to the variations in the biology of the organism of interest. For example, a species ubiquitous to oak woodlands in California might require that study be conducted at various locations throughout the range of that organism. Further, research must also incorporate temporal variations in resource use, as many species use different resources or different habitats during different times of the year (Block and others 1988, Block 1989). Only by examining a species' population and ecological responses along gradients that encompass environmental variations typically found within the range of the species can effective management be developed. Species that

exhibit pronounced ecological differences among areas will likely require different types of management depending on location. Species that exhibit very specific habitat requirements that vary little across their range may require only one set of management strategies. We have begun analyses using our data set to develop predictive habitat models for many of the common species found in oak woodlands. Models will be developed initially using data from one time and place, and then tested and refined using data from other times and places. We think that our model development will represent the first step in defining species-specific management strategies. Additional data will be needed to further test the models that we develop. Also, we must get adequate data for the species about which we lack enough information. We believe that this strategy of adaptive management will eventually provide the necessary information to permit effective management of wildlife in oak woodlands.

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Wildlife-Habitat Relationships in California's Oak Woodlands: Where Do We Go from Here?[1]

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Abstract: We discuss management goals and research directions for a comprehensive study of wildlife in California's oak woodlands. Oak woodlands are under intensive multiple use, including urbanization, recreation, grazing, fuel wood cutting, and hunting. Research in oak woodlands is thus complicated by these numerous, often competing, interests. Complicating understanding of resource requirements of wildlife is the historic emphasis on the use of these woodlands for grazing by domestic livestock and consumptive wildlife (game). The introduction of exotic wildlife species has further impacted the oak woodland environment. We review ecological principles that must be considered when developing any management plan for oak-woodland wildlife, including habitat selection, the ecological niche, spatial and temporal aspects of resource use, and ecological scale. We outline a research program that: (1) develops research and management goals based on sound ecological concepts, (2) recognizes the scale-dependence of research results and management decisions, and (3) considers the acceptable level of accuracy and precision to be achieved. We suggest that maintenance of biological diversity at the watershed level is an attainable goal. A wider range of practicing field scientists must be involved in future research and management decisions.

Oak woodland describes a diverse vegetation type that includes numerous species of trees, shrubs, grasses, and forbs. These plants provide a varying array of food for wildlife, including arthropods, seeds, and fruits, and numerous other habitat components, including roost and nest sites, and cover. Further, these resources vary both within and between seasons; this variation usually changes between years depending upon environmental conditions. The types, amounts, and distribution of resources determine, in part, the types, abundance, and distribution of wildlife present (Block and Morrison 1990).

These complex relationships make it difficult to accurately predict the resource requirements of specific wildlife species. Models of wildlife-habitat relationships are further complicated by human-induced variations in resource abundance and species composition, including: grazing changes the amount, composition, size, and shape of grasses and forbs, thus potentially changing competitive relationships and population regulation; hunting and predator control could change predator-prey relationships; recreation increases stress on wildlife; and land conversion for housing reduces the absolute area of land available.

Numerous people have conducted research on wildlife in oak woodlands during the past 100 years. These studies have ranged from anecdotal natural history accounts to detailed analyses of resource use. Most of these studies have been species- and site-specific, and as such, provide limited data that can be used to manage oak woodlands. In response to increased human impacts on oak woodlands, and in response to public interest in oak-woodland wildlife, the California Department of Forestry and Fire Protection (CDFFP) and the University of California initiated a research program to address the many changes facing oak woodlands (the Integrated Hardwood Range Management Program [IHRMP]).

Given the varied and diverse nature of research, and the ever-increasing impacts upon oak woodlands, we think it is essential that present management goals and research directions be evaluated with regard to ecological principles. Our specific objectives in this paper are (1) to review ecological concepts as background for research needs and field procedures, (2) to summarize what we need to know about wildlife in oak woodlands, and (3) to develop a foundation from which reliable research and management can proceed.

DEFINITIONS

Throughout this paper we refer to "oak woodlands" rather than the currently popular "hardwood rangelands" to describe areas in California dominated by species of *Quercus.* First, although many species of hardwoods co-occur with oaks, oaks are usually the dominant species by cover, biomass, and density. Plant ecologists usually refer to an area by its dominant or co-dominant species (e.g., pine-fir forest, which may contain 5-6 conifer species). Our field research was conducted in areas dominated by oaks; the term "hardwood" is appropriate when used to discuss hardwood-dominated areas in the general sense (e.g., the "hardwood" in IHRMP). In general, however, "rangelands" is an inappropriate descriptor in that range implies a specific, usually commercial, use. As noted above, oak woodlands, and more generally, hardwoods, are under intensive multiple use. "Rangelands" stems from historic, dominant activities of ranchers and range managers in these areas, but now suggests a rather narrow focus and is clearly inappropriate.

[1]Paper presented at the Symposium on California's Oak Woodlands and Hardwood Rangeland, 31 October-2 November 1990, Davis, California.

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RESEARCH IN OAK WOODLANDS

Current Research Direction

Most current research in California is complicated by numerous competing interests, from the standpoint of both the allocation of limited research dollars and conflicting public interests. The emphasis on commercial production of range animals, most notably cattle and sheep, has driven research efforts historically. One need only note the many university and government research stations that emphasize cattle production: Sierra Foothills Range Field Station of the University of California, for example, was established to "support livestock and agronomic productivity of foothill rangelands" (Raguse and others 1990). Only recently have new research topics, including wildlife research, been added to the goals of these stations. It is notable that this expanded research role was initiated to "accommodate increasing public concern about management of renewable natural resources" (Raguse and others 1990).

Complicating and inhibiting understanding of noncommercial resources in oak woodlands has been the emphasis of the California Department of Fish and Game (CDFG) towards consumptive wildlife. Few species of wildlife inhabiting oak woodlands are classified as game. Most information available on the distribution and abundance of nongame species in oak woodlands has been provided by various naturalists and university researchers. Recently, however, CDFG has reacted to increasing public concern for a more holistic approach to wildlife management by expanding their relatively small nongame branch through initiation of the Natural Heritage Program. However, in many management programs, the predominant nongame species are assumed to benefit from management practices initiated for their game counterparts. As we discuss below, this assumption has no basis in ecological theory and knowledge.

Much of the problem with management of oak woodlands is that most of the land is privately owned. Thus, it is understandable that resource agencies and extension branches of universities have responded historically to the predominant, commercially oriented user groups in these lands. Further, implementation of management activities on oak woodlands are complicated by private land ownership rights. Recognizing this, the California Board of Forestry and the University of California (Extension) have initiated steps to conduct research and educate the public on a more holistic basis than previously seen. Of course, all wildlife species are under the purview of the U. S. Fish and Wildlife Service (USFWS) and CDFG, regardless of land ownership, although they can do little concerning habitat management without the cooperation of the private landowner or land-management agency.

Management of oak woodlands is complicated by restricted knowledge, emphasis on only a limited set of resources, and land ownership. Underlying the difficulty in applying a more holistic approach to resource management is uncertainty on defining the *goals* of this management and the appropriate spatial scale that should be applied to this management. Should the goal be maintenance of "natural" species diversity on all or part of the land base? And how can these decisions be applied to an increasingly fragmented landscape? We think that answers to the issues we have raised and the questions we have posed can be found only after a sound framework has been established, based on the ecological principles that structure and organize the oak-woodland ecosystem. Below we review some of these principles.

ECOLOGICAL CONCEPTS

Habitat

The foundation of wildlife-habitat relationships is the clear definition and determination of the factors that comprise "habitat." Much confusion exists in the literature over the definition of habitat. Wildlife habitat is defined by the animal itself; that is, the complex association of interrelated factors used by an individual (and, collectively, the population) defines habitat. Determination of the specific factors that comprise this habitat, and their functioning and mechanisms of influence and control of animals, is the goal of wildlife-habitat-relationships studies. This broad definition of habitat can—and usually does—vary by age and sex, time and space, populations (i.e., ecotypes), and the like (Block and Morrison 1990). These variations are influenced by innate and learned abilities of animals, and natural and human-induced changes in the environment (including biotic and abiotic factors). Habitat is composed of all of the many factors that supply the life requisites, including plant structure and floristics, food, and water. Exploitation of these items comprises "resource use" by the species. Numerous other factors, including disease, predators, and competitors, affect the use of habitat by individuals in specific locations at specific times.

By contrast, "vegetation type" refers to human-defined categories of plant structure and floristics that do not necessarily equate to habitat. This is an important distinction, as researchers and managers often try to force wildlife-habitat relationships to fit their own vegetation categories.

Ecological Niche

Related to resource exploitation is the concept of the niche. Simply, the niche of an animal is the total suite of environmental factors to which the animal is adapted, including food, competitors and predators, vegetation structure and floristics, weather conditions, and numerous other factors. The interrelated and multifaceted nature of these factors has been recognized conceptually by Hutchinson's n-dimensional niche hypervolume (Hutchinson 1957), and statistically through multivariate analy-

ses (Green 1971, Verner and others 1986). Thus, only through careful and detailed evaluation of the niche of an animal can full understanding of its resource requirements be obtained.

Spatial and Temporal Variation

As previously mentioned, habitat (and more generally, resource) use is scale-dependent. At the geographic level, we know that resource use varies according to local environmental conditions. Thus, resource use often varies dramatically between areas. And because environmental conditions are seldom synchronized among areas, patterns of resource use likewise vary (Morrison and others 1990).

Nuttall's Woodpeckers (*Picoides nuttalli*), for example, occur in oak woodlands throughout the state. We studied resource use by this woodpecker at four locations ranging along a latitudinal gradient of 800 km from southwest Riverside County, north to Yuba County (see Block 1989, In press). Tree species used for foraging differed among study areas as the birds used different combinations of blue (*Q. douglasii*), valley (*Q. lobata*), California black (*Q. kelloggii*), interior live (*Q. wislizenii*), canyon live (*Q. chrysolepis*), and Engelmann (*Q. garryana* var. *brewers*) oaks and gray pine (*Pinus sabiniana*) (table 1). Patterns of tree-species use differed both spatially and seasonally. Had we restricted study to only one location and one season, we would have reached different conclusions regarding patterns of resource use than we did having studied this species across different locations within its geographic range.

Ecological Scale

Our descriptions of habitat depend largely on the scale at which we record our measurements. We know that plot size, for example, influences subsequent descriptions of the plant community (e.g., density). It is becoming increasingly evident that different animals perceive their environment—and thus select habitat—at different scales; techniques are available that acknowledge this (Ludwig and Reynolds 1988).

Table 1—*Relative frequencies (pct) of tree species used by Nuttall's woodpeckers at four locations in California*[1].

Tree species	SFRFS	SJER	TR	SRPP	TOTAL
Blue oak	66.2	39.7	57.1	0.0	51.0
Live oaks[2]	18.0	26.3	9.0	17.3	19.0
California black oak	1.0	0.0	4.9	0.0	2.0
Valley oak	0.0	0.0	29.0	0.0	7.0
Engelmann oak	0.0	0.0	0.0	82.7	4.0
Gray pine	14.8	34.0	0.0	0.0	17.0

[1]Sample size: Sierra Foothill Range Field Station (SFRFS; n = 157); San Joaquin Experimental Range (SJER; 162); Tejon Ranch (TR; 111); Santa Rosa Plateau Preserve (SRPP; 23); sexes combined.
[2]Live oaks include interior live, canyon live, and coast live oaks.

Exotic Species

Critical to maintenance of biological diversity is the question of exotic species. Exotics fall into several categories based on their mode of introduction into regions previously unoccupied. Many native species are expanding their ranges within California because of human-induced habitat changes. Notable here are the chestnut-backed chickadee (*Parus rufescens*) and green-tailed towhee (*Pipilo chlorura*). Other species, native to North America but previously unknown in California, now breed within its borders, including the Virginia opossum (*Didelphis marsupialis*) and barred owl (*Strix varia*). These are not true "natural" expansions based on evolutionary changes by the species or natural changes in the environment. Several species that are not native to North America have invaded California, including the well-known European starling (*Sturnus vulgaris*) and house sparrow (*Passer domesticus*). Finally, many species have been introduced directly into the state to promote increased hunting opportunities, including northern bobwhite (*Colinus virginianus*), white-tailed ptarmigan (*Lagopus leucurus*), chukar (*Alectoris graeca*), ring-necked pheasant (*Phasianus colchicus*), and wild turkey (*Meleagris gallopavo*); the latter two species occur in oak woodlands.

Thus, the study of habitat relationships involves describing the numerous environmental factors that are encountered by an animal; this is complicated by temporal and spatial variation in the availability and use of these factors. It is wrong to think that simple descriptions of habitat use can be translated into meaningful management plans except at the most superficial level. Gross categorizations that violate these basic ecological principles, regardless of the size and sophistication of the computer system used to retrieve and manipulate data, are inappropriate. And because habitat describes only part of the environment used by an animal, we should more appropriately be referring to this area of research as "wildlife-resource-use relationships." Vegetation-habitat may form the foundation upon which other factors operate, but still describes only part of the activities of the animal. The Wildlife-habitat Relationships (WHR) data base and Habitat Suitability Index (HSI) models are examples of procedures designed to simplify natural systems. As we discuss below, all study and modeling of wildlife must clearly state and justify a specific and acceptable level of precision and accuracy.

EXTERNAL STRUCTURE OF RESEARCH PROGRAM

Historically, research efforts in oak woodlands have been limited to short term (1-3 years), species- and location-specific descriptions of vertebrate natural history, especially game species. Most of these studies do, indeed, provide useful knowledge on resource use. Unfortunately, gaps in our knowledge are the rule rather than the exception. Few validated studies of resource-

use relationships are available.

The current "hardwood range" program has begun to address wildlife issues in oak woodlands by funding studies on basic habitat relationships and geographic scale, riparian woodlands, and urbanization. Unfortunately, these studies were not integrated in their goals or approach, all were short term, and no follow-up validation of initial results was funded (discussed in more detail below). The program has, however, allowed us to accumulate valuable data and provide direction for future research. To further advance our understanding of wildlife in oak woodlands, a well-organized research program is needed that:

1. Develops goals based on sound ecological concepts.
2. Recognizes the scale-dependence of research results and management decisions.
3. States the acceptable level of accuracy and precision to be achieved.

The geographic-spatial scale at which the oak-woodland ecosystem functions should be used to set the limits to human management activities, especially if maintenance of biological diversity is the goal. (We define biological diversity as the number of species, and their distribution and abundance, over some defined area.) In fact, we think that maintenance of biological diversity at a reasonable, ecologically-sound level, is an attainable and desirable goal for oak woodlands. The level of examination-management should be sufficiently large to encompass all essential environmental factors and the home ranges of the largest vertebrates present. We follow U.S.D.A. Forest Service guides in recommending the watershed level. This level should maintain the properties of the ecosystem and thus maintain the diversity of the environment. Attempts to manage smaller parcels of land, apart from the whole system within which they are found, will likely fail. We must also acknowledge that all changes, both natural and human-induced, will alter resources and thus biological diversity. The goal should not be maintenance of a static system. Rather, the goal should be to allow a dynamic system to function naturally without being forced into an unnatural state by improper management activities.

Detailed studies are necessary that determine the influence of intentional and unintentional introductions of exotics on native wildlife (Pimm and Gilpin 1989). Like habitat changes, exotics perturb the environment. Although their impact on the environment is difficult to predict, numerous examples exist of the ecological changes caused by starlings, house sparrows, exotic deer, and numerous feral species. Whenever introduction of a new exotic is proposed, the burden of proof for the lack of impact to the system must clearly be placed on the proponents (Bratton 1988, Pimm and Gilpin 1989). The Wildlife Society has drafted language that notes that the introduction of exotic flora and fauna into ecosystems often has been more detrimental than beneficial, and that responsible agencies prevent the accidental introduction of exotics (*The Wildlifer* (240), May-June 1990:19).

An overall strategy is needed for evaluating resource relationships in oak woodlands that considers issues of temporal and spatial scales, levels of acceptable accuracy and precision, geographic scale of application of results, the question of exotics, and related issues. Research should not be dominated by historic, economic goals. We address this issue further in the last section of our paper.

INTERNAL STRUCTURE OF RESEARCH PROGRAM

The specific methods used to evaluate resource relationships are goal-dependent and must acknowledge temporal changes and be set in the appropriate spatial scale. Although it could be argued that different goals necessitate different methods, such views fail to acknowledge that (1) an integrated program should promote cooperation and thus compatibility of results, and (2) all studies can include a common, base method and still allow expansion into goal-specific methods as required. Unfortunately, current research in oak woodlands is fraught with differing and often contrasting methods. Methods used to count birds among the various studies previously funded by the "hardwood range" program are but one example. One study used short-duration counts at points along transects; another used much longer-duration counts placed differently from the first study; another has used intensive counts in fixed plots; yet another counted birds while driving slowly along roads; none of these methods can be safely compared to another. This is especially distressing because detailed studies *in oak woodlands* have been done to determine proper ways to conduct these counts, including development of a monitoring program (Verner 1987). Research results are determined, largely, by the methods used to collect the data. Many studies are available in both the wildlife- and plant-ecology literature that show that the number, size, and juxtaposition of plots, transect spacing, number of observers and their training, and numerous other aspects of methodology all interact to bias results (see Verner and others 1986, Morrison and others 1990). Guides for the use of appropriate and comparable methods should be established.

MANAGEMENT RESOLUTION: SYNTHESIS

We think that the goal of wildlife management in oak woodlands should be the conservation of biological diversity. Thus, composition of native species must be conserved. This requires protection of system interactions at all (trophic) levels, and necessitates management at a "landscape" level. A reasonable and manageable geographic scale appears to be at the watershed level, although this topic requires rigorous study. Research would then emphasize the mechanisms of biological diversity at this geographic scale. Also required is the exclusion of all additional exotics unless it can be shown, unequivocally,

that no unacceptable perturbations to the system will be caused by their introduction. Standards for retention of oaks (and all hardwoods) must be based on ecological knowledge, and not driven by narrow focused, recreational or economic interests.

Agency environments need to acknowledge these new goals. This requires clear and rigorous leadership by the Board of Forestry and implementation by CDFFP. Also required is a reorientation that recognizes (1) the importance of *all* species in the system, (2) that the system is extremely complex, and (3) that past emphasis on game and exotic species is both inappropriate, given public demand for wildlife protection, and deleterious to the integrity of oak woodland ecosystems. We are not suggesting that the absolute amount of time and money spent on game management be reduced. It is the small amount of effort placed on nongame *relative* to their game counterparts that requires change. Although this will obviously require new funding sources, we think that all wildlife biologists and managers in California could increase the amount of attention they give nongame species.

The "hardwood range" program has helped to provide critical, baseline data on wildlife-habitat relationships in oak woodlands. These data, and the methods used to collect them, can serve as a starting point for development of an overall, detailed strategy for further research. To accomplish this, all proposals for funding should be rigorously reviewed, and all scientists that wish to be part of the program should meet regularly to discuss past accomplishments and plan future studies. Practicing field scientists should be consulted to develop research priorities and organize field studies in a truly integrated manner. Administrators and nondirectly practicing scientists cannot be expected to adequately develop such a program. Such a program would:

1. Develop goals that embrace the concept of biological diversity, set these goals within reasonable and attainable spatial scales (e.g., watershed level), and specify acceptable error levels.

2. Develop a step-by-step research agenda that addresses each of the goals developed in (1); standards of specific methods would also be provided by qualified field scientists. Laboratory and field experimentation would likely be included.

3. Research results would be incorporated into management recommendations for the maintenance of biological diversity in oak woodlands at the appropriate spatial scale.

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Using Wildlife Species Richness to Identify Land Protection Priorities in California's Hardwood Woodlands[1]

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Abstract: A geographic information system was used to assess wildlife species richness (number of species) in valley-foothill hardwood habitats throughout California to set priorities for conservation attention. Species richness values were assessed and compared using three methods: one that included all species without considering canopy cover conditions and species preferences; a second that restricted the analysis to sensitive species; and a third that used sensitive species and considered canopy cover conditions and species canopy preferences. The identified locations of species rich areas were markedly altered with the inclusion of information on habitat structure and species sensitivity. Comparison of different species richness analyses showed that the greatest difference in areas identified in richness classes was produced when species sensitivity and canopy closure requirements were included. The largest areas of high species richness were in the southern Sierra Nevada foothills. Valley-foothill hardwood habitat is not well represented in reserved areas. Only 3.8 percent of a total 4.5 million acres were classified as reserved by virtue of ownership. Similarly, only 4.5 percent of the 1.1 million acres in the highest species richness class was reserved. Areas of sparse canopy closure supported the most species. Selecting conservation areas based solely on species richness would, however, omit species that favor or are restricted to denser canopy closure classes. Ensuring protection of the maximum number of species requires examining the distribution, size, and species composition of species rich areas identified. Site specific considerations are essential as a second step in the ranking of local habitats for management or protection.

Due to its varied topography, soils, and climate, California has one of the most diverse assemblages of plants, animals, and natural communities in the United States. In the course of the state's settlement, many habitats were altered by mining, grazing, timber harvest, and agricultural development. Despite regulation to reduce the impacts of these land uses, demands from a growing population has led to continued habitat degradation and loss.

Current causes of major habitat loss and disturbance are construction of housing, roads, industrial facilities, water storage and delivery systems, and mining. Habitat loss and fragmentation have contributed to the extinction of plant and animal species and subspecies, loss of unique plant communities, and substantial reductions in acreages of the more widely distributed habitats in many parts of the state (Jones and Stokes Associates 1987).

Perpetuation of wildlife species requires maintenance of the habitats that support them. Habitat maintenance can be accomplished through acquiring and managing lands by agencies or private groups, managing existing public and private lands for diversity values, regulating detrimental private land uses, and providing incentives for private habitat protection. Common to all these approaches is a need to determine the specific areas of land that warrant action.

Nearly 12 percent of California has been designated as parks, refuges, and wilderness (California Department of Forestry and Fire Protection 1988), but these reserves do not equally protect all cover types. High elevation cover types are well protected in designated wilderness areas. In contrast, cover types such as ponderosa pine, blue oak-digger pine woodland, montane hardwood, valley-foothill hardwood, valley riparian, coast scrub, annual grassland, and perennial grassland each has less than 8 percent of its total acreage in reserved status (California Department of Forestry and Fire Protection 1988).

One systematic approach proposed to address conservation of biological communities and their constituent species involves protecting a sufficient amount and juxtaposition of habitat that support all taxa before individual species decline to the point of endangerment (Scott and others 1987). Early protection of species rich areas is more effective and less costly than deferring action to recover individual species after they are nearly eliminated (Scott and others 1988).

Species richness analysis recently has been proposed as a technique for assessing biological diversity and establishing priority areas for land protection. Kepler and Scott (1985), Scott and others (1987), and Davis and others (1990) outlined the utility of geographic information systems to identify species rich areas and to assemble and analyze diverse data for specific geographic regions.

Habitat structural characteristics such as tree canopy height and crown closure are recognized as important determinants of habitat quality for vertebrate species (Airola 1988). Previous attempts to identify species rich areas, however, have been based on the distribution of species ranges and general habitat types. Inclusion of mapped vegetation structure information (e.g. canopy cover) could significantly refine maps of predicted species

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distributions. In addition, species sensitivities to land uses and other factors have not always been considered in identifying species richness areas. If sensitivities of species to land uses is not considered, resilient and widespread species could disproportionately influence the selection of species rich areas to the detriment of localized and sensitive species.

The species richness approach uses existing information on the distribution of wildlife species to identify areas that support high numbers of species as candidate sites for protection. Underlying this method is the assumption that protecting habitat areas that support the largest number of species will provide the greatest level of protection for all species. In this way, the species richness method contrasts with an approach that emphasizes protecting those sites occupied by rare species (Scott and others 1988).

The valley-foothill hardwood habitat[3] was selected for this study due to its wide distribution (4.5 million acres) and small amount of total acreage in reserved status (167,000 acres; 3.8 percent). Much of this cover type (7 percent of total acreage) was converted to urban and agricultural uses during 1950-1980 (California Department of Forestry and Fire Protection 1988). Regeneration of several dominant tree species in this habitat may not be adequate to maintain their presence over time (Tietje and Schmidt 1988). Over half of the state's 600 terrestrial vertebrate species find hardwood-dominated habitats important for breeding (Ohmann and Mayer 1987).

The goal of this study was to compare several approaches to identifying areas of species richness within valley-foothill hardwood habitat. Objectives were to: 1) conduct a species richness analysis for valley-foothill hardwood habitat that accounts for species preference for different canopy closure classes; 2) identify areas of high species richness as priority areas for future habitat protection; 3) compare results of our approach to one that does not consider canopy closure preferences and species sensitivities; and 4) assess adequacy of protection of species rich areas under existing land ownership patterns.

METHODS

The ARC/INFO geographic information system (GIS) maintained by the California Department of Forestry and Fire Protection's Forest and Rangeland Resources Assessment Program (FRRAP) was used to develop the vegetation and land use information for the analysis. Data layers within the GIS consisted of WHR (Wildlife Habitat Relationships) species range maps, valley-foothill hardwood distribution by canopy closure class, and land ownership information. The California WHR system (Airola 1988) provided basic information on habitat relationships of wildlife species.

[3]As defined by Airola (1988) and Mayer and Laudenslayer (1988) for the Wildlife Habitat Relationships System and distinguished from cover type.

Species Maps

Range maps for the 91 wildlife species that find optimum breeding habitat within valley-foothill hardwood habitat were obtained from the California WHR system. Because the generalized species range maps encompass habitat types other than valley-foothill hardwood habitat, for this analysis, we refined species' breeding distributions by intersecting species range maps with the distribution of valley-foothill hardwood (Pillsbury and others 1990).

Ranges for each species were further refined to include only canopy closure classes mapped by Pillsbury and others (1990) that were rated as optimal for breeding in the WHR database (Airola 1988).

Habitat Maps

We used a digital version of Pillsbury and others' (1990) map of California's hardwoods. Polygons supporting blue oak (*Quercus douglasii*), interior (*Q. wislizenii*)/canyon live oak (*Q. chrysolepis*), coast live oak (*Q. agrifolia*), and valley oak (*Q. lobata*) vegetation types were considered as WHR valley- foothill hardwood habitat (Mayer and Laudenslayer 1988). The canopy closure classes used by Pillsbury and others (1990) were modified to match those of WHR (table 1). Although some imprecision was introduced in this translation, it still served to refine the distribution of optimal breeding habitat based on differences in vegetation structure over alternative mapping systems such as CALVEG (Parker and Matyas 1979).

Land Ownership

GIS land ownership information was digitized from 1979 Bureau of Land Management Surface Management Status Maps (1:100,000 scale) updated by using the most current National Forest maps. Ownerships that contained valley-foothill hardwood habitat were categorized as reserved or unreserved based on level of habitat protection as follows:

Reserved	Unreserved
Calif. Dept. of Parks and Recr.	Calif. Dept. of Forestry and Fire Protection
Calif. Dept. of Fish and Game	Other State lands
U.S. Fish and Wildlife Service	Bureau of Indian Affairs
National Park Service	Bureau of Reclamation
U.S. Forest Service	Bureau of Land Management
Wilderness Areas	U.S. Forest Service (other)
Research Natural Areas	Department of Defense
Special Areas	Private Lands
City/County/Regional Wildland Parks	

Identification of Key Species

We identified key species as those most likely to be affected by habitat loss in the valley-foothill hardwood type. These species should be expected to receive the greatest emphasis in

Table 1—*Translation used to convert Pillsbury and others (1990) canopy cover classes to WHR classes.*

	Canopy Closure				
Source	Scattered	Sparse	Open	Moderate	Dense
Pillsbury and others (1990)	<10 pct	10-33 pct	N/A	34-75 pct	>76 pct
WHR (Mayer and Laudenslayer 1988)	N/A	10-24 pct	25-39 pet	40-59 pct	>60 pct

identifying areas for possible protection (Diamond 1976, Rapoport and others 1986).

Key species were identified using a two-step process from the original list of 91 species that found optimum breeding habitat in the valley-foothill hardwood type. First, the WHR database was used to calculate for each species the percent of: one degree of latitude and one degree of longitude blocks occupied in California, WHR habitat types occupied, WHR habitat types for which at least one stage was rated as optimal for breeding, and total WHR habitat stages rated as optimal for breeding for all habitat types occupied. Percentage values were then summed and species ranked by their cumulative scores. Species with low scores were preliminarily identified as key species. This procedure eliminated those species that occupied large geographic ranges and found optimum breeding conditions in many habitats and seral stages.

The preliminary list of key species was modified further to reflect species' tolerance to habitat disturbance, susceptability to avian competitors (e.g., starling and brown-headed cowbird), by requirements for important habitat elements that may be altered management actions (e.g., cavities for nesting), whether a native species or introduced, and legal or management status (California Department of Fish and Game 1990). Application of these criteria resulted in the deletion of the American crow (*Corvus brachyrhynchos*), scrub jay (*Aphelocoma coerulescens*), wild turkey (*Meleagris gallopavo*), fallow deer (*Cervus dama*), and wild pig (*Sus scrofa*) and addition of western bluebird (*Sialia mexicana*), ash-throated flycatcher (*Myiarchus cinerascens*), burrowing owl (*Athene cunicularia*), and long-eared owl (*Asio otus*).

Species Rich Areas Identified by Different Methods

The effect of using canopy closure information and selection of key species on the outcome of the species richness analysis was conducted by calculating the extent of overlap between areas mapped in equivalent species richness classes (high, high- moderate, moderate, low) for all 91 species, 41 key species, and 41 key species with canopy closure information. If the locations of areas identified in each richness class were similar for each analyses, it would indicate that the additional efforts needed to identify key species and canopy cover requirements and to map canopy structure classes may not be worth performing in future efforts to identify areas of species richness in the valley-foothill hardwood habitat type.

Species richness class ranges were first determined for the 41 key species/canopy closure analysis by plotting number of species against canopy closure. The resulting histograms defined the range for each species richness class. To compare the overlap in species rich areas identified under the three analyses it was necessary to ensure that each species richness class contained similar acreages for the 91 species and 41 key species analyses. Therefore, the acreage within each species richness class for the 41 key species/canopy closure analysis was used to define the cut points for species richness classes for the 91 species and 41 key species maps. The extent of overlap between equivalent species richness classes was then compared for each of the three analyses as a measure of map similarity.

RESULTS

Procedures for the Identification of Species Rich Areas

Species rich areas were identified statewide for each of the three analyses. The central Sierra Nevada foothills provide an example to illustrate the changes that occur in the location of species rich areas when canopy closure and species sensitivity is considered. Species rich areas in the central Sierra were identified for all 91 species (without considering species sensitivity or canopy closure information) and occurred primarily at middle elevations (fig. 1). The addition of species sensitivity information to the analysis did not substantially change the distribution of species rich areas (fig. 2). The addition of canopy closure information, however, markedly altered the distribution of species rich areas by largely eliminating previously identified areas of high species richness from this region (fig. 3).

The three analyses were evaluated by comparing the agreement in the assignment of acreage to equivalent richness classes, using the analysis with the 41 key species and canopy closure as the standard for comparison (fig. 4). Restricting the analysis to key species without canopy closure information did not substantially alter the assignment of acreages to species richness classes. Assignments made by all 91 species and the 41 key species, however, differed substantially from that made by an analysis of key species in concert with canopy closure information.

The largest blocks of high richness area were in the Sierra Nevada foothills in Mariposa, Madera, Fresno, Tulare, and Kern Counties. Substantial but scattered concentrations of these areas were found in the central Coast Range from Contra Costa County south to San Diego County. More isolated areas of high species richness were in Tehama County and the inner Coast Range in Yolo and Glenn Counties.

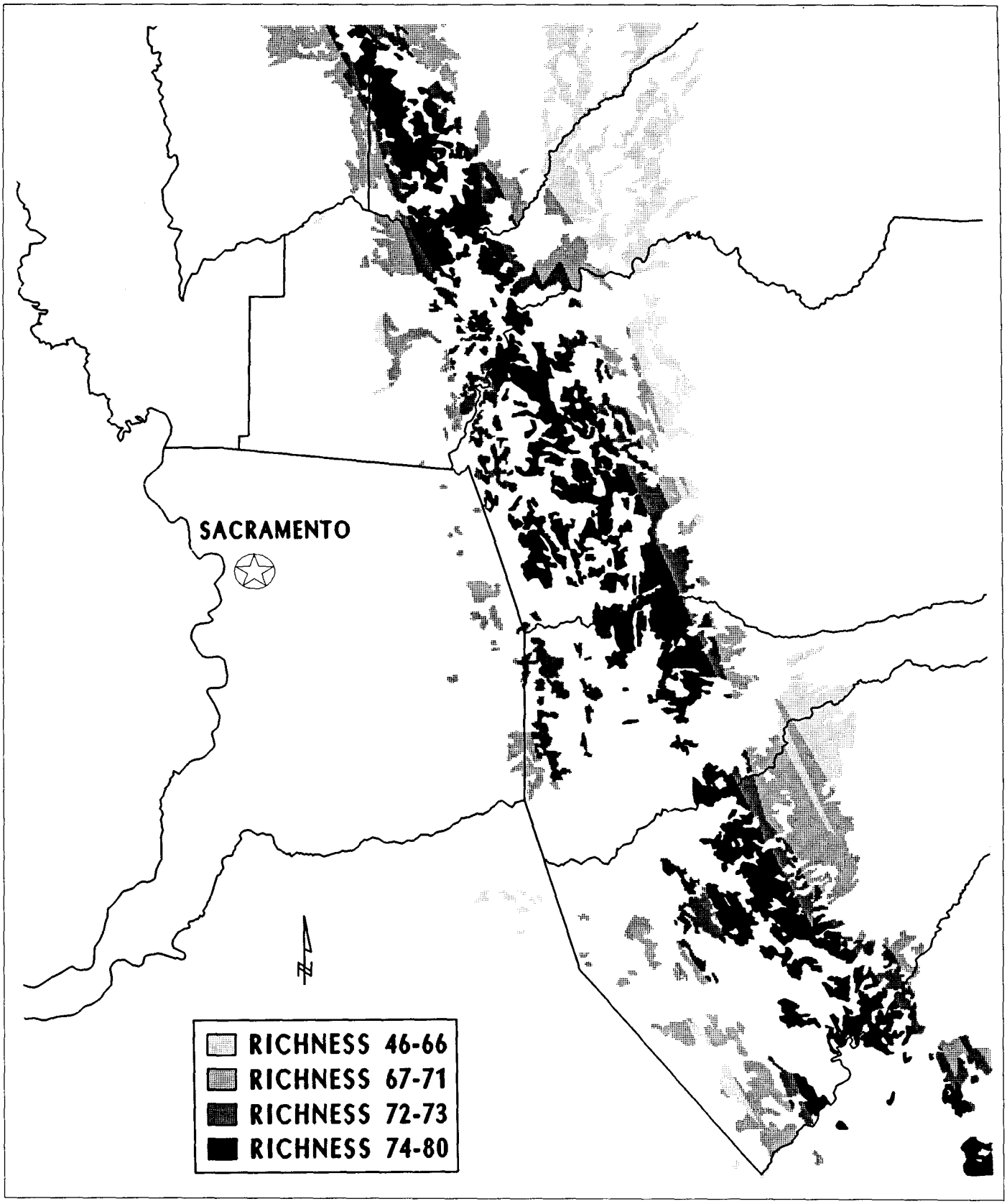


Figure 1—Distribution and extent of species–rich areas for 91 breeding species in the central Sierra Nevada foothills.

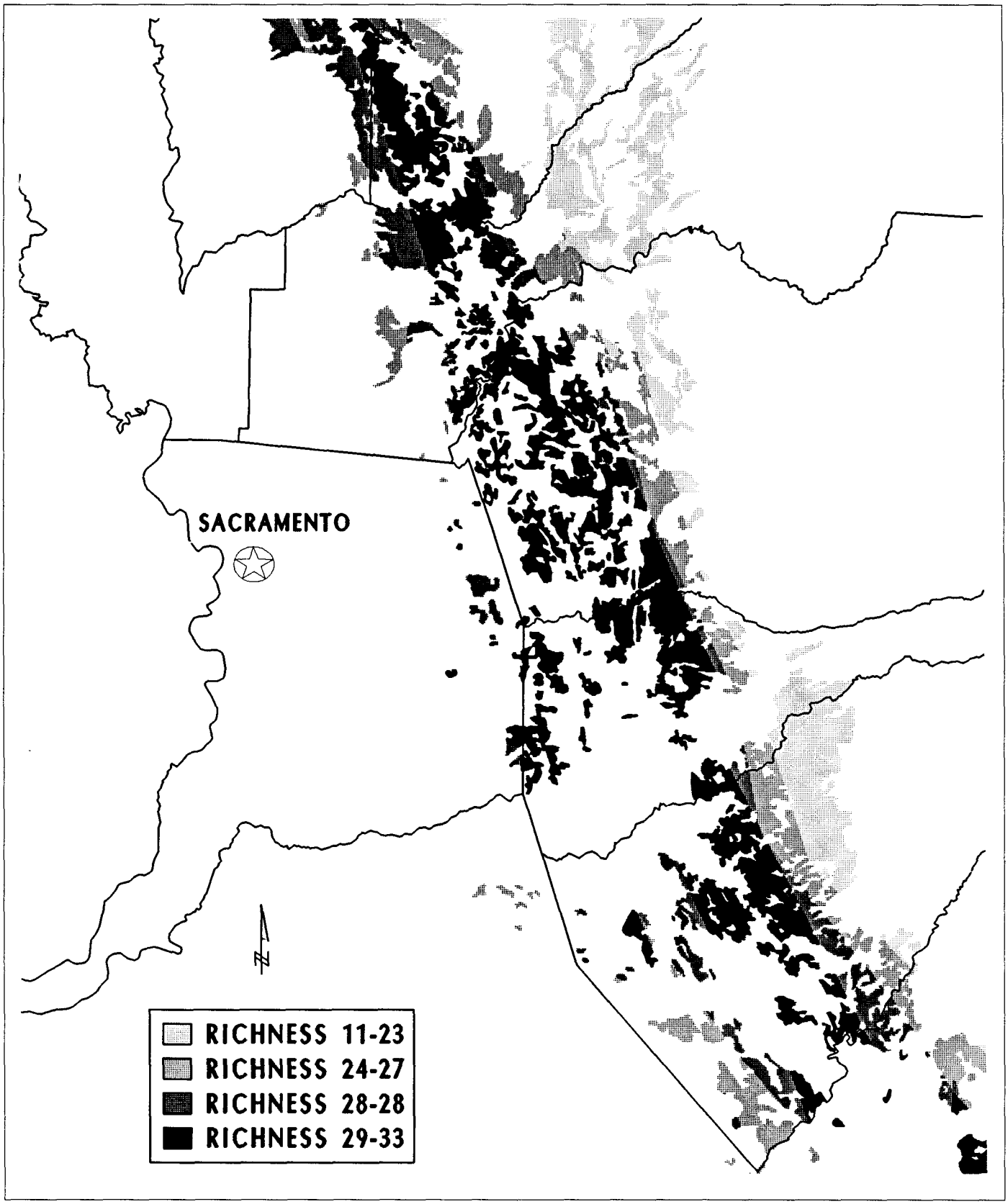


Figure 2—Distribution and extent of species–rich areas for 41 breeding species in the central Sierra Nevada foothills.

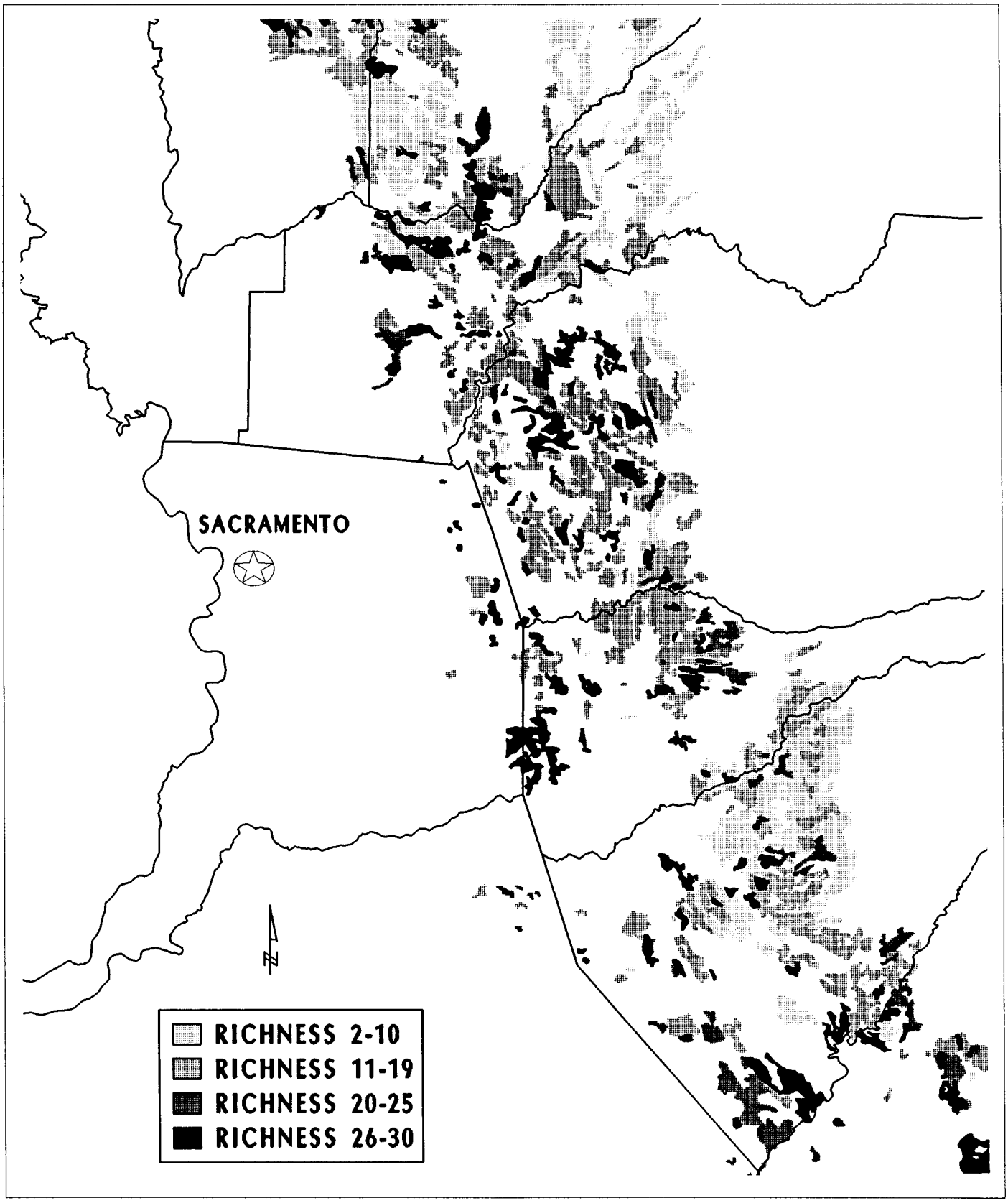


Figure 3—Distribution and extent of species–rich areas for 41 key breeding species including optimal canopy closure for breeding in the central Sierra Nevada foothills.

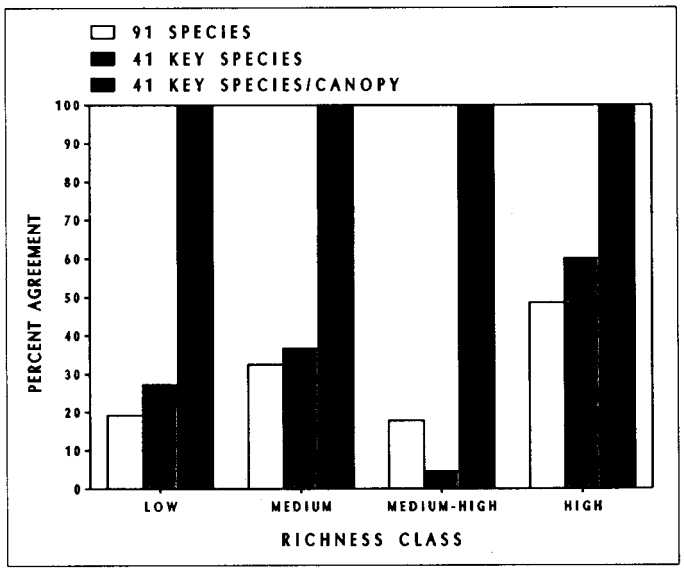


Figure 4—Predictive agreement of three different species richness methodologies by richness class for a statewide analysis of valley–foothill hardwood habitat.

Table 3—*Valley-foothill hardwood habitat type ownership by canopy closure class.*

Ownership	Canopy closure class-thousand acres			
Reserved	Dense	Moderate	Sparse	Total
Calif. Dept. Parks and Recreation	12	17	16	45
U.S. Forest Service	9	27	52	88
Other Public	5	13	16	34
Total Acres	26	57	84	167
Percent of Total Reserved	16	34	50	
Percent of Grand Total	0.6	1.3	1.9	
Unreserved				
Bureau of Land Mgmt	33	53	72	158
Dept. of Defense	2	33	70	105
U.S. Forest Service	39	106	176	321
Other Public	4	12	21	37
Private	529	1,405	1,768	3,702
Total Acres	607	1,609	2,107	4,323
Percent of Total Unreserved	14	37	49	
Percent of Grand Total	13.5	35.8	46.9	

Because most species were predicted by WHR to favor stands with sparse canopy closure (table 2), the addition of canopy closure data tended to identify as highest richness, areas in the southern part of the state where sparse canopy closure is most common. Conversely, the dense canopy closure class which is more common in the north state showed the lowest level of species richness and overall acreage.

Land Ownership of Species Rich Areas

The valley-foothill hardwood habitat is not well protected in California based on ownership (table 3). Approximately 3.8 percent of a total 4.5 million acres are reserved. If all Department of Defense lands are considered a reserved ownership, as suggested by Jensen (1983), the total increases to 6 percent. Eighty-two percent of the habitat acreage is privately owned. Although private sanctuaries and refuges were not classified as reserved in our analysis, they would not add significant acreage to the reserved total.

Areas with high species richness were also not well protected (table 4). Only 4.5 percent of the acreage in the highest species richness class was reserved. Similarly, 4.3 percent of the lowest species richness class, corresponding to the most dense canopy closure, is reserved.

Table 2—*Canopy closure associations for 41 key species finding optimum breeding habitat in the valley foothill hardwood habitat type.*

CANOPY CLOSURE	NUMBER OF SPECIES
Sparse	15
Sparse and Moderate	11
Sparse/Moderate/Dense	10
Moderate	0
Moderate and Dense	3
Dense	2
Total	41
Cumulative Total by Canopy Closure Class	
Sparse	36
Moderate	24
Dense	15

Table 4—*Species richness classes and ownership by percent of total acres for the 41 key species/canopy closure analysis.*

	Species Richness Class			
Ownership	2-10	11-19	21-25	26-30
Reserved				
Calif. Dept. Parks and Recreation	1.8	1.0	0.6	0.9
U.S. Forest Service	1.3	1.7	1.5	2.9
Other Public	1.2	0.6	0.8	0.7
Total	4.3	3.3	2.9	4.5
Unreserved				
Bureau of Land Management	5.6	3.4	4.2	1.9
Dept. Defense	0.4	2.0	4.1	2.7
U.S. Forest Service	7.5	6.8	8.1	6.8
Other Public	1.3	0.8	0.4	1.3
Private	80.9	83.7	80.3	82.8
Total	95.7	96.7	97.1	95.5
Total Acres (thousands)	680	1,726	978	1,121

DISCUSSION

Three attempts have been made to quantify the level of protection provided California's plant communities from a statewide or multi-ownership perspective. Klubnikin (1979) used Kuchler's (1977) map of potential natural vegetation of California to assess occurrence of vegetation types within parks and other reserved lands. Jensen (1983), inventoried the presence or absence of 65 natural communities within state and federal managed areas in each physiographic province of the state. California Department of Forestry and Fire Protection (1988) summarized the approximate percentage of each cover type reserved regionally and statewide. However, vegetation structure and wildlife habitat relationships information were not included in these analyses.

As Scott and others (1987) noted, the most obvious way to determine the current protection of biological diversity is to identify the occurrence of species and communities in protected areas. Our study tested the usefulness of incorporating canopy cover information and species sensitivity in identifying species rich areas. We interpreted differences in the location of high richness areas between our refined and the less detailed approach as evidence that the predictive ability of these maps were substantially changed by incorporating the mapped canopy closure values and species' preferences for canopy closure.

Use of canopy closure information identified stands with sparse cover as exhibiting highest species richness. These areas, however, are highly interspersed with other stands of dense canopy closure. Selecting areas for management based solely on species richness would omit key species that favor or are restricted to areas of dense canopy closure. Specific reserve areas selected for protection, if large enough, would usually include areas of each canopy closure class. The markedly smaller amount of acreage of dense canopy closure in the valley-foothill hardwood habitat also argues for the protection of examples of all canopy closure classes within regions if doing so adds to overall species richness.

The use of optimum habitat to define species distribution for the analysis is consistent with recommendations by Ruggiero and others (1988). Persistence of a species' population is determined by reproductive success and survival rates, which are both influenced by habitat suitability. Habitat suitability for species may be modified by succession or management actions. Therefore, habitat preferences may need to be more carefully considered as human activities alter habitat conditions. Reserve design and management must recognize the dynamics of vegetation change to maintain habitat quality for species of concern.

Several levels of more detailed data could be incorporated into the methodology to identify species rich areas at a statewide scale. These include addition of other vegetation structural components (e.g., tree size class), site specific locational data for threatened and endangered or other species of special concern, refinement in the definition of reserved areas, improvements in species-habitat relationship models, and inclusion of other species and sensitive plant communities. Conducting richness analyses for specific areas of the state (e.g., faunistic or biogeographic provinces [Udvardy 1969, Udvardy 1975]) could improve the identification and procedures for ranking species rich areas.

Consideration of other species groups, whose distributions are well known (e.g., trees [Griffin and Critchfield 1972], and fish [Moyle 1976]) could improve the species richness methodology. Similarly, species that occur in aquatic types that cross several terrestrial habitats could be incorporated. Lepidoptera have been recommended for inclusion in species richness analysis (Scott and others 1988), but maps of their ranges are not available for California (Davis and others 1990).

Areas of high species richness that we identified differed geographically in their wildlife species composition in that the highest species richness sites never supported more than 30 of the 41 key species (fig. 3). Thus, ensuring protection of the maximum number of species requires examining individual species distributions and selecting areas of high species richness that include all species.

Although the WHR database models have received extensive use, model evaluation has been infrequent and generally confined to information on the presence or absence of bird species. WHR model evaluations have indicated that substantial variation exists in the accuracy of predictions of species occurrence in habitats (England and Anderson 1985, Raphael and Marcot 1986, Dedon and others 1986, Avery and van Riper 1990). Predictions of species' habitat suitabilities within individual canopy closure classes of a habitat are less accurate (Airola 1988). WHR models are updated and verified by research and use of the system, test results reinforce the caveat that the models should be used with caution and are more reliable over large geographic areas (Raphael and Marcot 1986) as in this analysis.

This study examined a methodology to be used with current information as well as with future improvements to the WHR system. The methodology is valuable for identifying high species richness areas that may warrant retention to maintain the state's biological diversity. Once high richness areas are identified, they may be analyzed by resource allocation models such as CALPLAN (California Department of Forestry and Fire Protection 1988) to assess projected future conditions (e.g., probability of land conversion) to further evaluate management priorities.

Successful use of results of species richness analyses depends on several practical considerations. The areas of high species richness identified on a statewide basis should guide the selection of potential management areas. Site specific considerations, however, are highly important in ranking local habitats for protection. These considerations may include the:

1. size of available high quality habitat parcels;
2. presence of existing protection areas that can be augmented;
3. extent of connection with or isolation from other suitable habitats;
4. presence of important special habitat elements;
5. proximity to other habitats with high protection priorities;

6. effects of existing and future land uses occurring on adjacent lands;
7. the presence of highly sensitive species;
8. land and incentive program costs; and
9. public acceptance of land protection.

Combining the identification of species rich areas with current strategies that emphasize site protection for rare species and significant natural areas (Hoshovsky 1989) also will provide a more comprehensive conservation effort. As Scott and others (1988:p44) noted "it is easier and more cost-effective to protect intact, functioning ecosystems with their myriad species than to initiate emergency room conservation measures for one endangered species after another, or to wait until common species become endangered before acting to protect them." We believe that the use of habitat structure and species sensitivity information in species richness analyses to identify priority land areas enhances this proactive approach to species conservation.

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Wildlife Diversity in Valley-Foothill Riparian Habitat: North Central vs. Central Coast California[1]

William D. Tietje Reginald H. Barrett Eric B. Kleinfelter Brett T. Carré[2]

Abstract: Habitat characteristics and diversity of terrestrial vertebrates were studied September 1989 to August 1990 in valley-foothill riparian habitat on two study areas: Dye Creek, Tehama County, and Avenales Ranch, San Luis Obispo County, California. The assumption considered was that differences between study areas in physical and vegetation characteristics would be reflected in wildlife diversity. Spring-season results showed that species richness of both higher plants and terrestrial-vertebrate wildlife averaged about twice as great at Dye Creek as at Avenales Ranch. No differences in vegetation structure between study areas were evident, thus, other factors such as elevation, mean annual rainfall, and plant-species richness were apparently influencing terrestrial vertebrate richness on these sites.

Valley-foothill riparian habitat (Mayer and Laudenslayer 1988) is vital for wildlife on California's three million ha (Bolsinger 1988) of oak-woodland (Griffin 1988) habitat. Valley-foothill riparian habitat provides for the needs of more California mammals than any other habitat in the state (Williams and Kilburn 1984). No other habitat in California compares in either bird density or species richness (Laymon 1984). Reptiles and amphibians also abound (Brode and Bury 1984).

During the past decade, Californians have become increasingly concerned about degradation of the state's valley-foothill riparian habitat and reductions in the wildlife that depend on it. The major oak component of valley-foothill riparian habitat, valley oak (*Quercus lobata*), is not regenerating well (Griffin 1971, 1976, Steinhart 1978, Muick and Bartolome 1986). Coupled with poor regeneration is increased use of valley-foothill riparian areas for livestock grazing, intensive agriculture, recreation, urbanization, and wood products. To ensure that oaks and wildlife remain a healthy component of valley-foothill riparian areas, it is imperative that we learn more about the characteristics that make riparian habitat of particular value to wildlife. With this information, land managers and biologists will be better prepared to develop management strategies for maintaining the valley-foothill riparian resource. Here we report preliminary results from spring 1990 sampling of valley-foothill riparian habitat characteristics and terrestrial vertebrate wildlife diversity (richness) at two geographic locations in California.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, 31 October 1990—November 2, 1990, Davis, California.

[2]Natural Resources Specialist, Associate Professor of Wildlife Management, and Graduate Students, respectively, all of the Department of Forestry and Resource Management, University of California, Berkeley, California.

STUDY AREAS

Dye Creek Study Area

The Dye Creek study area is located at the eastern edge of the Sacramento Valley in Tehama County on the 18,180-ha Dye Creek Ranch, about 25 km southeast of Red Bluff (fig. 1). Topography is generally flat along lower Dye Creek where it dissects the valley floor prior to entering the Sacramento River, but rugged at the valley edge where the creek enters the foothills of the Sierra Nevada. Elevation ranges from 76 m in the valley to 762 m in the foothills (Barrett 1978); mean elevation of valley-foothill riparian habitat where study data were collected was 115 m (range 75 to 180 m).

Average monthly temperatures at Dye Creek range from 7° C in January to 27° C in July and average yearly precipitation on the study area totals about 65 cm (Barrett 1978). Little rain falls during summer—90 pct of the yearly total falls in the seven winter months from October to April. Snowfall is rare.

Valley-foothill riparian habitat at Dye Creek is dominated by interior live oak (*Quercus wislizenii*), valley oak, sycamore (*Platanus racemosa*), and white alder (*Alnus rhombifolia*). California wild grape (*Vitis californica*), poison oak (*Rhus diversiloba*), and Himalaya berry (*Rubus procerus*) are important understory species. Since the late 1800's, the primary land-use at Dye Creek has been cattle grazing. A recreational hunting enterprise has operated on the ranch since 1965.

Avenales Ranch Study Area

The Avenales Ranch study area is located in the western foothills of the Coast Range on the 7,085-ha Avenales Ranch in south-central San Luis Obispo County about 34 km east of San Luis Obispo, California (fig. 1). Elevation ranges from 366 to 952 m; at sites where data were collected, elevation averaged 490 m (range 421 to 573 m).

Average monthly temperatures at Avenales Ranch range from 6° C in January to 21 ° C in July. Precipitation averages 53 cm, falling primarily during October to May (U.S. Weather Bureau, Sacramento, CA). Snowfall is rare.

Canopy trees in valley-foothill riparian habitat at Avenales Ranch are valley oak, blue oak (*Quercus douglasii*), coast live oak (*Q. agrifolia*), sycamore, and Fremont cottonwood (*Populus fremontii*). Where subcanopy occurs, it consists of willow (*Salix* spp.), redberry (*Rhamnus crocea*), chaparral honeysuckle

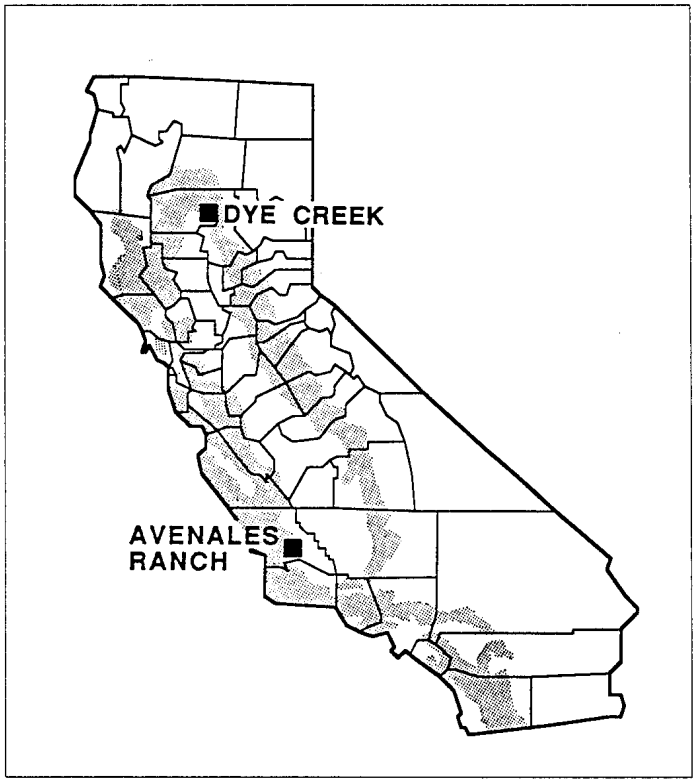


Figure 1—Location of the Dye Creek study area in Tehama County and the Avenales Ranch study area in San Luis Obispo County, California.

(*Lonicera interrupta*), and poison oak. The primary land use since the late 1800's has been cattle grazing.

METHODS

Survey Design

With minor modifications, survey design followed that described by Dedon and Barrett (1982). At each study area, a two-person field crew housed on site collected all habitat and wildlife data. During July and August 1989, the field crews familiarized themselves with the identification of the local flora and fauna, and with field methodologies. Thirty 0.25-ha (50- by 50-m square) permanent sampling plots were established systematically along 10 km stretches of Dye Creek on the Dye Creek Study Area (half the plots were along lower Dye Creek on the valley floor and half along the creek where it enters the Sierra foothills) and Alamo Creek on the Avenales Ranch study area. Plot centers were about 250 m apart; aspects included all cardinal directions. Forty 0.001-ha circular (3.56 m radius) subplots (*elements*) were established at 5-m intervals along eight transects radiating from each plot center (fig. 2). On both study areas, a year of almost daily collection of field data began on 1 September 1989 and continued to 31 August 1990. This period was divided into fall (September to November), winter (December to February), spring (March to May), and summer (June to August) seasons. In this report, data are presented from only the spring season.

Habitat Sampling

On the 20 even-numbered elements within each sampling plot, percentages of an element covered by water, soil (< 2 cm diameter), rock (> 2 cm diameter), litter (< 2 cm diameter), dead wood (> 2 cm diameter), and all live vegetation were estimated ocularly within eight vertical strata (1= ground to 0.5 m, 2 = 0.5 to 2 m, 3 = 2 to 5 m, 4 = 5 to l0 m, 5 = 10 to15 m, 6 = 15 to 20 m, 7 = 20 to 30 m, and 8 = 30 to 40 m). An optical rangefinder was used to assign the vertical strata. Botanical composition was also recorded for each even-numbered element with a cover class (0-5 pct, 6-25 pct, 26-50 pct, 51-75 pct, 76-90 pct, 91-100 pct) estimated for each species (Dedon and Barrett 1982).

All tree stems larger than 2 cm diameter breast high (dbh), i.e., 1.4 m (4.5 feet) above ground level, were identified and the dbh, height, and plant condition (live or dead) recorded. Percent canopy cover for each plot was determined using a spherical densiometer (Lemmen 1956). Basal area was calculated by tree species and diameter class.

Wildlife Sampling

Small mammals were inventoried by positioning a Sherman live trap baited with Purina lab rat chow within each of the 40 elements of each sampling plot. Traps were checked each morning for three consecutive days. Ear marks were used to identify recaptures. A frequency index was calculated as the proportion of the 40 trap stations (elements) that caught at least one individual of a given species. Abundance was the number of different individuals of a given species captured.

One track plate (Barrett 1983) per sampling plot (fig. 2) was used to detect mammalian carnivores. A track plate consisted of two 800- by 400-mm aluminum sheets, blackened by a kerosine flame and placed side-by-side on an area cleared of debris. Track plates were baited with a can of tuna pet food. All tracks found over a 10-day period were identified and measured in the field using keys developed by Taylor and Raphael (1988). Tracks not easily identified in the field were collected by pressing transparent tape over the track and mounting it onto a white sheet of paper for later identification and measurement. Freshly blackened plates were provided as necessary.

Ungulates (mule deer [*Odocoileus hemionus*], wild pigs [*Sus scrofa*], horses [*Equus caballus*], and cattle [*Bos tarus*]), black-tailed jackrabbits *(Lepus californicus),* broad-foot moles (*Scapanus latimanus*), and Botta's pocket gophers (*Thomomys bottae*) were surveyed by noting presence of sign (droppings and digging) while sampling vegetation within each of the 20 even-numbered elements on each plot.

Pitfall traps were used to capture amphibians, reptiles, and certain mammals. Within each sampling plot, but outside any element (fig. 2), a 19-1 plastic bucket was buried flush with the

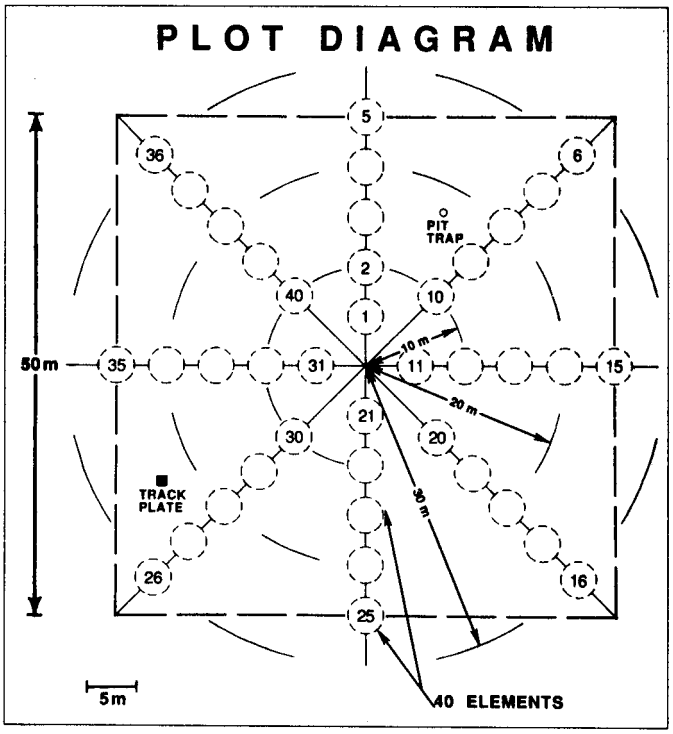


Figure 2—Diagram of a 0.25-ha sampling plot. Elements used for vegetation analysis, dead-and-down wood survey, small mammal trap sites, and animal-signs sampling. The square is a track plate and the small open circle is a pitfall trap.

ground and a square 1- by 46- by 46-cm plywood cover supported by rocks was placed about 7 cm over it. Pitfall traps were run consecutively with track plates. Captured animals were identified, marked, and released.

Birds were censused seasonally on each of the 30 sampling plots on each study area using a modification of the variable circular-plot method (Reynolds and others 1980). Counts began 30 minutes after sunrise. During the succeeding 20 ten-minute periods, the species and number of birds detected visually or acoustically (either perched on or flying over the plot) were recorded. Only different individuals were recorded within a 10-minute period, but these individuals could be recorded again in a subsequent period. Cloud cover and wind speed were recorded each 10-minute period; temperature was recorded at the start and end of each bird census.

Finally, we recorded as an incidental observation, any wildlife species or its sign observed anywhere within a sample plot. In this study, a detected wildlife species was counted only if it was judged (based on a review of all observations regardless of technique used) as having a seasonal home range covering at least half of a plot.

Data Analysis

Mean frequency and abundance of all habitat and wildlife variables were calculated across all 30 plots for the Dye Creek and the Avenales Ranch study areas. Student's *t*-tests were used to estimate the significance ($P \leq 0.05$) of study area differences in habitat characteristics.

RESULTS

Physical Characteristics Between Study Areas

At Dye Creek and Avenales Ranch, over three years of drought occurred prior to beginning the study in September 1989. The drought continued during the study period (1 September 1989 to 31 August 1990), but considerably more rain fell at Dye Creek (51.0 cm) than at Avenales Ranch (36.6 cm).

Vegetation Characteristics Between Study Areas

Vegetation Structure.—Vegetation characteristics measured on the Dye Creek and Avenales Ranch study areas were similar (table 1). Most notably, tree canopy cover averaged about 25 pct at both study areas. Although there were several vertical strata-cover characteristics that, ostensibly, were much different between study areas in stratum 1(e.g., rock, litter, forbs and ferns, evergreen broadleaf foliage, and deciduous broadleaf foliage) and in each of the four vegetation characteristics (dead wood, live wood, evergreen broadleaf foliage, and deciduous broadleaf foliage) examined in strata 2-8, the differences were in both directions and none was significant (table 1). The total volume of vegetation on the sampling plots (total live plant cover index) (table 1) was also similar between study areas (83.9 at Dye Creek and 90.0 at Avenales Ranch; $P > 0.05$).

Botanical Composition.—A total of 281 different species of higher plants was recorded at Dye Creek and Avenales Ranch in spring 1990. These included 43 species of grasses, 191 forbs, 31 shrubs, and 16 different tree species. Comparison of plant-species richness between study areas in spring revealed a clear trend (table 2). We observed 1.6, 2.5, 2.8, and 2.9 times as many species of forbs, grasses, trees, and shrubs, respectively, at Dye Creek (209 species) as at Avenales Ranch (111 species) (table 2).

Most recorded plant species, moreover, were unique to either Dye Creek or Avenales Ranch. An average of only 15 pct (range 13 pct for shrubs to 19 pct for trees) of the total number of different species of grasses, forbs, shrubs, or trees found on Dye Creek and Avenales Ranch study areas was found on both (table 2). For example, 11 trees were unique to Dye Creek compared to two on the Avenales Ranch study area; interior live oak was found only at Dye Creek and coast live oak only at Avenales Ranch. Blue oak and valley oak occurred on both sites. The species with the highest frequency times abundance (F by A) for grasses, forbs, shrubs, and trees in spring on the Dye

Table 1—*Comparison of selected habitat characteristics averaged across thirty 0.25-ha plots at the Dye Creek (DC) and Avenales Ranch (AR) study areas (data are presented from four of the eight vertical stata examined) during Spring 1990. One Standard Error (SE) is in parentheses.*

Habitat Characteristic	Study Site DC	AR
Litter and Trees		
Litter depth (cm)	1.3(l.3)	1.0(0)
Canopy height (m)	4.1 (3.8)	3.4 (3.0)
Canopy closure (percent)	25.2 (18.7)	23.0 (21.9)
Basal area (m^2/ha)	7.8 (7.4)	8.2 (6.5)
Selected Vertical Strata Cover (percent)		
Strata 1 ground level; 0.0-0.5 m)		
Water	0.7(l.6)	0.0 (0.0)
Rock	16.9 (11.4)	6.5 (4.2)
Bare soil	10.3 (6.4)	13.7 (6.3)
Litter	18.5 (11.2)	10.6 (4.7)
Dead wood	1.4(l.8)	1.7(l.3)
Moss	1.2 (2.8)	0.2 (0.8)
Grass	26.3 (18.1)	24.4 (9.6)
Forbs and ferns	18.5 (9.8)	42.3 (9.8)
Live wood	0.6 (0.7)	0.4 (0.6)
Evergreen broadleaf foliage	0.6 (0.9)	<0.1 (0.2)
Deciduous broadleaf foliage	5.2 (7.2)	0.1 (0.4)
Strata 3 (2-5 m)		
Dead wood	0.1 (0.3)	1.1 (1.4)
Live wood	1.1 (1.2)	2.5 (2.5)
Evergreen broadleaf foliage	3.4 (4.5)	1.1 (2.6)
Deciduous broadleaf foliage	4.8 (4.4)	2.9 (2.7)
Strata 5 (10-15 m)		
Dead wood	<0.1 (0.2)	0.6(l.0)
Live wood	0.5(l.0)	1.6 (2.2)
Evergreen broadleaf foliage	0.2 (0.5)	0.6(l.9)
Deciduous broadleaf foliage	3.0 (4.5)	2.1 (3.2)
Strata 7 (20-30 m)		
Dead wood	0.0 (0.0)	0.0 (0.0)
Live wood	0.1 (0.4)	0.0 (0.0)
Evergreen broadleaf foliage	0.0 (0.0)	0.0 (0.0)
Deciduous broadleaf foliage	0.2 (l.1)	0.2(l.3)
Total live plant cover index (sum of all living plant cover in the vertical strata)	83.9 (27.5)	90.0 (20.9)

Creek and Avenales Ranch study areas are given in table 3.

Wildlife Characteristics Between Study Areas

Accumulated detections of terrestrial vertebrates on the Dye Creek and Avenales Ranch study areas during spring 1990 totaled 138 different species (table 2). Records included seven species of amphibians, 10 reptiles, 90 birds, and 31 mammals. As with plants, there were more species of amphibians, reptiles, birds, and mammals detected in spring at Dye Creek than at Avenales Ranch (table 2). Species richness of mammals, birds, amphibians, and reptiles was 1.6, 1.7, 1.7, and 2.3 times greater, respectively, at Dye Creek (120 species) as at Avenales Ranch (70 species).

Also similar to the plant data, many species of terrestrial vertebrates detected were unique to each study area (table 2). An average of only 30 pct (range 14 pct for amphibians to 41 pct for birds) of the total number of different species of amphibians,

Table 2—*Numbers of species of plants (by life form) and animals (by class), found during spring at only Dye Creek (DC), only the Avenales Ranch (AR), on both study areas (DC & AR); and the total number of species found on Dye Creek and Avenales Ranch.*

Life form/Class	Only DC	Only AR	Both DC & AR	Total Species DC	AR
Plants					
Grass	29	8	6	35	14
Forbs	108	57	26	134	83
Shrubs	22	5	4	26	9
Trees	11	2	3	14	5
Totals	**170**	**72**	**39**	**209**	**111**
Animals					
Amphibians	4	2	1	5	3
Reptiles	6	1	3	9	4
Birds	43	10	37	80	47
Mammals	15	5	11	26	16
Totals	**68**	**18**	**52**	**120**	**70**

reptiles, birds, and mammals found on Dye Creek and Avenales Ranch was found on both study sites.

During spring, 43 and 10 bird species were unique to the Dye Creek and Avenales Ranch study areas, respectively. Each species was placed into a foraging guild based on information from *The Birder's Handbook* (Ehrlich and others 1988) (table 4). Many more ground feeders and aquatic feeders (mostly ducks) were recorded at Dye Creek than at Avenales Ranch.

Rodent Control on Avenales Ranch

We learned after the study began that during June 26-30, 1989, 1080 (sodium monofluroacetate) had been applied around ground squirrel (*Spermophilus beecheyi*) burrows on about 5,000 ha (application rate of 0.16 kg/treated ha) of the Avenales Ranch (pers. comm.; San Luis Obispo County Agricultural Commissioner's Office). Our study plots were included in the treated area. Field observations indicated that ground squirrel burrows were prevalent during summer and fall, 1989, while sightings of ground squirrels were virtually nonexistent. This observation suggests the poisoning program at Avenales Ranch was so effective that it may have influenced the results of our survey of small mammal populations (and some other wildlife) on the ranch.

Table 3—*Plant species, by life form, with the highest frequency (F) times abundance (A) numbers (F by A) in spring 1990 on the Dye Creek (DC) and Avenales Ranch (AR) study areas.*

	Study area						
	DC			AR			
Life form	Species	F	A	F by A	Species	F	A	F by A
Grasses								
	Ripgut grass *(Bromus diandrus)*	72.5	8.4	609	Slender wild oat *(Avena barbata)*	72.9	9.5	693
	Soft chess *(Bromus mollis)*	50.7	2.8	142	Ripgut grass *(Bromus diandrus)*	53.4	6.2	331
	Hare barley *(Hordeum leporinum)*	25.7	2.7	69	Soft chess *(Bromus mollis)*	67.7	4.6	311
Forbs								
	Broadleaf filaree *(Erodium botrys)*	46.7	9.5	444	Storksbill *(Erodium obtusiplicatum)*	86.2	18.1	1,560
	Barnaby's thistle *(Centaurea solstitialis)*	51.0	2.6	133	Redstem filaree *(Erodium cicutarium)*	59.8	7.6	455
	Proliferous pink *(Tunica prolifera)*	50.8	1.5	76	Clarkia (Clarkia spp.)	27.9	2.0	5 6
Shrubs								
	Himalaya-berry *(Rubus procerus)*	13.0	2.3	30	Chaparral honeysuckle *(Lonicera interrupta)*	5.0	0.3	2
	Poison oak *(Rhus diversiloba)*	18.8	0.9	17	Poison oak *(Rhus diversiloba)*	3.2	0.3	1
	California wild grape *(Vitis californica)*	11.5	1.1	13	Redberry *(Rhamnus crocea)*	2.0	0.3	1
Trees								
	Valley oak *(Quercus lobata)*	16.7	5.3	89	Blue oak *(Quercus douglasii)*	18.0	5.7	103
	Interior live oak *(Quercus wislizenii)*	18.0	3.4	61	Valley oak *(Quercus lobata)*	7.8	3.5	27
	Blue oak *(Quercus douglasii)*	7.5	2.0	15	Coast live oak *(Quercus agrifolia)*	5.5	2.5	14

Table 4—*Number of bird species that were unique to Dye Creek (DC) and Avenales Ranch (AR) study areas during spring 1990, grouped by foraging guilds.*

	Study area	
Guild	DC	AR
Omnivores	4	0
Ground feeders	13	1
Foliage gleaners	3	4
Bank feeder	1	0
Air insect feeders	1	2
Aquatic feeders	16	0
Vertebrate feeders	5	3
Totals	43	10

DISCUSSION

The most apparent difference between oak riparian habitat at Dye Creek Ranch, Tehama County, and Avenales Ranch, San Luis Obispo County, is the greater number of higher plant and terrestrial vertebrate wildlife species at Dye Creek. Physical and vegetation factors may be involved. Perhaps reflected in the presence of more aquatic-feeding birds, Dye Creek has a higher rainfall than the Avenales Ranch. Moist sites commonly have greater plant and animal diversity than dry sites (Harris 1984, Perkins and others 1984, Krzysik 1990). Avenales Ranch was especially dry during the study; the 1989 to 1990 field season occurred during the fourth year of a severe drought on California's central coast. Terrestrial vertebrate species diversity also increases with vegetation diversity (Smith 1986). The data analyzed to date do not show that vegetation structure was more complex at Dye Creek although plant-species richness was greater.

Diversity of terrestrial vertebrates in California's three million hectares of oak woodland habitat is high, apparently due to regional and local differences in temperature, rainfall, botanical composition, and vegetation structure. In a field study conducted during 1986-1988 in oak woodland habitat at three study sites, Block (1989) accumulated 90 species of birds during the spring breeding seasons in north-central California (Sierra Foothill Range Field Station, Yuba County), 88 species in southeast California (San Joaquin Experimental Range Field Station, Madera County), and 83 species in south-central California (Tejon Ranch, Kern County). Notably, this trend of fewer species from north to south parallels the trend in the present

study. During spring and fall 1988 at the Sierra Foothill Range Field Station, two amphibian, seven reptile, and seven small mammal species were detected (Block and Morrison 1990).

To what extent a rodent control program caused a low trapping frequency of small mammals at Avenales Ranch is unknown. Since the poisoning certainly depressed ground squirrel numbers on Avenales Ranch, it may have affected occurrence of other animals as well. But, consistently fewer species of amphibians, reptiles, birds, and mammals at Avenales Ranch compared to Dye Creek suggests that other factors, such as geographic location of the study areas, mean annual precipitation, and vegetation composition and structure were more influential for most wildlife species. This set of circumstances highlights the importance of care in choosing a study area and of replicating study areas to minimize the effect of confounding by uncontrolled factors.

We have presented only partial results from only one season of a year-long study. When all available data have been analyzed we expect to provide recommendations on what specific characteristics of riparian habitat are correlated with the presence of particular wildlife and the implications for managing valley foothill riparian habitat for wildlife in conjunction with other land uses.

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Covariance Patterns Among Birds and Vegetation in a California Oak Woodland[1]

Randolph A. Wilson Patricia Manley Barry R. Noon[2]

Abstract: We sampled characteristics of vegetation and estimated abundances of bird species on 23 plots representing a continuum of tree densities of the blue oak phase of the Coast Range foothill woodland near Hopland, California. Fifty-one bird species were found breeding. Cavity-nesters dominated the bird community in number of species and individuals. Cavity-nesters used a variety of tree species for nesting, highlighting the importance of tree species richness. Large deciduous oaks were found to be important as granary trees for acorn woodpeckers, as well as substrates for nest cavity excavation by primary cavity nesters. Large evergreen trees were important in providing natural cavities to many secondary cavity nesting bird species. Both individual bird species and guilds showed few covariations with tree density. We discuss why a guild approach is not always a useful way to describe relationships between bird abundance and vegetation. Effects of spatial scale and plot size on observed bird/habitat relationships are discussed.

Approximately eight million hectares in California, or 20 percent of the state's land area, are vegetated by one or more species of oak (*Quercus* spp.). The rate of harvest of oak trees in California, however, has increased to the point where many oak habitats are threatened. Fuelwood harvest, for example, has increased steadily since 1959, turning sharply upward in 1973 (Menke and Fry 1980, Walt and others 1985). The rate of conversion of oak woodlands to pasture land and for agricultural, residential and commercial development has also increased markedly since 1973 (Bolsinger 1987). Unfortunately, the harvest of oaks may severely reduce habitat quality for many wild animals, or preclude some wildlife species entirely. A further problem is that many oak woodlands are experiencing very poor regeneration and extremely low seedling and sapling survival. The exact cause for the low recruitment is unknown, but has been attributed in some cases to excessive predation by small mammals (Griffin 1980, Knudsen 1987) and overgrazing by deer and cattle (Bowyer and Bleich 1980, Griggs 1987).

In the face of these threats and an increasing trend of exploitation, it is particularly disturbing to discover that there remain significant gaps in our understanding of the relationship between California wildlife and oak woodlands. Muick and Bartolome's (1985) listing of studies conducted in California oak habitats between 1953 and 1985 included 16 bird studies, 15 mammal studies, and only one reptile and amphibian study. Few of these studies addressed the results of habitat disturbance or habitat loss on the wildlife community.

California oak woodlands are particularly rich in bird species—approximately 110 species of birds can be observed during the breeding season (Verner 1980). Verner (1983) reported that oak woodlands in North America rank among the top three habitat types in the number of bird species for which they provide breeding habitat. In order for a resource manager or agency to make recommendations on the management of oak woodlands for birds, more information is needed on how birds respond to variation in the vegetation structure and composition of these habitats. For example, at this time the density, size, or spatial distribution of trees required to meet the needs of the bird community on managed woodlands is unknown. It is important that the needs of the wildlife community be considered along with economic and aesthetic considerations in the management of California's oak woodlands.

Two silvicultural options which can easily be targeted for management are the residual density of trees remaining after the harvest and tree species composition. Tree density and tree species composition can be optimized for a variety of purposes including regeneration potential, forage production, aesthetic quality, and wildlife value. This paper reports on the relationship among various attributes of the breeding bird community and the vegetative community, primarily tree density and tree species composition. The relationship of the bird community to the vegetative community is defined by changes in bird species composition and changes in the abundance of particular bird species. In addition, we described the nest site selection patterns of the cavity nesting birds and granary tree selection by acorn woodpeckers. Selection was explored in terms of used and available tree species and tree diameters.

STUDY AREA

The study area was located at the University of California Hopland Field Station five miles east of Hopland, in Mendocino County, California. The dominant vegetation was the blue oak (*Quercus douglasii*) phase of the Coast Range foothill woodland (Griffin 1977). Blue oak was the dominant tree species in association with valley oak (*Q. lobata*), interior live oak (*Q. wislizenii),* California black oak (*Q. kelloggii*), Oregon white oak (*Q. garryana*), California bay (*Umbellularia californica*), and buckeye (*Aesculus californica*). Annual grasses and forbs dominated the ground cover. Adjacent vegetation types in-

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cluded chaparral, mixed hardwood and conifer forest, and meadows. Sheep grazing was the primary land use.

The topography was characterized by moderate to steeply sloped hills. The study area had a westerly aspect and covered an elevational gradient ranging from 200 to 1000 meters. The steep westerly aspect promoted vegetative growth along east-west strips aligned with intermittent streams and ravines. The ravines, dominated by live oaks, bay, and shrubs, dissected upland habitats, dominated by deciduous oaks. Average rainfall was 90 cm, generally occurring between September and June.

METHODS

Study Plots

Twenty-three, five ha (100 by 500 m) study plots were established throughout the continuum of available tree densities in the 2,143 ha study area. Plots were systematically selected to represent a steep gradient in tree density. For individual plots, uniform tree density and distribution within and adjacent (within 50 m of plot boundary) to the plots were criteria for placement. Plot width was based on the ability to detect and accurately map the location of birds. Plots were spaced at least 100 m apart and dispersed throughout the study area.

Censusing

The fixed-width belt transect method was used to collect data on the bird community (Christman 1984). Each plot was censused once per week between late March and mid-June during 1986 and 1987 for a total of ten censuses per plot per year. Censuses were conducted between 0500 and 0900 Pacific Standard Time. A census consisted of walking down the center transect line of a plot at a pace of 50 m every six minutes and mapping the location and recording the behavior of all birds detected within 50 m on either side of the transect line. The total area censused for each plot was 5 ha. Each census required one hour to complete. Bird species abundances were described by estimating the mean number of detections occurring within 50m of the transect line per census for each bird species on each plot (1986 and 1987 data combined).

Nest Search

During the spring of 1986, we located as many nests as possible of all breeding species. During 1987, we focused on locating nests of cavity nesting species. Nests were located opportunistically and by active search.

Vegetation Measurements

The vegetation on each plot was described by mapping the location and recording descriptive information on each individual woody plant. We recorded the following information for each plot: species, total height, diameter at breast height (DBH), number of natural and excavated cavities, and use as a granary tree. Tree height was measured primarily by ocular estimation. DBH was measured with a diameter tape. Trees with natural and/or excavated cavities were each categorized as containing 0, 1-3, or >3 cavities. Cavities were counted when the entrance appeared of suitable dimensions for use by cavity nesting birds. Acorn woodpecker granary tree use was categorized as: no evidence of use, <10 percent use, or >10 percent use. These categories reflect the variation in use patterns observed on our study plots.

Data Analysis

A variety of univariate and multivariate analyses were used on each data set. Normality of the data was assessed by visual inspection of histograms. Some variables required normalizing transformations. Analysis of variance and Tukey's test were used to describe relationships between tree diameter and cavity abundance, and between tree diameter and use as granary trees. Chi-square goodness-of-fit tests were used to test for differences in use versus availability of tree species for cavities and granary trees. Bonferoni's normal statistic (Neu and others 1974) was used to determine which tree species were used greater or less than available. A total of 412 trees, with ≥ 1 excavated cavity, were assumed available for secondary cavity nesters, and we assumed that all trees (n =16,066) on our plots were available for primary cavity nesters. An alpha of ≤ 0.05 was used for all tests of significance.

We estimated the value of a large number of structural and compositional vegetation variables. The major axes of variation in the vegetation among plots were estimated by principal components analysis (PCA) from a correlation matrix of 22 untransformed vegetation variables described by their mean values and counts for each study plot. Variables used in the analysis represented both the vegetation structure and composition of each study plot. The PCA included a varimax rotation of the principal components followed by ordination of each study plot according to its standardized factor scores.

Weighted average positions of the 10 most common bird species were computed for the three-dimensional vegetation space estimated by PCA. Species coordinates were computed by weighting each plot's ordination scores by the species' abundance on that plot, summing these weighed scores and then dividing by the sum of the weights.

We investigated the potential influence of plot size on observed vegetation patterns. Canopy closure, which was highly correlated with tree density and distribution, was used as an indicator of the vegetation heterogeneity in the study area. Canopy closure was estimated at four different plot sizes (5, 10, 20, and 50 ha). Concentric 10, 20, and 50 ha plot boundaries

were drawn on mylar overlays around the boundary of the 5 ha study plot. Canopy closure was estimated with a dot grid by overlaying the mylar on air photographs (1:7000 scale) of each study plot and counting dots obscured by overstory canopy.

All possible subsets regression was used to select a "best" subset of vegetation variables (independent variables) to explain variation in the abundance of individual bird species and bird guilds (dependent variables). Bird species were grouped into eight guilds based on foraging behavior (bark foragers, air salliers, foliage gleaners and ground foragers), nesting behavior (primary cavity nesters and secondary cavity nesters), and season of residence (winter residents and migrants). All possible subsets regression using Mallow's Cp criterion was chosen because it provided a "best" subset which minimizes the total mean squared error of fitted values (Neter and others 1985:421). A set of 11 variables describing the composition and structure of the vegetation was available as independent variables. These included numbers per 5 hectares of the following tree species: blue oaks, black oaks, white oaks, evergreen oaks, buckeyes, shrubs, and snags. Other variables include number of cavities, canopy cover, average basal area, and tree diversity. The abundance of individuals of each species and bird guild were used as dependent variables.

RESULTS AND DISCUSSION

Bird Community

Seventy-two bird species were detected during censusing in 1986 and 1987. Based on territorial behaviors, 49 were believed to be breeding species. These results provide additional confirmation of the richness of breeding bird species in California oak woodlands (Verner 1980). Relative to other California oak woodlands, the Hopland Field Station had high numbers of breeding bird species. Block (1989) recorded a range of 40-43 breeding bird species detected in three other oak woodlands in California during the same time period. The high number of breeding bird species in our study area may be partially attributed to the relatively high annual rainfall per year, and proximity to conifer dominated habitats. The latter factor accounts for a number of observed species that were near the southern limit of their breeding distribution.

Of the ten most abundant bird species detected over all study plots, six were cavity nesting species (table 1). Primary and secondary cavity nesters comprised approximately 25 percent (12 species) of the breeding bird species and almost 60 percent of the breeding individuals (fig. 1). Our estimate of the relative number of cavity nesting species is comparable to conifer dominated habitats across the western United States (Scott and others 1980, Raphael 1981). However, our estimate of the relative density of cavity nesters is considerably higher than for most temperate breeding bird communities (Scott and others 1980).

Table 1—*Ten most abundant breeding bird species across all study plots, Hopland, CA (1986-1987)*

BIRD SPECIES	#/40 HA[1]	S.E.[2]
VIOLET-GREEN SWALLOW[3]	58.2	5.0
PLAIN TITMOUSE[3]	49.0	2.6
ACORN WOODPECKER[3]	25.6	2.5
LESSER GOLDFINCH	20.2	2.8
AMERICAN ROBIN	16.4	2.0
WHT-BREASTED NUTHATCH[3]	13.7	1.2
SCRUB JAY	11.0	1.5
MOURNING DOVE	10.5	1.2
EUROPEAN STARLING[3]	10.3	2.5
WESTERN BLUEBIRD[3]	10.2	1.3

[1]Abundance estimates are mean number of detections over all plots, 1986 - 1987.
[2]Standard error of the mean abundance.
[3]Cavity nesting species.

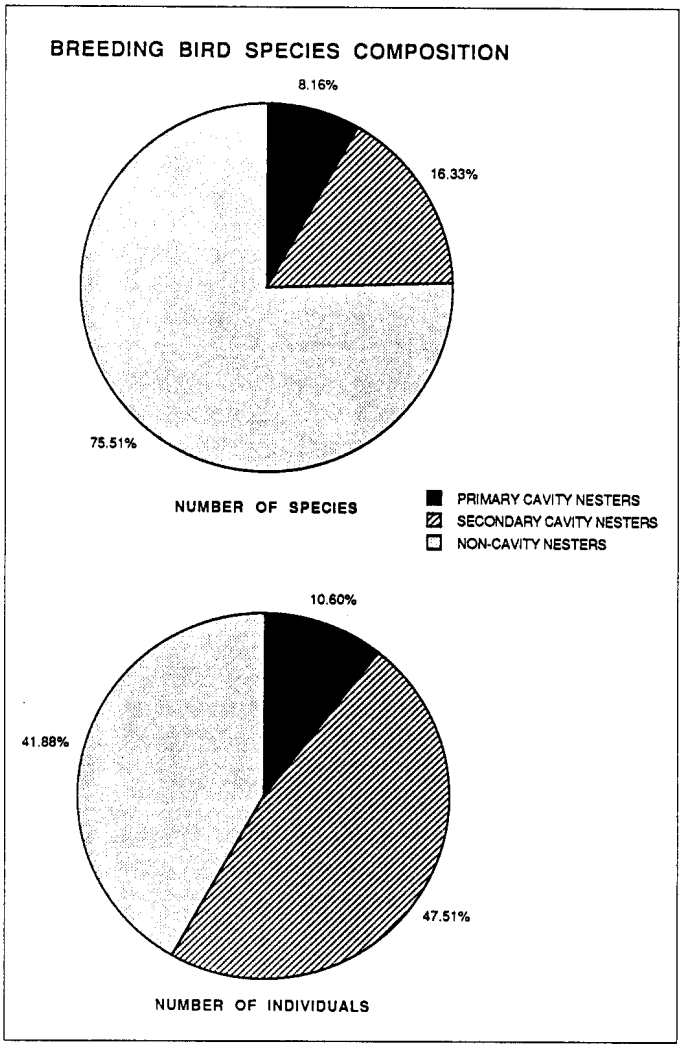


Figure 1—Proportion of the breeding bird community comprised of cavity nesting (primary and secondary) and open-nesting species. Abundances are estimated from census data for all 23 study plots during both breeding seasons (1986 and 1987).

Vegetation

We counted approximately 16,000 trees of eight oak and four other tree species, identified them to species, and characterized their structure (table 2). When ordered by number of trees, the study plots represented a smooth, but steep, gradient in tree density, with densities ranging from 20.2 to 403.6 trees per ha.

The relative abundance of tree species was influenced by elevational variation among plots (fig. 2). For example, blue oak and buckeye were more abundant on lower elevation plots, whereas white oak and bay were more abundant on higher elevation plots. In general, tree species evenness increased with elevation.

Six principal components with eigen values >1.0 described 89 percent of the variation in vegetation structure and composition among plots. Our discussion is limited to the first three principal components which described over 55 percent of the vegetation variation among plots (fig. 3). Principal component 1 (PC 1; 21.1 percent of the explained variation) represented variation in tree density among plots, the primary objective when the plots were systematically selected. PC 2 (20 percent) represented variation in the number and basal area of the most abundant broadleaf evergreen species. One outlier plot ac-

Table 2—*Tree species detected based on data from all study plots, Hopland, California 1987.*

COMMON NAME	SCIENTIFIC NAME	FREQ[1]	STEMS[2]	RANGES[3]
OAK TREE SPECIES				
Blue Oak	*Quercus douglasii*	100	467.1	5 - 1643
Interior live oak	*Quercus wislizenii*	100	63.4	12 - 182
Coast live oak	*Quercus agrifolia*			
Canyon live oak	*Quercus chrysolepis*			
Valley oak	*Quercus lobata*	91	58.3	0 - 423
Oregon white oak	*Quercus garryana*			
Black oak	*Quercus kelloggii*	78	26.9	0 - 143
Oracle oak	*Quercus morehus*	70	2.8	0 - 20
OTHER TREE SPECIES				
Buckeye	*Aesculus californica*	83	56.9	0 - 350
California bay	*Umbellularia californica*	70	14.0	0 - 86
Madrone	*Arbutus menzesii*	48	5.1	0 - 52
Oregon ash	*Fraxinus latifolia*	4	0.2	0 - 5

[1]Percent frequency of occurrence across all plots.
[2]Number of stems > 5 cm DBH per 5.0 ha plot.
[2]Range in number of stems per plot.

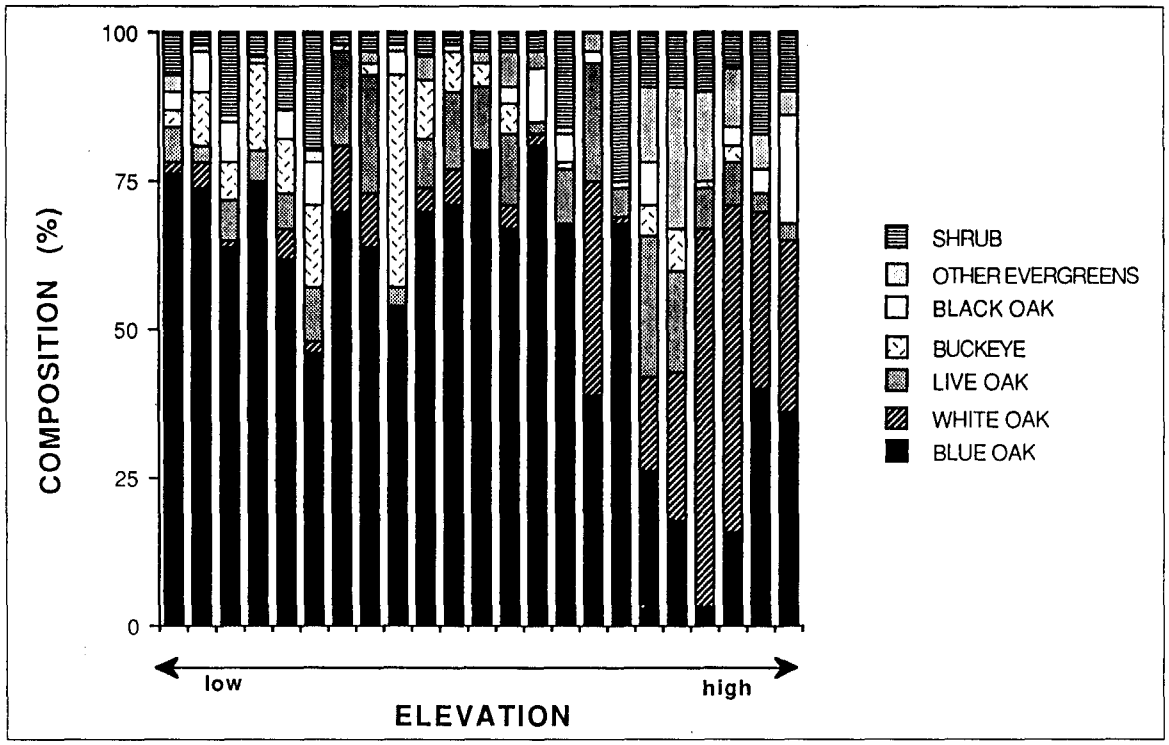


Figure 2—Tree species composition of each study plot, with the plots arranged according to elevation (range was 200-975m above sea level).

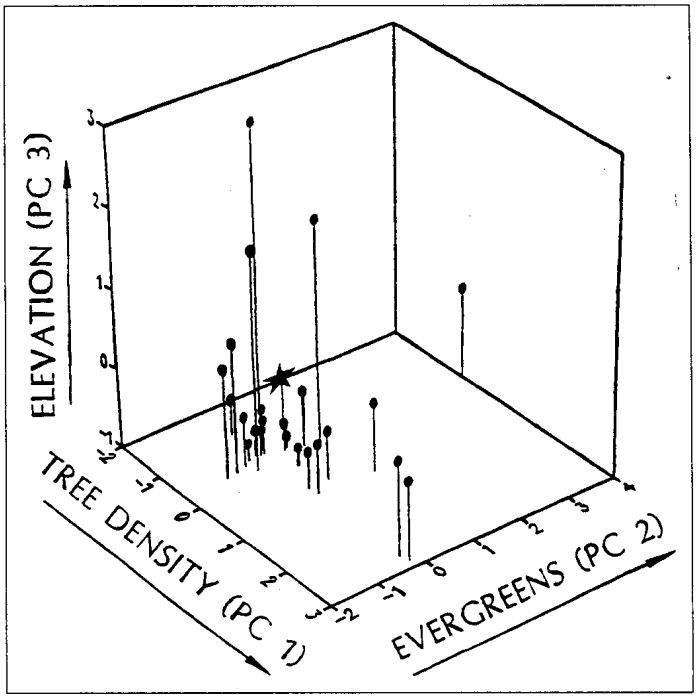


Figure 3—Ordination of the 23 study plots along the first three principal components. Axis 1 represents variation in the number of trees and shrubs, axis 2 the number of live oak and madrone trees per plot, and axis 3 vegetation characteristic that changed with elevation. The star in the figure indicates the approximate, weighed location of the 10 most abundant bird species in this vegetation space.

counted for the majority of the variation explained by this component. Most of the plots did not differ greatly along PC 2. PC 3 (14 percent) represented a gradient from blue oak (at lower elevations) to white oak and bay (at higher elevations), and paralleled an underlying gradient in tree species composition. In general, most vegetation variation among our plots was in tree density, and tree species composition which was influenced by the physical and biological variables associated with changes in elevation.

Covariation of Bird Abundance and Tree Density

At the scale of 5 ha plots, variation in overall bird abundance and bird species richness was not strongly associated with variation in tree density (n = 23; r = -0.25, p = 0.17 and r = 0.00003, p = 0.43, respectively), even though we had sampled a steep gradient.

When birds were grouped by foraging or nesting guild, the number of species in each group ranged from three to 19. The abundance of individual bird groups was not strongly associated with changes in tree density. The secondary cavity nesting guild showed the strongest relationship with variation in tree density, declining in abundance with increasing tree density (fig. 4a; r = -0.384, p = 0.038). Though significant, the magnitude of the correlation coefficient indicates that little of the abundance

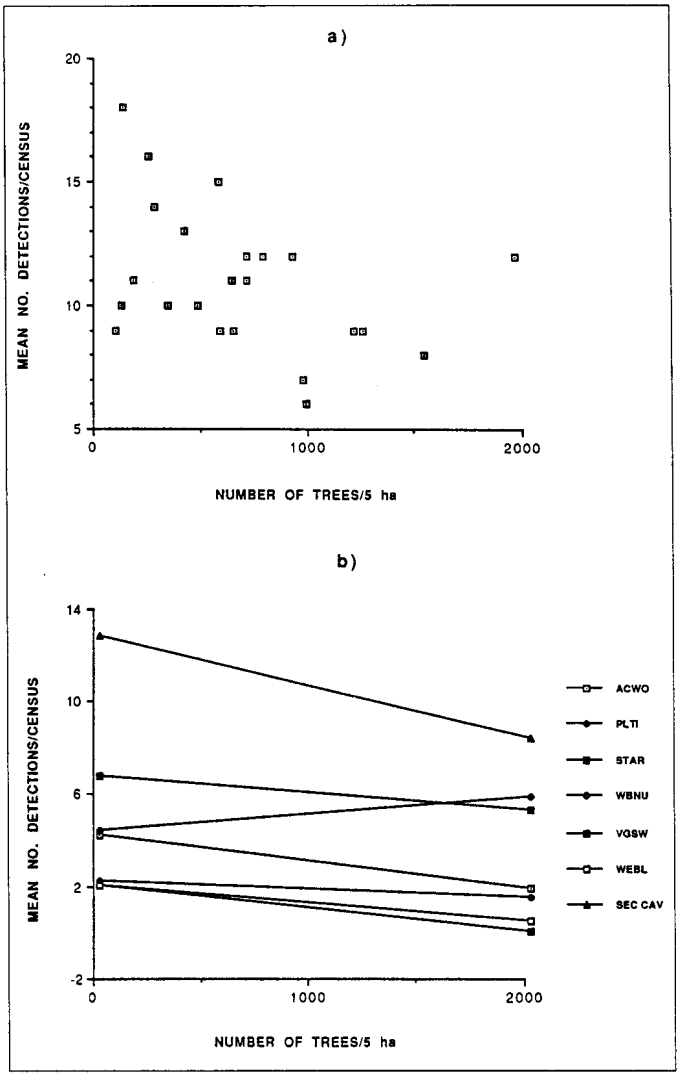


Figure 4—Mean number of detections per census of secondary cavity nesting species as a function of tree density. Estimates are from all 23 study plots: a) bivariate scattergram of the mean number of detections for the entire guild (r = -0.384, p = 0.035). b) regression lines for individual species.

variation within this guild was explained by changes in tree density.

The secondary cavity nesting species illustrate why a guild approach is not always a useful way to describe relationships between bird abundance and vegetation. In our study, not all species in this guild showed a consistent response to variation in tree density (fig. 4b). The abundance of all species, except plain titmouse, decreased with increasing tree density. The individual regression lines (fig. 4b) illustrate that different species within a group do not always show the same pattern of response to vegetation variation, even when the characteristic may affect the abundance or availability of a key resource (i.e., availability of cavities for secondary cavity nesters). Variation in habitat relationships among members of a guild may reflect variation in other life history characteristics. Secondary cavity nesters in our study varied in the food resources they exploited (omnivorous versus insectivorous), foraging strategies (salliers, gleaners, and hawkers), and foraging substrates (ground, leaf, bark, and air).

Habitat relationships of the ten most abundant bird species and Nuttall's woodpecker (the second most abundant primary cavity nester) were of special interest because they comprised almost 60 percent of all the individuals in the bird community. Based on the independent variables selected in regression analyses and other variables with which they were highly correlated, a number of species showed similar habitat associations (table 3). Five of the seven cavity nesters and one open nester were more abundant on plots with large diameter (>50 cm DBH) trees and an abundance of cavities, indicating an association with low tree densities (<100 per ha). The remaining two cavity nesters and one open nester were more abundant on plots with moderate tree densities (100 to 180 per ha). Two open nesters were more abundant on plots with moderate tree densities, but on plots where the distribution was clumped because of dense vegetation in ravines. Ravines were typically occupied by dense patches of evergreen trees which provided cover and nesting substrates in otherwise open plots.

No abundant bird species showed a strong association with high tree density (> 180 per ha). Areas with high tree densities, however, appeared to provide habitat for some less abundant species, specifically pygmy owl, brown creeper, barn owl, and turkey. The abundances of these species covaried positively with tree density, but detections were too few for statistical significance. Areas with high tree density may be associated with lower levels of disturbance from grazing animals; dense plots were not grazed as heavily because of reduced forage. Dense plots may have offered greater cover from avian predators, and provided concealed roost sites.

An additional way to explore a species' response to multivariate habitat gradients is in the context of the vegetation PCA. We plotted the location of the 10 most abundant species (table 1) in the three-dimensional PCA space (fig. 3). Because all points, except the European starling, fell very near the origin (0,0,0), we have simply indicated this position by a star (fig. 4). A common location for all these points indicates that the most common species did not vary systematically with either tree density or elevation. This pattern arose despite the fact that most species showed substantial density variation across plots (coefficients of variation > 40 percent). The weighted locations near the origin indicate that none of the abundant species found optimal conditions at the extremes of any vegetation gradient.

The lack of strong covariation between tree density and bird species abundance may be partially attributed to the strong association of tree density with other vegetative characteristics including average tree diameter and tree species composition. For example, plots with the highest tree density were stands of small diameter blue oak, and open plots were invariably dominated by large diameter blue and white oaks. In addition, our estimate of tree density contained no information about the distributional pattern of trees within a plot. Unfortunately, the levels of resolution at which bird species perceive their environment (grain) is unknown to us. The distribution of trees (evenly spaced versus clumped) at some unknown spatial scale may have more influence on habitat quality than the overall tree density based on our 5 ha study plots.

Resource Use by Cavity Nesting Birds

Tree Species Use

We assume the distribution and abundance of natural and excavated cavities to be important to cavity nesting birds. Comparisons were made between the number of trees of a given species across all plots and the relative number of trees of each species with one or more cavities (fig. 5). Of the more than 16,000 trees measured on our plots, 412 (2.5 percent) had at least one excavated cavity, and 2,207 (13.7 percent) had at least one natural cavity. The number of cavities varied by tree species (fig. 5). The majority of natural and excavated cavities occurred in blue oaks, though less than expected based on the abundance of this species. Natural cavities occurred significantly more frequently in evergreen tree species (primarily live oak) than expected. A greater than expected number of evergreen and buckeye trees had natural cavities compared to their availability (fig. 5b). White oaks contained a significantly greater number of excavated cavities than expected based on their availability (fig. 5a). White oaks made up nine percent of the trees measured, yet comprised 30 and 36 percent of the trees containing 1-3 and

Table 3—*General habitat associations of 11 common bird species, Hopland, California 1987-1988.*

LOW TREE DENSITY,[1] LARGE TREE DIAMETER	MODERATE TREE DENSITY, MODERATE[2] TREE DIAMETER	MODERATE TREE DENSITY, MODERATE TREE DIAMETER, BUT CLUMPED DISTRIBUTION
CAVITY NESTERS		
Acorn woodpecker	Plain titmouse	
Nuttall's woodpecker	Violet-green swallow	
White-breasted nuthatch		
Western bluebird		
European Starling		
OPEN NESTERS		
Mourning dove	Lesser Goldfinch	Scrub Jay
		American robin

[1]Less than 100 trees per ha; average DBH of 45 cm.
[2]100-180 trees per ha; average DBH of 31 cm.

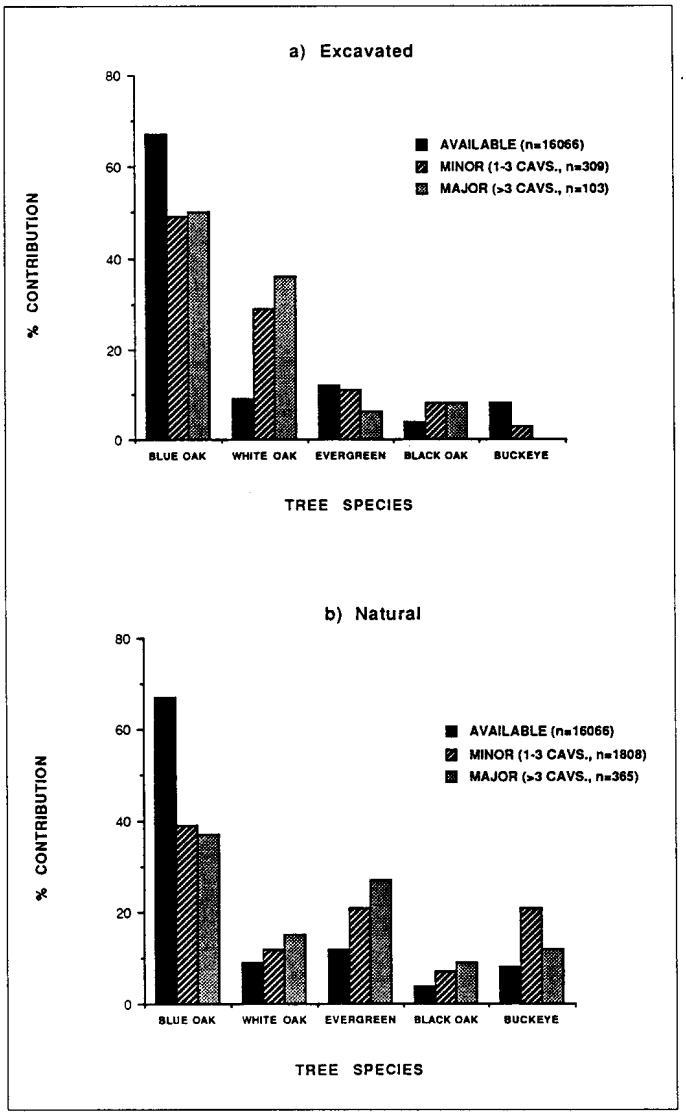


Figure 5—Excavated (a) and natural (b) cavity use by tree species for cavity nesting birds compared with tree species availability.

>3 excavated cavities, respectively. Black oaks comprised a small proportion (<5 percent) of the total number of trees; however, they also contained significantly more excavated cavities than expected.

Natural versus Excavated Cavity Use

Both natural and excavated cavities were important to cavity nesting species in the study area. Based on 306 nests from seven species of cavity nesting birds, we compared their relative use of excavated and natural cavities as nest sites (fig. 6). Species were arranged from those exclusively using excavated cavities (acorn and Nuttall's woodpeckers) to predominantly natural cavity nesters (plain titmouse and white-breasted nuthatch). All secondary cavity nesters used excavated cavities to some degree; however, the majority (65 percent) of nests occurred in natural cavities. The extent to which natural cavities were used for nesting by secondary cavity nesters was high compared to oak woodlands at the San Joaquin Experimental Range (34 percent use; J. Waters, pers. comm).

In addition to the differential use of cavity types, cavity nesters chose to nest in a number of different tree species (fig. 7). Acorn woodpeckers excavated cavities most often in blue oaks and chose white oaks in proportion to their availability (fig. 7b). We did not find any Nuttall's woodpecker nests in white oaks even though more excavated cavities occurred in white oaks than expected. Nuttall's woodpecker nested primarily in blue oaks, evergreens, and black oaks. The number of plain titmouse nests in excavated cavities did not differ from expected for any tree species (fig. 7a). White-breasted nuthatches also chose tree species with natural cavities in proportion to availability (fig. 7c). These two species are potential competitors for cavities since they both preferred natural cavities, chose similar tree species, and both were early nesters (late March). The introduced European starling used excavated cavities exclusively, with blue oak and white oak tree species chosen in equal numbers. Western bluebirds chose 67 percent excavated and 33 percent natural cavities, with blue oak being the dominant choice (>60 percent in both cases).

Even though a large number (488) of buckeye trees contained natural cavities, it was not selected as a nest tree. We speculate that cavities in buckeye were too low to the ground and therefore easily accessible by snakes. Gopher snakes were seen in cavities on at least six occasions, and destroyed at least three occupied nests.

Tree Diameter

The abundance of both natural and excavated cavities covaried positively with tree diameter for most tree species. The number of natural cavities increased significantly with diameter when all tree species were combined (fig. 8a; $F = 632$, $df = 2$, $p < 0.001$). The number of excavated cavities also increased significantly with tree diameter for all species combined ($F = 384$, $df = 3$, $p < 0.001$, fig. 8b) and each individual tree species except evergreen oaks and buckeye. These associations occur for two primary reasons: 1) larger trees are generally older and have had greater time to accumulate cavities; and 2) older trees are more likely to have experienced loss of limbs and disease, factors which promote natural and excavated cavities.

Collectively, the results of tree species and diameter use patterns suggest that large (> 50 cm DBH), old trees of both

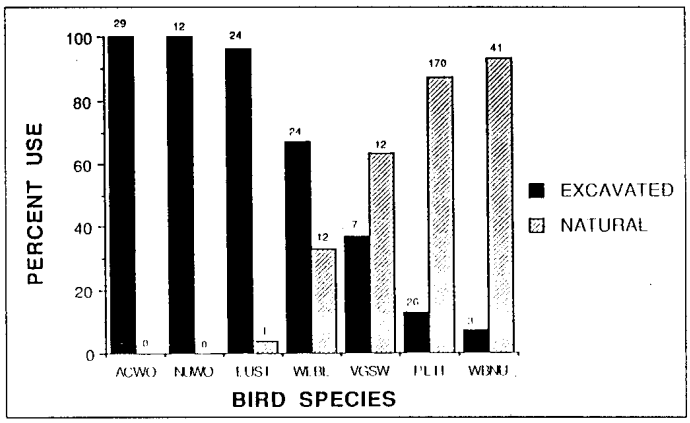


Figure 6—Proportions of cavity type used (excavated or natural) for nesting by seven species of birds, 1987 and 1988.

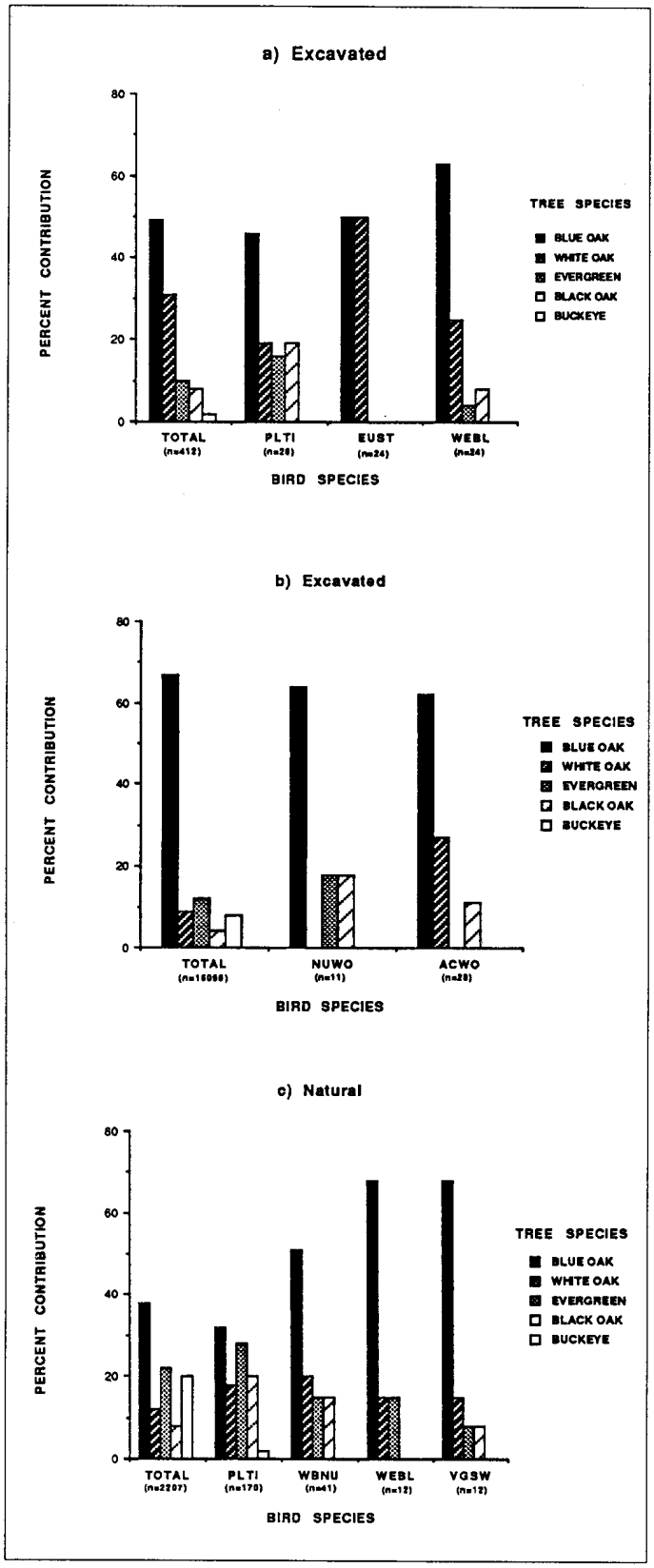


Figure 7—Nest tree selection by: a) secondary cavity nesters, and b) primary cavity nesters using excavated cavities, and c) secondary cavity nesters using natural cavities.

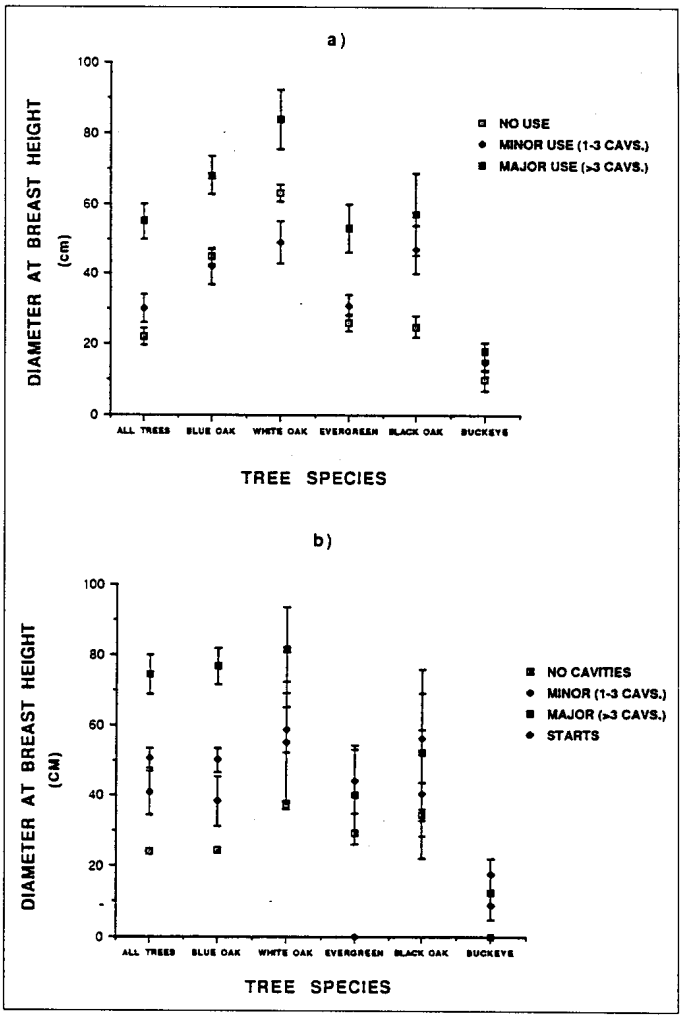


Figure 8—Mean, with 95 pct confidence interval, tree diameter by species for trees with a) natural and b) excavated cavities. Diameter classes are based on the relative number of cavities. Starts indicate incomplete excavations.

deciduous and evergreen oaks are important to meet the needs of primary cavity nesters for nest substrates and secondary cavity nesters for natural and excavated cavities.

Acorn Woodpecker Granary Trees

Acorn woodpeckers, cooperative breeders, spend considerable time storing acorns in small excavations in tree boles and limbs. The quantity and quality of stored acorns apparently have an influence on clutch size, reproductive success, group size, group composition, and winter survivorship (Koenig and Mumme 1987). Comparing use versus availability of each tree species for acorn storage, we found use to be significantly different than availability for both minor (X^2= 90, df = 4, $p < 0.001$) and major granary trees (X^2=62, df = 4, $p < 0.001$). White oaks were used as both minor and major granary trees significantly greater than expected. White oaks comprised approximately 10 percent of all trees, and yet over 25 percent of the minor granary trees and almost 50 percent of the major granary trees occurred in white oaks.

Blue oaks were used extensively as minor and major granary trees, but significantly less than expected. Although the use of blue oaks as granary trees was less than their availability (70 percent), blue oaks still provided over half of the trees used for acorn storage. All other trees species comprised a relatively small proportion of the available trees and were used equal to or less than their availability.

The DBH of granary trees were significantly ($F = 189$, $df = 2$, $p < 0.001$) larger than those of non-granary trees (fig. 9b). The differential use of larger diameter trees for granaries was not consistent across all tree species. Only white, blue, and black oak granary trees were significantly larger than non-granary trees.

The almost exclusive use of deciduous oak trees greater than 75 cm in diameter for major granary trees is an important management consideration. The ability of an oak woodland to support acorn woodpeckers depends on the availability of storage trees and acorns. Our data provide additional support for the need for large diameter trees for acorn storage.

Maintenance of large diameter oak trees of a variety of species is also an important component of providing an adequate supply of acorns for acorn woodpeckers. Large diameter trees produce greater quantities of acorns, and each species of oak has unique responses to environmental conditions and unique acorn characteristics (Koenig and Mumme 1987). Maintenance of a variety of oak species will help ensure that at any one point in time the environmental conditions will be favorable for the production of acorns by one or more species of oak.

Effects of Plot Size on Bird Community Patterns

Each study plot was selected to be homogeneous in tree density and spatial arrangement of trees, but to vary in these characteristics among plots. Given this study design, we were surprised to find so few bird species associated with variation in tree density. We believe our plots were representative, however, of the inherent variation in oak woodlands in our study area, at least at the scale of 5 ha sample units. The study area was heterogeneous in tree structure and composition, and the spatial pattern of the vegetation. There were few discrete boundaries separating the various vegetation patches. Because of the heterogeneity of northern oak woodlands, we were uncertain as to the correct spatial scale for sampling and analysis to characterize bird community patterns. In an attempt to gain insight into this question, we analyzed the influence of increasing plot size on among-plot variation in canopy closure (a correlate of tree density), using each 5 ha study plot as a nucleus for plots of increasing size up to 50 ha. The among-plot variation in canopy closure decreased as plot size increased, but remained high even with 50 ha plots. This pattern suggests that bird community studies may require plots in excess of 50 ha to represent the inherent variation in tree density, canopy closure, and spatial pattern of trees representative of oak woodlands in our study area. This approach could be taken with other vegetation variables to estimate the plot size at which among-plot variation is acceptably low. Large study plots, however, increase the difficulty of spatial replication.

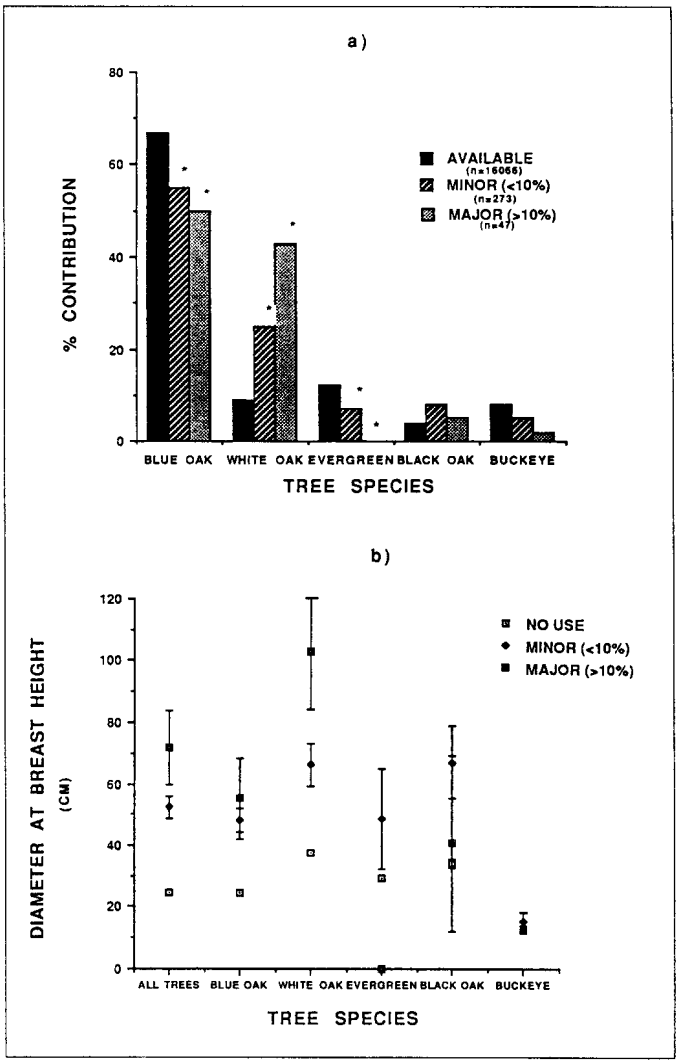


Figure 9—Characteristics of granary trees created by acorn woodpeckers: a) tree species used for granaries compared to tree species availability (* indicates $p < 0.05$); b) mean, and 95% confidence interval, tree diameter by species. Diameter classes are based on the relative number of cavities.

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

(1) Cavity-nesting species comprised a significant proportion of the breeding species and the majority of the breeding density. Thus, this guild deserves special consideration in any management decisions.

(2) The cavity-nesting guild used a variety of tree species for nest sites. This suggests that maintaining a high tree species richness, as alternative substrates for nesting, is important for this guild of breeding birds.

(3) The acorn woodpecker plays a key role in the cavity-nesting guild. This species is the primary source of excavated cavities for the secondary cavity-nesting species. We recommend maintaining large (> 50 cm DBH) blue and valley oaks, particularly those with some degree of decadence.

(4) Plain titmouse and white-breasted nuthatch nested primarily in natural cavities. These cavities result from injury to the tree followed by diseases which soften heartwood. Trees with these characteristics should be maintained as they are important to both primary and secondary cavity-nesters.

(5) The large (>75 cm DBH) deciduous oaks are particularly important as sites for acorn woodpecker granary trees. We recommend maintaining large valley and blue oak trees whenever possible.

(6) The abundance of the most common breeding species covaried with a large number of vegetation variables. Among these were seven species of hardwood trees. These results suggest that a high tree species richness is important to oak woodland birds, perhaps as alternative substrates for nesting and foraging.

(7) The abundance of some of the most common and least common breeding species covaried with tree density, both positively and negatively. To maintain the integrity of the breeding bird community, we recommend maintaining a variety of tree densities. In general, however, we failed to find a significant association between bird abundance and variation in tree density.

(8) Oak woodlands are very diverse in terms of the spatial distributions of their trees. Our data suggest that bird species respond to this variation at a variety of spatial scales. We recommend that oak woodlands be managed at large spatial scales. Until better data are forthcoming, we tentatively recommend 50-100 ha as the minimum size of a management unit.

(9) Given the spatial scale of our study (5-10 ha plots) and the spatial scale at which plots had homogenous canopy closure (~50 ha), we tentatively recommend that future community studies of oak woodland birds be done on large plots.

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Determinants of Acorn Productivity Among Five Species of Oaks in Central Coastal California[1]

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Abstract: We measured acorn production of five species of oaks (genus *Quercus*) over a ten year period (1980-1989) at Hastings Reservation in Monterey County, California. Crop production was highly variable and generally asynchronous between species. Variance in crop size decreased directly with increasing species diversity across sub-areas within the study site. Sources of variance in mean annual crop size include annual and interspecific differences and extrinsic factors correlated with different sub-areas of the study site. However, the majority of variance remains unexplained after controlling for these factors and is apparently due to individual variation in crop production. Climatic variables were not found to correlate with mean annual crop productivity in any of the species, with the possible exceptions of *Q. chrysolepis* and *Q. kelloggii*. However, strong autocorrelations were found within the crop sizes of individuals indicating the existence of masting cycles on the order of three years for *Q. douglasii* and *Q. agrifolia*, two to three years for *Q. lobata*, and possibly six years for *Q. chrysolepis* and *Q. kelloggii*. These results indicate distinct reproductive strategies in California oaks; continued studies will be necessary in order to identify the relative importance of the evolutionary factors that have resulted in these patterns.

Acorn crop size is of fundamental importance both to the understanding of oak regeneration problems and to the diverse assemblage of wildlife dependent on acorns as food. However, surprisingly little is known concerning the factors determining acorn crop size or variability. This ignorance is acutely evident in California, where oaks dominate millions of hectares of land area (Griffin and Critchfield 1972, Griffin 1977, Bolsinger 1987), and acorns are a primary food resource for a wide variety of wildlife (Barrett 1980, Verner 1980).

The difficulties of assessing the factors important to crop size are formidable. Acorn crops are notoriously variable, not only at the species level but also at the community, site, and individual tree levels. Moreover, the pattern of spatial heterogeneity in crop sizes is likely to be complex given the diverse geographic and climatic range inhabited by oaks in California. Finally, the logistic problems associated with reliably assessing acorn crop size are considerable. Short-term data collected by different observers are unlikely to be of value unless carefully coordinated. Acorn traps can provide an accurate estimate of acorn fall for individual trees, but unavoidably miss acorns removed prior to maturity by birds and other animals, require considerable maintenance, and are difficult to put out in sufficient numbers to yield satisfactory sample sizes. Visual estimates (Graves 1980, McKibben and Graves 1987) are subject to considerable variation depending on the observers but have the potential advantage of yielding large sample sizes with reasonable time investment.

With these difficulties and challenges in mind, we began a study in 1980 of the fruiting patterns of five species of sympatric oaks at Hastings Reservation in Monterey County, California. Our goal in this continuing endeavor is to quantify the patterns of intraspecific, interspecific, annual, and spatial variability in acorn production and to determine the environmental and intrinsic factors responsible for the observed variation. Analyses based on the first seven years of data were presented earlier (Carmen et al. 1987). Here we extend our earlier results using data through 1989 (10 years), emphasizing the masting patterns observed at Hastings and the factors, both extrinsic and intrinsic, contributing to individual variation in acorn productivity. We also discuss some of our results concerning local variation in mast production among and within species and the implications of our findings to the understanding of the relationships between acorn producers and their predators.

STUDY AREA AND METHODS

Hastings Reservation is a 900 ha reserve located in the Santa Lucia Mountains of central coast range of California, approximately 42 km inland. Elevation ranges from 467 to 953 m. Mean annual temperature is 17°C. Annual rainfall ranges from 26.1 to 111.2 cm, with a 50-yr mean of about 55 cm. Topography includes relatively narrow valleys amid rugged foothills. Common at the lower elevations are *Quercus lobata, Q. douglasii,* and *Q. agrifolia,* while at higher elevations *Q. kelloggii* and *Q. chrysolepis* are also present. These five species include oaks of all three subgenera (*Quercus: Q. lobata, Q. douglasii; Erythrobalanus: Q. agrifolia, Q. kelloggii;* and *Protobalanus: Q. chrysolepis*), both evergreen (*Q. agrifolia* and *Q. chrysolepis*) and deciduous (*Q. lobata, Q. douglasii,* and *Q. kelloggii*) species, and species that require one year (*Q. lobata, Q. douglasii,* and *Q. agrifolia*) and two years (*Q. kelloggii* and *Q. chrysolepis*) for acorns to mature.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

[2]Associate Research Zoologist, Post-doctoral Research Associate, and Graduate Student, respectively, Hastings Reservation, University of California, Carmel Valley, California; and Assistant Professor, Department of Biology, Allegheny College, Meadville, Pennsylvania.

Beginning in 1980, we established transects in foothill woodland, savanna-grassland, and riparian woodland vegetation types (Griffin 1983). Along these transects we sampled 250 oaks including 87 *Q. lobata,* 63 *Q. agrifolia,* 57 *Q. douglasii,* 21 *Q. kelloggii,* 21 *Q. chrysolepis,* and 1 obvious *Q. lobata* x *Q. douglasii* hybrid. Sample sizes decreased slightly in later years as several trees died and were not replaced. DBH of each tree was measured. Each autumn at the height of the acorn crop and prior to acorn fall, generally between mid-September and early October, we measured the relative abundance of acorns of each of the 250 individual trees using two methods. First, two observers scanned different areas of the tree's canopy and counted as many acorns as possible in 15 s. These counts were added to yield "acorns per 30 s". Second, the two observers agreed on a score between 0 and 4 describing the overall size of the acorn crop for each tree. This score, modified from the visual estimate scale pioneered by Graves (1980), was as follows: 0 (no acorns), 1 (a few seen after close scrutiny), 2 (a fair number, acorns seen readily), 3 (a good crop), and 4 (a bumper crop, acorns just about everywhere on the tree). At least one of the original observers has participated in the annual counts each year since we initiated the study.

Based on elevation and habitat, we divided the 250 trees into four sub-areas: (1) the Arnold, a high-elevation area located in the southern end of the reservation (all five species present, elevation 780 to 878 m), (2) the Road, a low-elevation area traversing the center of the reservation (all but *Q. kelloggii* present in good numbers, a semi-permanent creek running through the area, elevation 470 to 512 m), (3) Big Creek, a low-elevation area running northeast of the Road with a seasonal creek running through it (only *Q. lobata, Q. douglasii,* and *Q. agrifolia* present, elevation 488 to 579 m), and Haystack/School Hill, two higher-elevation hills located on either side of Big Creek (only *Q. lobata, Q. douglasii,* and *Q. agrifolia* present in good numbers, elevation 579 to 637 m). All four areas are less than a km in diameter and are within 4 km of each other.

Weather data was taken from a station permanently located at the headquarters near the northern edge of the reservation in the "Big Creek" sub-area. Included in the weather station during the study period was a rainfall gauge, a max-min thermometer, and a Campbell Stokes-type sunshine recorder.

STATISTICAL ANALYSES

Using the first year of data (1980), the Spearman rank correlation between the two different measures of acorn productivity is 0.963 (n=250, P<0.001); thus, the choice between them is largely a matter of taste. In this paper we have used the number of acorns counted in 30 s (henceforth "N30"), which is a continuous, interval measure, in most of our analyses. In order to reduce the dependence of the variance on the mean, N30 was logarithmically transformed (ln(N30+1)) prior to parametric procedures. The 0 to 4 categorical score was used in the weather and the autocorrelation analyses because we suspect it is less sensitive to tree size, foliage density, acorn color, and acorn size, and thus is probably more comparable across years than N30.

RESULTS AND DISCUSSION

Pattern and Sources of Variation

Acorn production varies considerably both from year to year and from species to species (figure 1). Indeed, there are no significant correlations between the mean yearly crop scores of any of the species except for between the closely related *Q. lobata* and *Q. douglasii* (table 1). There is, however, a tendency for the species requiring a single year to mature acorns to be out of synchrony with those requiring two years: all six correlations of mean crop scores between the one-year species and the two-year species are negative, while all four correlations between species within these categories are positive (Fisher exact test, $P < 0.05$; table 1).

One important consequence of the asynchrony of acorn production across species is that variability in masting patterns are dampened. This is shown by comparing the annual variation of the individual species (figure 1) with the mean acorn crop score of all individuals combined (figure 2). Annual variation measured by the coefficient of variation for the mean annual score of all species combined was considerably less (34 percent) than that for any of the five individual species (range 55 to 128 percent).

This decrease appears to be a direct consequence, at least in part, of increased species number, as indicated by the relationship between the coefficient of variation in the mean annual crop score of all trees within sub-areas of the study site and the number of species of oaks commonly present in those sub-areas (figure 3a). Values decrease from a mean of 63 percent in the sub-areas with three species to 36 percent in the sub-area with five species. For acorn-dependent wildlife, this asynchrony acts to moderate the otherwise potentially disastrous effects of poor acorn years.

These data indicate that annual, local, and interspecific variation in acorn production all contribute importantly to community-wide patterns of crop size. However, all these factors are apparently overshadowed by individual variation. This is shown by a three-way analysis of covariance (ANCOVA) in which year, sub-area, and species were analyzed as main factors and diameter at breast height (DBH) included as a covariate (table 2). Each factor and the covariate are analyzed controlling for all other variables. All variables and their interaction terms are highly significant. However, in total, they account for less than half (46.1 percent) of the variance in crop scores present in the data. Of the individual variables, most important appears to be yearly variation, while sub-area, species, and DBH of individual trees account for only a small proportion of the total variance.

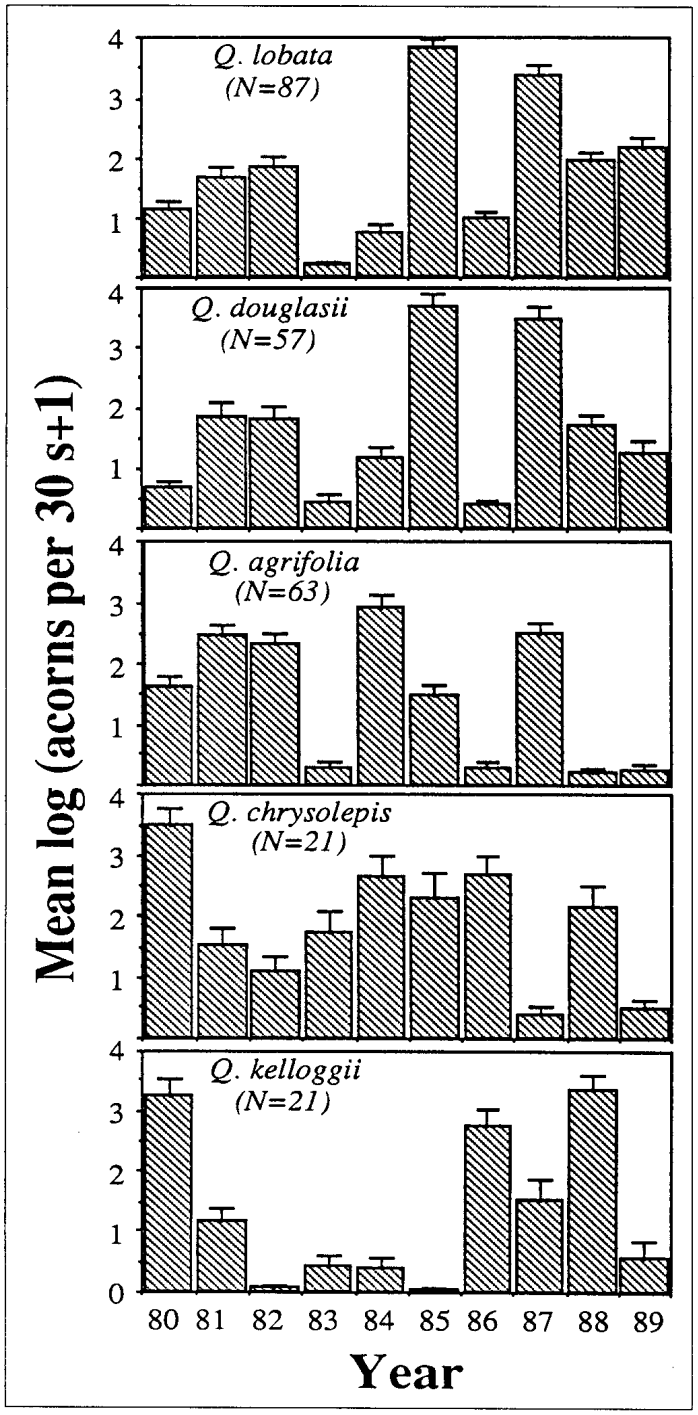


Figure 1—Mean (±S.E.) number of acorns counted per 30 s (log transformed) for each of the five oak species at Hastings for the ten years 1980-89.

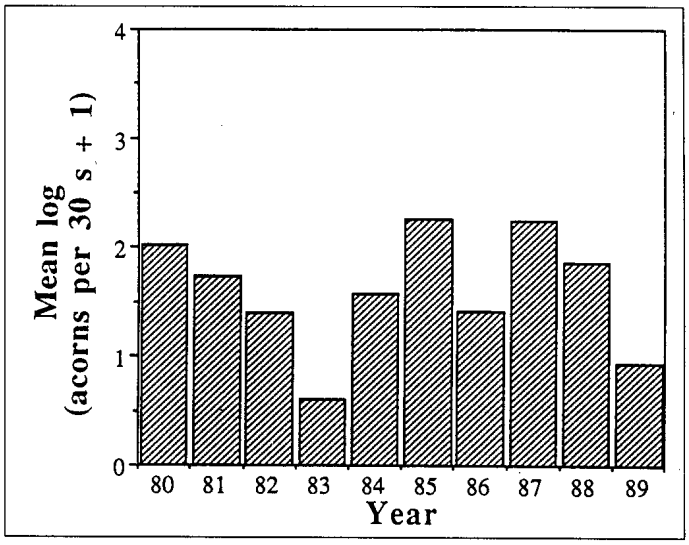


Figure 2—Mean number of acorns counted per 30 s (log transformed) for all five species combined. For each year, values were averaged for the five species to yield a community-wide estimate of overall acorn production.

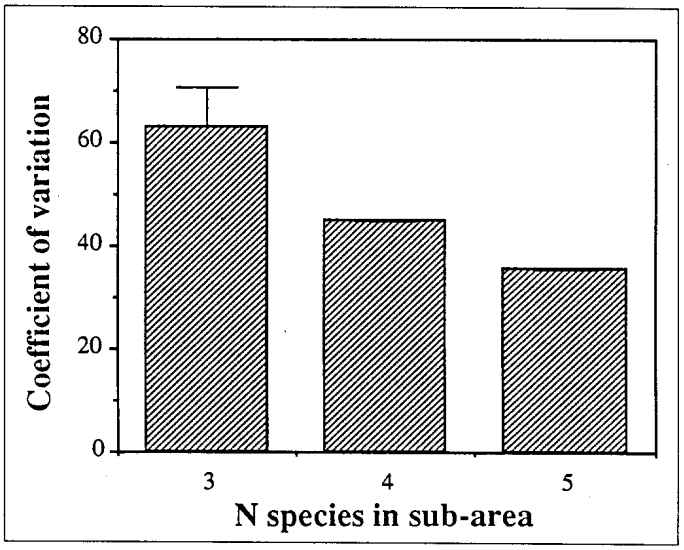


Figure 3—Coefficient of variation in the mean number of acorns counted per 30 s (log transformed) for the four sub-areas of Hastings Reservation, graphed according to the number of species commonly present in those sub-areas. Two sub-areas have three common species while one each have four and five. For the sub-area with three common species, the mean ± S.E. is plotted.

Table 1—*Spearman rank correlations of acorn production by five species oak oaks using mean annual data (mean number of acorns counted per 30 s; see text). N =10 years. * = P < 0.05.*

	Q. lobata	*Q. douglasii*	*Q. agrifolia*	*Q. chrysolepis*
Q. douglasii	0.83*	—	—	—
Q. agrifolia	0.14	0.43	—	—
Q. chrysolepis	-0.42	-0.46	-0.18	—
Q. kelloggii	-0.18	-0.41	-0.39	0.21

However, the significant interaction terms make it impossible to determine with confidence the importance of the individual factors, since their effects are not independent of each other. This analysis indicates that individual variation is responsible for a larger proportion of the total variance in crop size than variance associated with different years, species, and sub-areas combined. Only a small part of this individual variation appears to be correlated with tree size.

Table 2—*Three-way analysis of covariance of number of acorns counted per 30 s (log transformed) using species, year, and sub-area within the study site as main factors and DBH as a covariate. Each variable is considered controlling for all other variables.* *** = P < 0.001.*

	Sum of squares	Percent of total variance	df	*F* -value
Main factors				
Year	436.8	—	9	29.3***
Area	120.1	—	3	24.2***
Species	51.7	—	4	7.8***
Interaction				
Species x year	1388.1	—	36	23.3***
Area x year	169.1	—	27	3.8***
Species x area	121.3	—	9	8.1***
Covariate				
DBH	22.5	—	1	14.2***
Explained	3374.1	46.1	89	22.9***
Residual	3950.8	53.9	2383	—
Total	7325.0	100.0	2472	—

Causes of Variation

Possible causes of the considerable variation observed in acorn productivity among individuals include extrinsic factors, such as rainfall, temperature, and correlated factors such as slope and elevation, as well as intrinsic factors such as age, condition, and prior breeding effort. Here we briefly explore the importance of both kinds of factors as causes of variation in the acorn crop at the individual level.

In order to look at the possible effect of climate, we correlated the mean crop score values for each of the five species with a series of 15 weather variables including winter rainfall (1 Sept.-31 May), spring rainfall (1 Mar.-30 April), minutes of spring sunshine, the number of days in spring with <100 min of sunshine, the mean daily sunshine during the winter (1 Dec.-29 Feb.), the number of days in which the temperature dipped below 0°C during March, the mean mean, mean maximum, and mean minimum winter temperatures (1 Dec.-29 Feb.), the mean mean, mean maximum, and mean minimum spring temperatures (1 Mar.-20 April), and the mean mean, mean maximum, and mean minimum summer temperatures (1 June-31 July). In addition, each of these 15 variables was lagged one and two years; that is, mean scores for each species in year *x* were correlated not only with rainfall in year *x*, but winter rainfall in years *x*-1 and *x*-2 as well. This analysis yielded a total of 45 climatic variables, each of which was correlated with the mean annual crop scores of each of the five species of oaks.

By chance, 11 to 12 of the 225 correlations can be expected to be significant at the 0.05 level and two to three at the 0.01 level; observed numbers were 12 and three, respectively. Correlations significant at the 0.01 level included inverse correlations between the mean crop score of *Q. douglasii* and spring sunshine two years earlier and between the mean score of *Q. chrysolepis* and both mean mean winter temperature one year earlier and mean maximum winter temperature one year earlier. Similarly inconclusive results were obtained from a factor analysis. Details are beyond the scope of this paper, but in essence these analyses extract a small number of uncorrelated variables each of which is made up of different weightings of the large number of often highly correlated climate variables entered into the analysis. The factors can then be treated as new variables and correlated with the mean acorn scores as before. We extracted the first four factors (accounting for an accumulated total of 73.6 percent of the variance in annual climatic differences); by correlating the factors with the mean crop score of each of the five oak species, a total of 20 correlations were obtained. Of these, two (one involving *Q. chrysolepis* and the other *Q. kelloggii*) were significant at the 0.05 level. Both of these involved a factor in which winter temperature one year earlier loaded especially heavily; that is, *Q. chrysolepis* and *Q. kelloggii* tended to produce larger crops one year following particularly cold winters. Although it is possible that these relationships are providing insight about the extrinsic factors influencing acorn production in these species, in general these analyses fail to offer persuasive evidence that the observed correlations between climate and mean acorn production are anything more than the result of chance.

Despite the overall failure of the climate variables to convincingly explain much of the variance in crop production, the significant differences in crop scores among sub-areas demonstrated in the ANCOVA discussed above indicate that extrinsic variables correlated with the four sub-areas significantly influence acorn crop scores (table 2). Thus, extrinsic factors are important, but on a smaller geographic scale than that expected if general climatic trends determined acorn crops from year to year.

Factors intrinsic to individual trees that potentially influence crop production include size, age, genetic differences, condition, and prior reproductive effort. Currently we have little information on any of these factors with the exception of size, measured by DBH, and prior reproductive effort, based on our acorn censuses performed in prior years.

We tested for an effect of DBH by including it as a covariate in three-way analysis of covariance discussed above. In the resulting analysis, DBH was significant and positively associated with N30. However, based on the sum of squares, DBH was of considerably smaller importance than any of the other variables considered, or their interactions. Tree size does appear to be correlated with acorn productivity, but is of relatively small importance compared to annual, interspecific, or micro-geographic variation.

Determining the importance of prior reproductive effort involves calculating autocorrelations of acorn scores for each individual tree with scores for the same tree in prior years. For each year n, the score (s_n) for each tree is correlated with s_{n-1}, s_{n-2}, and so on. Sample sizes decline by one for each successive autocorrelation; for s_n with s_{n-1}, the sample size is the number of years of data (N) minus 1; for s_n with s_{n-2} the sample size is N-2, and so on. With only 10 years of data thus far, we were thus able to go back only as far as s_{n-6} and still have enough points for each tree (N=4) to obtain a reasonable correlation coefficient.

We calculated all autocorrelation coefficients of s_n with s_{n-1} through s_{n-6} for each of the 250 trees in our sample. We then (1) averaged the autocorrelation coefficients for a given lag time

(*n*-1 to *n*-6) for each of the five species and (2) counted the number of times the autocorrelation coefficient was positive and number of times it was negative. We tested the significance of the difference in the resulting number of positive and negative correlations for each of the six lagged intervals for each of the five species of oaks with a 2-tailed binomial test.

The results for the three species requiring one year to mature acorns are shown in figure 4 and for the two species requires two-years to mature acorns in figure 5. For all species except *Q. kelloggii* there is a highly significant inverse correlation between the score in year *n* and that in the prior year *n*-1. In other words, a good crop in one year generally is followed by a relatively poor crop the next year, and vice-versa. Both *Q. douglasii* and *Q. agrifolia* exhibit a significant three-year masting cycle as indicated by the highly significant autocorrelations of s_n with both s_{n-3} and s_{n-6}. (figure 4). Support for a three-year cycle is further enhanced by the recurrence of the highly significant inverse correlation coefficient of s_n with s_{n-4} as expected given the inverse correlation of s_n with s_{n-1}. Autocorrelations of the intermediate years (*n*-2 and *n*-5) are not significant.

The masting pattern of *Q. lobata* as revealed by the autocorrelation analyses is not clear. The highly significant inverse correlation of s_n with s_{n-1} is followed by a significant positive correlation with s_{n-2}, suggesting a two-year cycle. However, the correlation with s_{n-3} is not significant while that with s_{n-4} is significantly negative, as with *Q. douglasii* and *Q. agrifolia*. This possibly suggests that the masting cycle in *Q. lobata* varies between two and three years. However, it is not strongly cyclic as indicated by the lack of any significant autocorrelations with years *n*-5 and *n*-6.

These patterns contrast with those for the two-year species *Q. chrysolepis* and *Q. kelloggii* shown in Figure 5. The only markedly positive autocorrelations found for either species are with years *n*-5 (for *Q. chrysolepis*) and *n*-6 (for both species); none of these is significant, however. Otherwise, *Q. chrysolepis* exhibits the strong inverse autocorrelation between s_n and s_{n-1}, as did the one-year species, while *Q. kelloggii* exhibits highly significant inverse autocorrelations with years *n*-3, *n*-4, and *n*-5.

Although not conclusive, these latter results suggest that possibility of a six year cycle for *Q. chrysolepis* and *Q. kelloggii*. To the extent that this is true, examination of figure 1 indicates that the pattern results from opposite strategies in the two species: overall masting of *Q. chrysolepis* was reasonably good in most years, with relatively poor years coming at five- to seven-year intervals (1982 and again in both 1987 and 1989), while malting of *Q. kelloggii* tended to be usually poor with good years occurring at approximately six-year intervals (1980 and again in 1986). Unfortunately, even the 10 years of data we currently have is insufficient to conclusively demonstrate these patterns. However, our results thus far do provide good evidence that several of the species at Hastings have distinct masting cycles and that the cycles are both asynchronous (figure 1) and of different lengths (figures 4 and 5) for the five species.

These findings, although preliminary, have several implications for resource managers and biologists interested in California oak woodlands. First, variation in crop size is considerable. Sources of variation include tree size and interspecific, annual, and local differences among areas even within the relatively small size of our study site. However, none of these factors appears to explain more than a modest amount of the total variance in acorn production; individual variation among trees uncorrelated with size remains the largest source of differences in acorn productivity within the community.

Second, oak species in central coastal California tend to produce crops asynchronously (Carmen et al. 1987). Because of this, the coefficient of variation in annual crop size within a local area decreases with increasing species diversity, as suggested by Bock and Bock (1974). On a community-wide basis, total crop failures are rare. However, on a local geographic scale such as the sub-areas considered here, crop failures can still occur and have significantly detrimental effects on animal populations, forcing local abandonment by species with limited home ranges

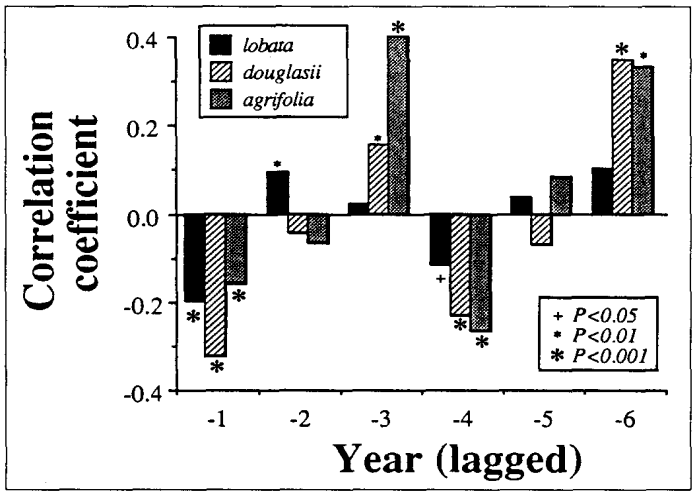


Figure 4—Average autocorrelations of the acorn crop score for each individual of the three species requiring one year to mature acorns with the scores for the same Individuals one to six years earlier. Significance values are based on two-tailed binomial tests (see text).

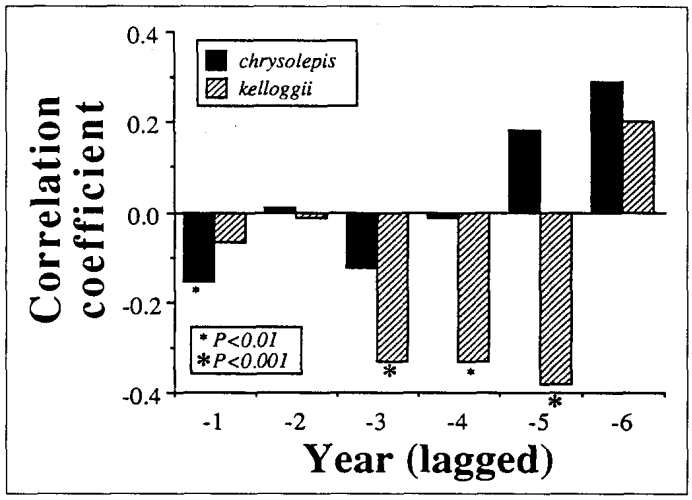


Figure 5—Average autocorrelations of the acorn crop score for each individual of the two species requiring two years to mature acorns with the scores for the same individuals one to six years earlier. Significance values as in figure 4.

such as scrub jays (*Aphelocoma coerulescens*) and acorn woodpeckers (*Melanerpes formicivorus*), both of which are highly dependent on annual acorn crop production (Carmen in press, Hannon et al. 1987). Such disasters are more likely to occur in local areas with fewer species of oaks.

Third, contrary to the findings of Sharp and Sprague (1967) working in eastern oak forests, we found little evidence for an effect of weather on mean acorn productivity for any of the species, with the possible exceptions of *Q. chrysolepis* and *Q. kelloggii*. Extrinsic factors related to differences among subareas significantly influenced crop size, but exactly what these factors may be remain to be identified.

Fourth, intrinsic factors, especially those related to prior reproductive effort, are important determinants of crop size within individuals. Significant inverse autocorrelations between the crops in successive years were identified for all species except *Q. kelloggii.* Distinct three-year cycles in acorn production are evident in *Q. douglasii* and *Q. agrifolia,* while possible six-year cycles are present in *Q. chrysolepis* and *Q. kelloggii*. In addition, *Q. lobata* exhibited a possible two- to three-year cycle. Thus, all five species appear to exhibit masting cycles, although not of the same length.

Masting cycles in California oaks have not, to our knowledge, been identified previously, although similar patterns have been found for several eastern species by Sork (1990). Two common hypotheses for the evolution of mast seeding are resource matching and predator satiation (Silvertown 1980). A complete evaluation of these competing hypotheses is beyond the scope of this paper. However, the predator satiation hypothesis predicts high synchrony among species within the population and that good masting should not occur in successive years. The autocorrelation between the acorn crop is year *x* and that in year *x-1* is negative for all five species (figure 1), as predicted by the predator satiation hypothesis. Nonetheless, neither of these predictions are strongly upheld in our population: successive malting years do occur, as shown by *Q. agrifolia* in 1980, 1981, and 1982 (figure 1), and asynchrony among species leads to relatively constant availability of acorns on a community-wide level (figure 2). The resource matching hypothesis suggests that annual reproductive investment is proportional to the variable level of available resources, and thus predicts synchrony with some important environmental cue such as rainfall or temperature. Although an exhaustive analysis is yet to be performed, no such correlation appears forthcoming, and the lack of synchrony between species further argues against some common resource influencing crop size in our study site.

Recently, Norton and Kelly (1988) have proposed several alternative hypotheses for masting cycles related to "economies of scale" by which a few large episodes of reproduction are more efficient than many smaller ones. Hypotheses invoking such economies of scale include the predator satiation hypothesis already mentioned and several others, including wind pollination and the attraction of generalist animal seed dispersers. Both are potentially applicable to oaks, which are both wind pollinated and whose seeds are dispersed by generalists such as scrub jays (Grinnell 1936). A full discussion must be left for the future.

Our study is beginning to yield concrete conclusions relevant to the determination of acorn crop size within one area. A variety of questions concerning the reproductive strategies of California oaks remain. Is there a tradeoff between vegetative growth and reproductive effort? Are there genetic differences among individuals correlating with overall reproductive effort or masting patterns? What are the geographic patterns of acorn crop production on a larger scale? We have initiated studies addressing the last of these questions by adding study sites approximately 160 km north (Jasper Ridge, Santa Clara County, California) and 200 km south (Pozo, San Luis Obispo County), each of which contain three of the same oak species found at our Hastings Reservation study site. We also hope to acquire data in the future not only extending our crop data but also examining growth patterns of our study trees based on growth rings and genetic correlates based on protein polymorphisms. Considered in concert, these data should eventually allow us to identify the factors determining the reproductive strategies of oaks, thereby yielding more enlightened conservation methods.

ACKNOWLEDGMENTS

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Seedling Establishment of Coast Live Oak in Relation to Seed Caching by Jays[1]

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Abstract: The purpose of this study was to simulate the caching of acorns by jays and rodents to see if less costly procedures could be developed for the establishment of coast live oak (*Quercus agrifolia*). Four treatments [(1) random - single acorn cache, (2) regular - single acorn cache, (3) regular - 5 acorn cache, (4) regular - 10 acorn cache] were planted in January 1990. No efforts were made to protect the acorns nor the emerging seedlings from herbivory. Emergence of epicotyls ranged from 23.4 percent (single acorn, random) to 64.6 percent (five acorn, regular). By October 1990 the percentage of established seedlings ranged from 9 percent (single acorn, random) to 30.6 percent (five acorn regular). Gopher caused mortality averaged 21.3 percent and drought caused mortality averaged 38.4 percent across the treatments. Conclusions about the efficacy of simulating jay and animal caching of acorns for the establishment of oaks must await a second growing season because of the unusual pattern of spring precipitation in 1990.

Animals serve as important vectors and cachers of plant seeds in a variety of ecosystems (Pijl, 1972). Seed caches serve as "graineries" to which birds return to feed upon seed stores. Frequently cached seeds are not recovered and ultimately germinate (Sukachev and Dylis 1964; Janzen 1971; Howe and Westley 1968). Vander Wall and Balda (1977; 1981) suggest that coadaptations for efficient seed harvest and dispersal exist between many birds and the tree species they feed upon. Grinnell (1936) attributed the occurrence of isolated coast live oak (*Quercus agrifolia*) trees to scrub jays (*Aphelocoma coerulescens californica*). Bossema (1979) found that a large number of oak seedlings result from the caching of acorns by jays. It was the objective of this study to evaluate the manner of acorn caching by jays as a potential source of information to apply to the problem of regenerating oaks in California's hardwood rangeland.

Acorn collection and caching by scrub jays has long been observed by several natural historians and ornithologists (Bent, 1946). As indicated above, Grinnel, attributed the occurrence of isolated oaks to this activity. A thorough study of acorn foraging and caching by scrub jays was conducted by Carmen (1988) at Hastings Reservation near Carmel, California. He found that each bird individually cached approximately 5,000 acorns each year in the autumn. Carmen (1990) estimated that about 95 percent of these cached acorns were subsequently relocated by the birds and eaten. Many of the acorns which were not recovered by birds, were observed to germinate. Acorns were cached individually in the soil in grasslands, in crevices in rocks, and at the base of fence post. Birds appear to attempt to drive the acorns straight down into the soil by striking the rounded top of the acorn. In most cases the acorns are driven in vertically to a depth of about 1 cm (the top of the acorn being 1 cm beneath the surface of the ground). Occasionally acorns will veer off at an angle as they are driven into the soil. Scrub jay territories averaged 2.5 ha. at the Hastings Reservation. With an average of 5,000 acorns planted over this area, an average density of planting would equal 2,000 acorns/ha. Blue jays (*Cyanocitta cristata*) cache acorns of eastern oaks. Unlike the scrub jay, they cache 5 to 10 acorns together (Johnson, 1988).

It was hoped that one result of the research presented here would be the elucidation of a more economical approach to the establishment of oaks. The Integrated Hardwood Range Management program has supported a number of projects concerned with regeneration of California oaks. These studies which have evaluated various seeding and planting techniques for successfully establishing oaks. Although many of these projects are still in progress, some general recommendations have resulted from the research. These recommendations were summarized by McCreary (1989). A major concern in oak regeneration projects has been the loss of acorns and seedlings to herbivory. An effective protection system for seeds and seedlings was proposed by Harris and Leiser (1979). The cost per seed spot or seedling spot protected by these recommended procedure may range from $15 to $25 depending upon labor cost (McBride and Zebroski, 1983). Much of this expense is associated with site preparation and screening the acorn or seedling from predation. This cost may be prohibitive to ranchers and resource managers concerned with establishing oaks on large areas of land. It was hoped that one result of the research presented here would be the elucidation of a more economical approach to the establishment of oaks.

STUDY AREA

This study is being conducted at the Russell Reservation near Lafayette, California. This 283 acre (115 ha.) research facility is managed by the Department of Forestry and Resource Management of the University of California, Berkeley. The

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Russell Reservation supports a mosaic of annual grassland, coast live oak woodland, northern coastal scrub, chaparral, and various conifer plantations Soils at the Russell Reservation which support annual grasslands and oak woodlands belong to the Los Osos series. Soil profiles in this series are characterized by clay loams to clays below 40 cm. Los Osos soils average about 3 feet (1 m) in depth and are generally developed on fine grained, slightly acidic sandstone.

The climate of the study area is classified as Mediterranean type climate. Average annual precipitation amounts to 26 inches (650 mm). Over 80 percent of this precipitation falls during the winter months. Usually no rain falls during June, July, and August. During the year of this study the average January minimum and maximum temperatures were 40.1 °F (4.5°C) and 61.7 °F (16.5 °C) respectively and the average July minimum and maximum temperatures were 55.4°F (13 °C) and 92.3 °F (33.5 °C). Soil temperatures ranged from a January low of 41 °F (5°C) to a July high of 98.6°F (37°C) at a depth of 1 inch (2.5cm).

An east facing slope with an angle of repose of 11-12° (26-27 pct) was chosen for this study. The California annual grassland type occurred on the slope. *Bromus rigidus* (ripgut grass) was the dominant species on the slope. Other common species included *Avena fatua* (wildoat), *Rumex acetosella* (sheep sorrell), *Lolium multiflorum* (Italian ryegrass) and *Bromus mollis* (soft chest).

METHODS

Four adjacent 10 m by 10 m plots were established and each plot was divided into 25 - 2 m by 2 m subplots. Twenty acorns were planted in each subplots as follows:

Treatment #1 (Random-single acorn cache) - each acorn was sown at a random location (the same random pattern was repeated in each 2 m X 2 m subplot in the treatment).

Treatment #2 (Regular - Single acorn cache) - each acorn was sown at 20 cm intervals along lines I m apart.

Treatment #3 (Regular - 5 acorn cache) - five acorns were sown as a cluster immediately adjacent to one another at 1 meter intervals along lines I m apart.

Treatment #4 (Regular - 10 acorn cache) - 10 acorns were sown as a cluster immediately adjacent to one another at 1 meter intervals along lines 2 m apart.

To plant the acorns, wooden dipples were made to push holes into the ground for the acorns. It was found, however, that most acorns could be easily pushed into the ground using one's thumb. When more resistant areas of soil were encountered dipples were used. All acorns were planted in a vertical orientation so that the rounded end of each acorn was approximately 1 cm below the surface of the ground. All four treatments were planted on January 4, 1990, 5 days after a 0.7 inch (20 mm) rainfall. This rainfall followed a December drought. Seed spots were not marked in any treatment but the south east corner of each 2 m by 2 m subplot was staked in treatment #1. The uphill and downhill ends of the planting lines in treatments 2, 3, and 4 were also staked.

To randomly locate the planting spots in each 2 m by 2 m subplot for treatment #1, four 1 m^2 frames were built with wires crossing to mark five random locations in each frame. The random locations were determined by selecting numbers from a table of randoms to be used as X and Y coordinates on each frame. A new set of random numbers were selected for each frame. The numbers chosen (from 1 to 100) were used as distances along "X" and "Y" coordinates on the frames. Wires were stretched from these points and their intersections wrapped with insulated red wire for easy recognition in the field. In the field the four frames (designated A, B, C, and D) were laid on the ground to form each of the twenty-five 2 m by 2 m subplot. A single acorn was planted under each of the five random locations marked by the insulated red wire. The frames were subsequently used to relocate the planting spots to monitor germination, growth, and herbivory.

Every four weeks following planting each seed spot was examined for the appearance of the epicotyl above the ground. When epicotyls were present their height was measured. Notes were taken concerning evidence of herbivory and damage to the seedling. Seedling mortality was also recorded.

A Foxburo recording thermograph with soil temperature probes was located immediately adjacent to the four treatments. The temperature probes were placed at 1 inch (2.5 cm) and 4 inches (10 cm) below the soil surface. Air temperature was recorded on a Bendix thermograph located approximately 300 feet south of the planting site on the same slope. At this location, maintained as a permanent weather station for the Russell Reservation, precipitation was also measured using a standard 8 inch diameter rain gauge.

Soil samples were collected once a month during the study and at times of change in vegetation growth and phenology or unseasonable precipitation for a gravimetric determination of moisture percentage. Approximately 100 grams of soil was taken at 10, 20, 30, 40, 60 and 90 cm in each of the four treatments. Each soil sample was weighed, dried for 24 hours at 105° C, and reweighed to provide data for calculating soil moisture percentage.

On June 1, 1990, a point intercept survey was taken to determine the plant species composition of each of the treatment plots. The plant species occurring at 100 points spaced 1 m by 1 m apart across each plot was recorded. At the same time and again on July 26 and October 18, 1990 an estimate of the percentage of the ground covered by soil brought to the surface by pocket gopher activity was made for each plot using the point intercept.

Concurrent with the field study, a germination and emergence study was conducted out of doors in Berkeley at temperatures similar to those on the field plots. Two hundred fifty acorns were planted in vermiculite in 20 cm wide by 30 cm deep pots. Germination (defined by the emergence of a radicle from the acorn) was recorded when the pots were harvested. At the end of 100 days, including 10 days without any new epicotyls, all acorns were dug out of the tray to determine the number which had produced radicles but not epicotyls, the number of

polyembrionic acorns, and the condition of those which had not germinated.

RESULTS AND DISCUSSION

The number of current shoots, new shoots, and dead shoots observed each month from March to October 1990 is shown in table 1. An initial period of shoot emergence began in March and continued through June. A second period of shoot emergence began in September, but involved very few seedlings. Shoot emergence ranged from 23.4 percent in the single acorn, random treatment to 64.6 percent in the five acorn, regular treatment (table 2). These percentages were less than the 85.4 percent shoot emergence observed in the pot study conducted in Berkeley. The differences between the field and pot study may have been due to differences in acorn viability, physical resistance of the soil to shoot emergence, and/or seed predation. We believe, that acorn viability was not different because acorns used in both the field and pot studies were taken from the same acorn collection. Furthermore, we started to dig up acorns in the field from sown seed spots which had not produced shoots by the end of May and found all of the acorns (in a 10 pct sample in each treatment) to have germinated. Germination reached 97.5 percent in the pot study (table 3) and we believe a similar

Table 1—Summary of oak shoot emergence, mortality, and damage on eight monthly survey date for four acorn cache treatments.

	Number in shoot status for survey month							
Treatment	3-29	4-26	5-24	6-21	7-19	8-23	9-13	10-25
Single Acorn, Random								
Current Shoots	1	16	85	80	78	56	53	45
New Shoots	1	15	73	10	16	0	1	1
Gopher Mortality	0	0	4	13	15	6	0	8
Drought Mortality	0	0	0	2	3	18	4	1
Damaged - Living	0	0	7	10	58	56	51	43
Single Acorn, Regular								
Current Shoots	5	78	159	148	157	114	101	89
New Shoots	5	78	91	13	35	0	0	1
Gopher Mortality	0	2	3	6	9	11	4	8
Drought Mortality	0	3	7	18	17	32	9	5
Damage Mortality	0	1	3	8	127	110	96	85
Five Acorn, Regular								
Current Shoots	44	164	285	283	253	198	164	153
New Shoots	44	121	125	22	9	0	0	2
Gopher Mortality	0	1	1	9	14	6	18	12
Drought Mortality	0	0	3	15	25	49	16	1
Damage Mortality	0	1	10	11	175	187	159	149
Ten Acorn, Regular								
Current Shoots	19	168	240	254	204	150	143	118
New Shoots	19	158	78	21	10	0	0	0
Gopher Mortality	0	0	0	5	9	0	0	8
Drought Mortality	0	0	5	2	51	54	7	17
Damage Mortality	0	9	21	10	169	148	137	114

Table 2—Total emergence of oak seedlings in four acorn cache treatments

Treatment	Total Emergence *(pct)
Single acorn, random	23.4
Single acorn, regular	44.6
Five acorn, regular	64.6
Ten acorn, regular	57.2

*from January to October, 1990

percentage would have been achieved in the field study in the absence of germination. Eighteen point nine (18.9) percent of the acorns which germination in the pot study did not produce an above ground shoot because the epicotyls was trapped by the shell of the acorn. Twelve point one (12.1) percent of the acorns in the pot study produced radicles but no visible epicotyls. We believe that the vertical planting orientation used in both the field and pot study resulted in the trapping of epicotyls within the acorn shell and was in part responsible for the differences in shoot emergence between the field and pot studies. Physical resistance of the soil may have also been a factor in the field. We believe clay loam texture of the A horizon of the Los Osos soil would have offered more resistance to the upward growth of the epicotyl that the vermiculite used in the pot study. The greater shoot emergence in the 5 and 10 acorn treatments may have been in part, due to a collective effort of more than one epicotyl breaking through the soil surface at one time. In April and May it was evident that emerging shoots had lifted the thin layer of surface soil as they had simultaneously emerged from the ground.

Seed predation must also account for the differences in shoot emergence between the four field treatments. We believe the lower percentage emergence observed in the single acorn, random cache (23.4 pct) and the single acorn, regular cache (40.6 pct) treatments was to a large part due to acorn consumption by pocket gophers (*Thomomys bottae*). Point intercept counts of gopher mounds indicated greater gopher activity during the germination period in the single acorn, random treatment plot (table 4). No acorns were found in the 10 percent sample spots excavated (to determine if acorns had germinated) on the single acorn, random treatment plot at the end of May. Griffin (1979) has reported high losses of acorns to predation by pocket gophers in his studies of valley oak (*Quercus lobata*) seedling establishment in the California coast range.

Post emergence shoot survival depended upon herbivory and the capacity of the seedlings to withstand summer drought. Table 5 shows the percentage of seedlings which succumbed to pocket gophers or drought and the percentage of seedlings alive in October which had been damaged by above ground herbivory. A little more than 1/3 of the seedlings (39.3 pct) in the single acorn, random treatment were killed by gophers. This is twice the number killed by pocket gophers in any of the other treatments. We believe the difference in mortality due to gophers is not a function of the treatments, but is related to the distribution of pocket gophers over the study area. More gopher activity occurred, as evidenced by gopher mounds, on the single acorn, random treatment plot. More gopher activity occurred on the single acorn, random treatment plot than on the other plots (table 4).

Drought mortality ranged from 23.9 percent in the single acorn, random treatment to 55.2 percent on the 10 acorn treatment. Greater drought mortality in the 10 acorn treatment may be due to competition for soil moisture among the oak seedling. However, a relatively low level (33.7 pct) of drought mortality was observed in the five acorn treatment. The drought mortality observed in this study may be less than one would see in a more typical rainfall year. An unusually heavy rain (69 nun) occurred in May, 1990. The average precipitation in May is 5 mm at the Russell Reservation. The heavy May, 1990 rain brought soil moisture levels back up to the levels observed in February and March in the upper 30 cm of the soil profile (table 6). This added soil moisture, at a time when the annual grasses had senesced, provided the oak seedlings with a typical summer soil moisture. In response to this moisture, new shoots emerged and shoot growth was resumed.

Herbivory was observed on shoots of nearly all seedlings in all treatments (table 5). Herbivory by insects, mice or other small mammals, and deer occurred on the plots. We believe that deer accounted for a relatively small percentage of the herbivory observed because only small amounts of shoots and foliage was removed by herbivores from most seedlings. Deer and rabbit droppings and mouse burrows were observed on the plots. Grasshoppers, earwigs, and unidentified insect larvae were also found on the plots. It is also possible that pocket gophers may have fed on the above ground portions of seedlings.

Table 3—*Summary of germination and epicotyl emergence of 280 acorns sown in pots after 100 days.*

	Number	Percent
Acorns that grew a radicle (germinants)	273	97.5
Germinants that grew epicotyl	239	85.4
(Polyembryony)	(18)	(6.4)
Germinants with an emergent epicotyl	186	66.4
(Polyembryony)	(11)	3.9
*Germinants with non-emergent epicotyl	53	18.9
(Polyembryony)	(9)	3.2
*Germinants without visible epicotyl formation	34	12.1
*Non-Germinants	7	2.5

*Acorn and any growth was completely or partially rotted at harvest.

Table 4—*Percentage of ground covered by soil excavated by pocket gophers on the four acorn cache plots as measure of pocket gopher activity*

	Single Acorn Cache		Multiple Acorn Cache (regular)	
	Random	Regular	Five	Ten
June 1	7	1	0	1
July 26	32*	7	10	1
Oct. 18	14	7	12	8

*Note: Some unknown part of the increase was probably due to the gopher responses to the late May rains and the cleaning out of old tunnels thus spreading the soil over a wider area during early June but still is an indication of gopher movement.

Table 5—*Percentage of oak seedlings killed by gophers or drought and percentage of above ground seedling alive in October, 1990 showing evidence of herbivory.*

Treatment	Gopher Mortality (pct)	Drought Mortality (pct)	Live Seedling showing Herbivory (pct)
Single acorn, random	39.3	23.9	95.6
Single acorn, regular	19.3	40.8	95.5
Five acorn, regular	18.9	33.7	97.4
10 acorn, regular	7.7	55.2	96.7

Table 6—*Soil moisture percent on Acorn Cache Plots (± 1.5 pct) for relevant tripicate soil samples*

Depth cm	Feb. 20	March 20	April 12	May 10	June 1	June 28	July 18
10	28	18	11	10	23	19	12
20	25	24	12	11	23	20	15
30	25	25	15	14	21	18	15
40	28	27	20	17	17	17	15
60	28	28	24	22	20	20	18
90	30	30	28	24	23	21	21

Note: Feb. 20 to April 12 - Period of grass growth from coleoptile stage to 18" to 24"
April 12 to June 1 - Maturation of grass and increased soil moisture withdrawal that is concurrent with seed production. Late May rainfall occurred after death of grass and oak seedling drought stress.
June to July 18 - Period of soil moisture recharge down to 40 cm. Some oaks resumed shoot growth and a few grassed germinated from this year's seed. Some acorns held back by prior low soil moisture produced an aerial epicotyls.

CONCLUSIONS

The expected results of this experiment have been somewhat clouded by unequal levels of acorn predation and seedling consumption by pocket gophers among the treatments. Interpretation of the results is further complicated by the unusual rainfall year. In spite of these complications, the study does demonstrate that coast live oak acorns can be sown to simulate the caching of acorns by scrub jays and seedlings will emerge and survive. More emergence could be expected if a horizontal orientation of the acorn was used (McCreary, 1989). That of course is not in the best interest of the jay, whose caching technique have evolved to minimize early emergence of the epicotyl and save as much storage material as possible for the jay.

We plan to continue monitoring seedling growth and survival in this study to record the response of the treatments over a five year period. If the survival rate after one growing season is maintained, we believe we will have demonstrated a cost effective alternative to establishment procedures currently recommended for California oaks. The sowing cost in our study amounted to $0.01 per acorn. At this price one could afford 35 to 77 percent mortality rates we observed and still regenerate coast live oak at a cost of about $5.00 per acre.

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Insect and Disease Impacts on Blue Oak Acorns and Seedlings[1]

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Abstract: We studied the impacts of diseases and arthropods on acorns and naturally occurring seedlings of blue oak, *Quercus douglasii,* in northern California. Damage levels were always significantly higher in acorns collected from the ground than those picked from the tree. Accurate assessments of damage levels could only be made by dissecting acorns, since external symptoms were frequently absent from acorns with severe damage to the embryo. Levels of insect and disease damage to acorns varied significantly between locations and between trees. Foliar feeding by several types of insects had no apparent effect on the survival of natural blue oak seedlings over 3 years. Water stress appeared to be the primary factor affecting seedling survival. Although many seedlings survived the complete loss of their shoots and resprouted, repeated resprouting was associated with increased mortality. Overall seedling mortality after 3 years was 25 percent, but ranged from 5 percent to 65 percent at different plots. We suggest that blue oak seedlings are adapted to persist for a number of years beneath mature trees and may constitute an important source of advance regeneration.

As part of a research project sponsored by the California Department of Forestry and Fire Protection we have been studying the effects of diseases and arthropods on different life stages of blue oak. Due to their small size and limited energy reserves, acorns and seedlings are potentially quite susceptible to destruction by insects and diseases. While losses of acorns due to insect and disease damage has been noted by various authors (Griffin 1971, Knudsen 1987, Borchert 1990), methods used to assess damage levels have not been standardized. A number of damage and mortality factors have been implicated in the failure of blue oak seedlings to develop into saplings. However, the impacts of arthropods and diseases on the survival of natural blue oak seedlings have not been studied previously.

We developed and applied methods to assess the impacts of diseases, arthropods, and other damage factors on acorns and naturally-occurring seedlings of blue oak throughout northern California. This paper summarizes some of the results of our studies conducted between the summer of 1988 and May 1990. Results from these and related studies are reported in Swiecki and others (1990).

METHODS

Acorns

Insect and disease impacts on blue oak acorns were assessed by visually rating internal and external symptoms of collected acorns. We rated 26 blue oak acorn samples in 1988 and 14 in 1989. Acorns were collected either from the ground beneath trees or from the lower branches of tree canopies. Over the 2 years, we also collected paired canopy and ground samples from 10 trees. Sampled trees were in blue oak and mixed oak woodlands in the northern California counties of Amador, Butte, Glenn, Napa, Sacramento, Solano, Sonoma, Tehama, and Yuba. Most of the sampled trees were in the vicinity of the seedling study plots described below. Acorns were placed in plastic bags and held at room temperature (20-25 C) until rated. From each sample, 25 acorns were drawn at random for rating.

External symptoms rated included the degree of external color change, the presence of insect oviposition injury and exit holes, and presence of mycelium and/or sporulation. Sporulating fungi were identified to genus where possible. After external symptoms were rated, each acorn was cut longitudinally into quarters, and the sections of the embryo were separated from the seed coat to allow inspection of all faces. The embryo sections were further sliced or broken as necessary to determine the extent of symptoms and inspect for insects. The percentage of the acorn embryo affected by discoloration, decay, and insect feeding was estimated using a 0 to 6 pretransformed scale, where 0 = no damage and 6 = >97.5 percent (Swiecki and others, these proceedings). The percentage intervals in this scale are pretransformed using the arcsin transformation, which permits analysis by parametric statistical techniques without further transformation (Little and Hills 1978). In addition, we noted the presence and type of visible fungal signs, type of insect injury, and the number and type of insect larvae within each acorn.

Seedlings

In the summer of 1988, we established nine plots to study naturally occurring seedlings in Amador, Butte, Glenn, Napa, Solano, and Sonoma counties. The locations of the plots are shown in Swiecki and others (these proceedings). Plots were selected to represent a variety of different site conditions (Swiecki and others 1990). At each location, 50 blue oak seedlings located along a belt transect were selected at random and marked by placing a small wooden stake or wire stake flag 10 cm due

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north of the seedling. Sites subject to cattle grazing were also marked prior to the start of seasonal grazing by anchoring an aluminum tag at ground level with a heavy gauge galvanized nail 10 cm due south of the seedling. A portable metal detector was subsequently used to relocate seedlings when the stakes or flags were destroyed or dislodged by cattle or rodents. With very few exceptions, seedlings selected for the study were no taller than 10 to 15 cm, and had no more than 20 leaves at the start of the study.

We rated the plots at irregular time intervals in the latter half of 1988 and throughout the growing season in 1989. Final ratings were made in the spring of 1990. During each rating, we collected data on seedling morphology and damage symptoms. Numbers of live and dead leaves were counted, and the percentage of leaf area affected by necrosis, chlorosis and other discoloration, chewing (free feeding through the entire leaf), window feeding (feeding on only one leaf surface), and stippling (fine chlorotic or necrotic spotting caused by arthropods with piercing-sucking mouthparts) was estimated using the 0 to 6 pretransformed scale previously described . We also coded the types of insects observed, disease symptoms, and other types of damage seen during each rating. We estimated the degree of shading each seedling would receive, based on its topographic position, position relative to the canopy, and canopy density. Three levels of shading were assigned: 0 = full sun, 1 = shaded part of the day, 2 = shaded most of the day, except at low solar angles.

At the start of the study in 1988, we examined each seedling carefully to determine whether shoots had been produced in previous years. If no evidence of stems formed in previous seasons was found, seedlings were assigned to the "new" seedling age class. Seedlings continuing growth on 1-year old or older wood and those with evidence of previous shoots were assigned to the "existing" seedling age class. In subsequent years, we rated seedlings for the age of the oldest live shoot only. If the oldest live shoot arose from ground level, seedlings were assigned to the "current" shoot age class. If new growth was produced on a preexisting stem above ground level, seedlings were assigned to the "previous" shoot age class.

Data Analysis

The statistical significance of mean differences was determined using fixed or mixed model analysis of variance. Correlations between continuous variables were evaluated with standard linear regression analysis or stepwise multiple regression. Nonparametric rank correlation analysis was used for ratings. Proportional data were subjected to contingency table analysis, and the significance of differences between proportions was determined by either Fisher's exact test or Chi square as appropriate. Tests or comparisons reported as significant are significant at the $P < 0.05$ level unless otherwise noted.

RESULTS

Acorns

Substantial numbers of acorns, many of which were diseased and/or insect infested, began to drop by early August in some of our study areas. The average internal damage rating for acorns collected from the ground (3.8 ± 2.3) was significantly higher ($P<.001$) than for acorns picked from oak canopies (.6 ± 1.2). For the 10 paired canopy/ground samples, site of collection (canopy or ground) and the site by tree interaction were both highly significant ($P<.001$) in the analysis of variance. The incidence of internal fungal growth, internal insect boring, feeding/oviposition wounds, exit holes, and internal damage ratings > 3 (more than 20 percent of the embryo affected) were significantly greater in acorns collected from the ground than those collected from the canopy. Average internal damage ratings for canopy and ground samples remained relatively constant over the period from late August through late October (figure 1).

External discoloration, oviposition injury, and fungal growth were not significantly associated with substantial internal injury, i.e. internal ratings > 3. Only insect exit holes were generally indicative of substantial internal damage; 81 percent of the acorns with exit holes had internal damage ratings > 3. However, acorns lacking exit holes could not be assumed to be sound, since 82 percent of acorns with internal ratings > 3 did not have insect exit holes.

The larvae of a filbert weevil, *Curculio pardus* (Chittenden), and the filbertworm, *Cydia latiferreana* (Walshingham), accounted for almost all of the insect injury we observed in blue oak acorns. No more than a single filbertworm larva was found in each blue oak acorn infested with this species, but 1 to 8 filbert weevil larvae were found in each acorn (overall mean 1.6 ± 1.2). Both insects were found in the same acorn 5.4 percent of the time. Up to 47 percent of the acorns in some samples contained weevil larvae whereas the incidence of filbertworm infestation ranged up to 60 percent. Average internal damage ratings in acorns infested by each species did not differ significantly (3.1 ± 1.6 for filbert weevil and 3.1 ± 2.1 for filbertworm).

Among the internal symptoms, internal fungal growth was most frequently associated with high damage ratings. Acorns were commonly colonized externally and/or internally by species of *Penicillium* and *Aspergillus.* In many cases, external fungal colonization was limited to the abscission scar at the cap end of the acorn, and did not progress into otherwise intact acorns. Extensive internal sporulation, particularly by *Penicillium,* was commonly seen in acorns with insect exit holes and moderate amounts of internal insect boring. Other fungi observed in or on acorns included *Fusarium oxysporum,* Schlechtend.:Fr. *Stemphylium* sp., *Trichothecium* sp., and an unidentified Coelomycete.

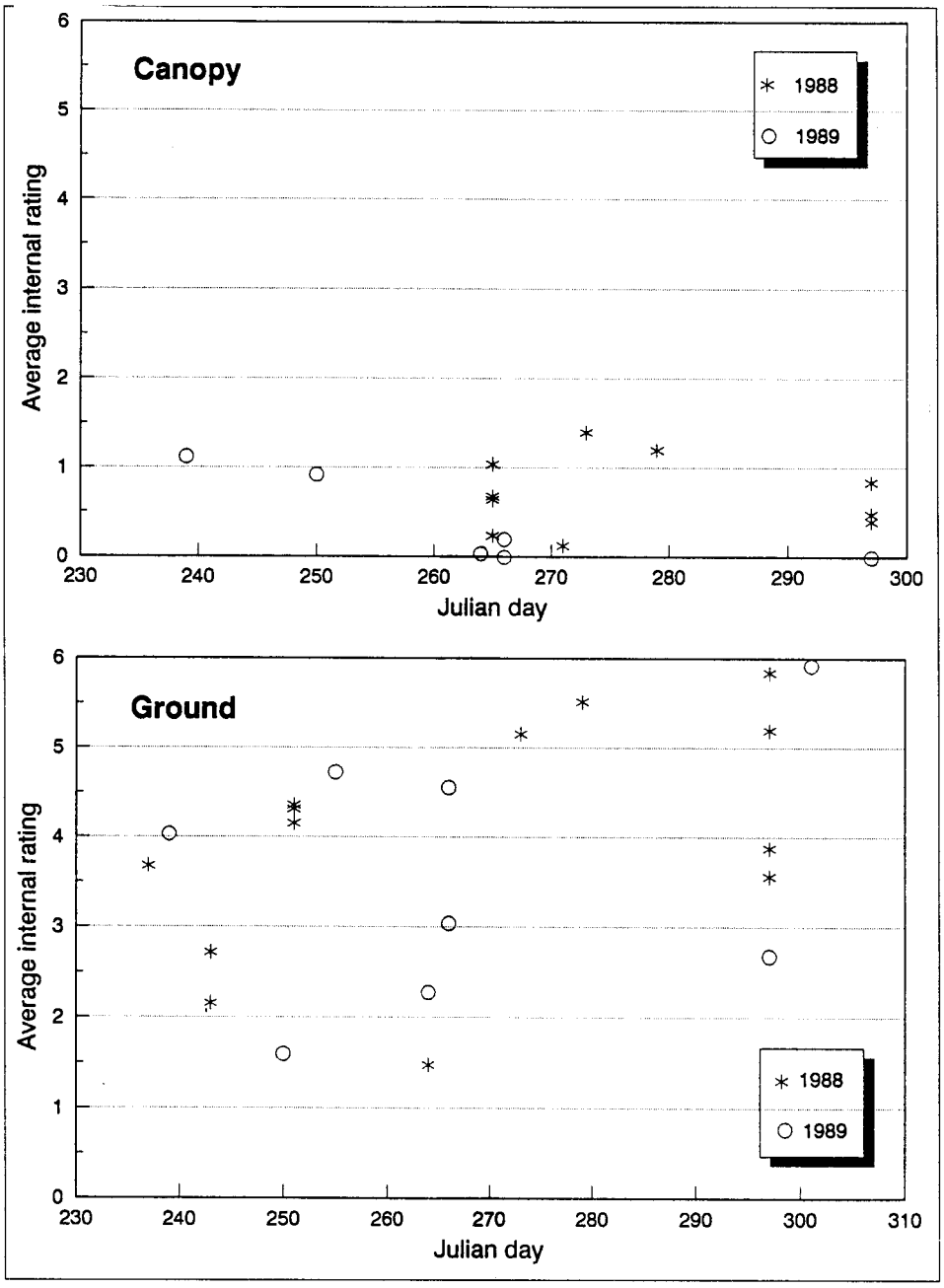


Figure 1—Average internal damage ratings for blue oak acorn embryos collected from the tree canopy or ground for August through November of 1988 and 1989 (Julian day 240 = 28 August, Julian day 300 = 28 October).

Seedlings

Various insects and their feeding symptoms or products were observed on seedlings, but only chewing, window feeding, and stippling were common enough and of sufficient intensity to warrant severity ratings. Of these, chewing damage was the most important, although average levels of chewing damage seldom exceeded a rating of 2 (2.5 to 20 percent of foliage affected) (figure 2). Most window feeding and stippling damage occurred before May. Early-season chewing damage to young foliage was seen through mid-June, and a second period of chewing damage was seen in July and August. Significant positive correlations ($P<.001$) were observed between the maximum leaf count and maximum levels of chewing, window feeding, and stippling damage in 1989. Within each plot, the distribution of seedlings with insect damage was highly variable. Heavily-damaged seedlings were often observed within close proximity (10 to 30 cm) of seedlings with little or no insect damage.

Progressive foliar necrosis was the most significant foliar symptom in all plots, and increased steadily throughout the season (figure 3). Foliar chlorosis also tended to increase over

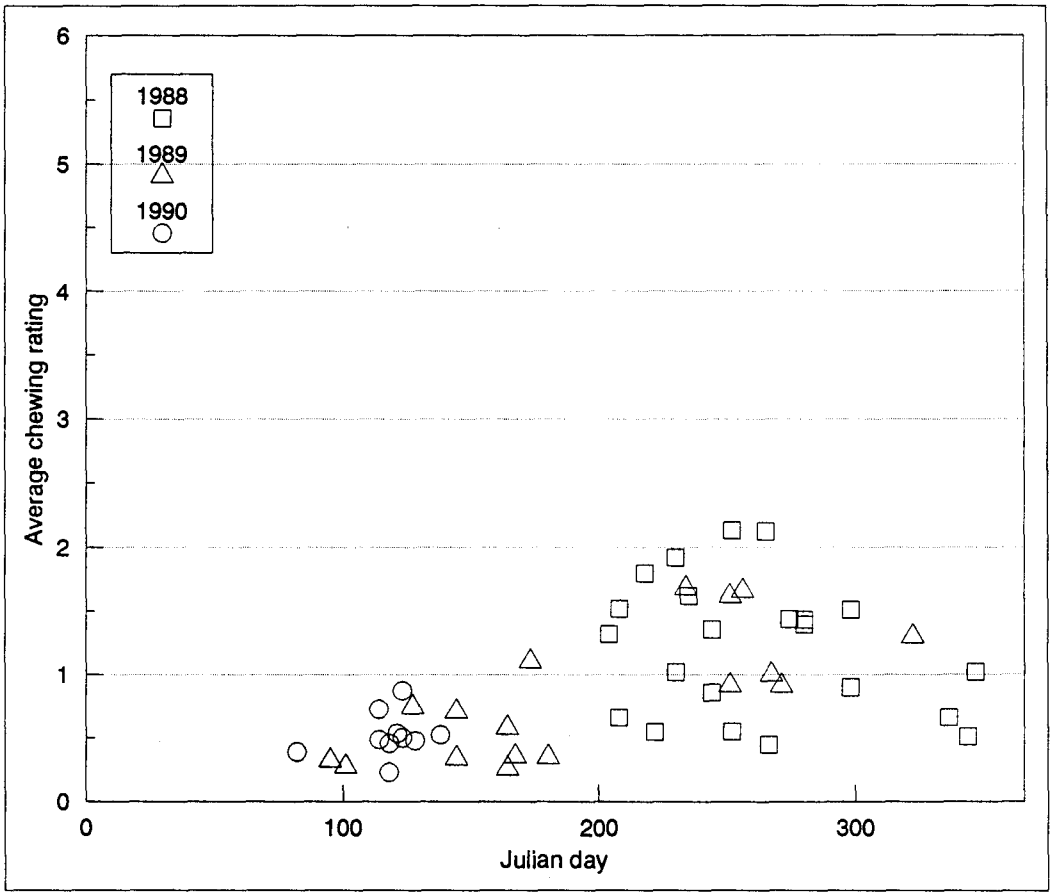


Figure 2—Average chewing damage ratings for blue oak seedlings for all plot ratings in 1988 through 1990 (Julian day 100 = 10 April, Julian day 200 = 19 July, Julian day 300 = 28 October).

the season from the beginning of July onward. Overall, these progressive chlorotic and necrotic symptoms were consistent with those caused by water stress. Damage to seedling foliage and shoots by aerial plant pathogens was insignificant at all of our study sites.

Mortality was based on the last year that a live shoot was observed at any rating because many seedlings successfully resprouted following complete foliar or shoot necrosis. A total of 383 seedlings were tracked across all 3 years of the study. Of these, 34 (8.9 percent) died in 1988 and 59 (15.4 percent) died in 1989, leaving 290 survivors (75.7 percent) in the spring of 1990. Survival over the study period varied widely between plots, and ranged from 95 percent to 35 percent. The average maximum number of leaves per seedling in 1989 was significantly lower in seedlings that died that year (4.7 ± 1.0), than in seedlings that survived into 1990 (10.5 ± 0.4).

Regression analysis showed that among individual site environmental variables, reference evapotranspiration (ETo) was positively correlated (r^2=.461, P=.044) and precipitation was negatively correlated (r^2=.394, P=.070) with seedling mortality. In the model derived through stepwise multiple regression analysis, mortality increased with increasing ETo and decreasing soil depth (r^2=.683, P=0.032): $(\text{percent mortality})^{0.5}$ = .443(ETo) - .049(Soil depth) - 44.2.

At the start of the study in 1988, 35 percent of the seedlings had no obvious evidence of shoots produced in previous years. However, many of these seedlings may still have been resprouts, since attached acorns were seldom observed. Of the seedlings that survived into 1989,26 percent resprouted from ground level after death of the previous year's shoot, whereas the remainder continued growth on stems that had been produced the previous year. In 1990, 31 percent of the surviving seedlings had resprouted from ground level due to death of the previous shoot. However, even though seedlings were able to resprout from ground level following death of the previous year's shoot, repeated resprouting was clearly associated with reduced survival. A comparison of seedlings that were alive in both 1988 and 1989 shows that subsequent mortality was highest in seedlings which died back to the ground and resprouted each year (37.5 percent) and lowest in plants whose shoots survived both years (92 percent). Seedlings rated as new in 1988 were more likely to die back to the ground in subsequent years, and had significantly lower rates of survival in 1989 and 1990 (79 and 56 percent, respectively) than those starting with existing shoots in 1988 (95 and 85 percent, respectively).

All of the major damage symptoms we rated varied significantly between plots. Among the damage variables, only chewing damage and total necrosis ratings were associated with

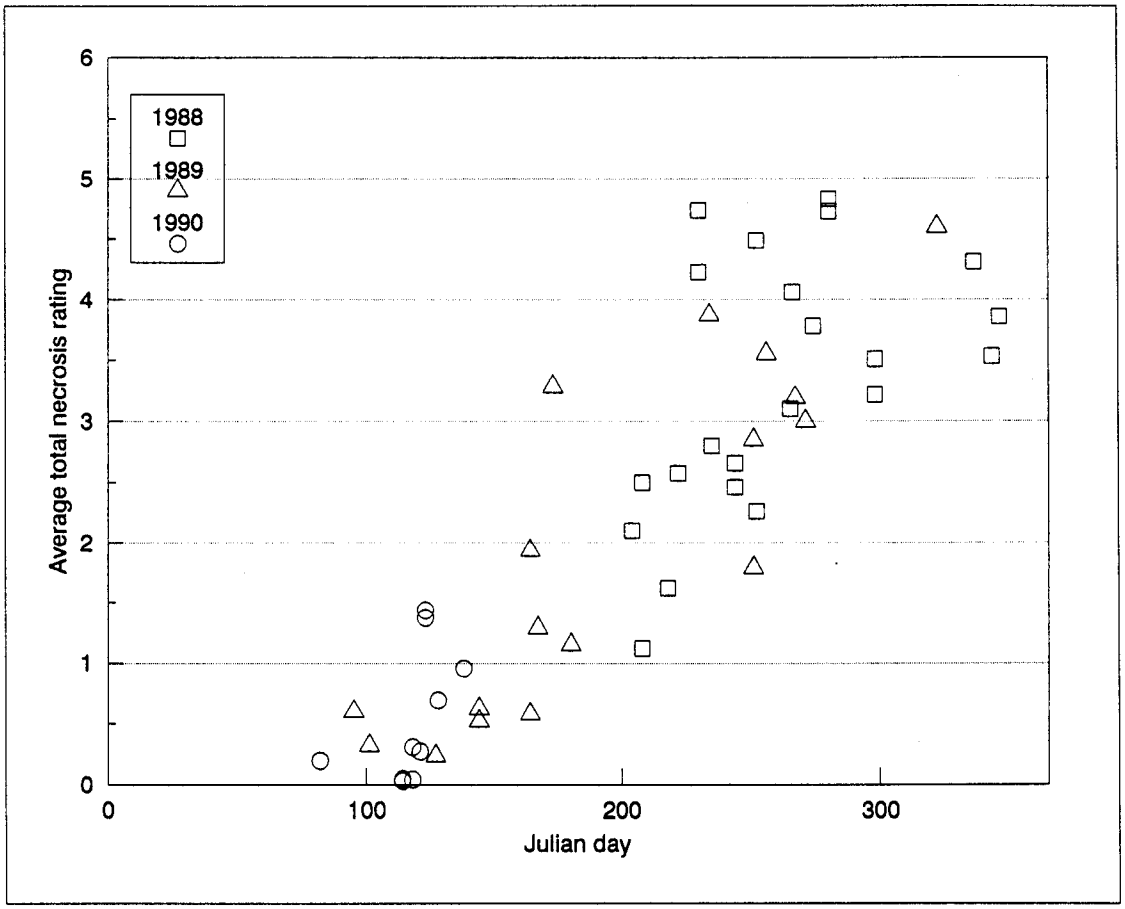


Figure 3—Average total foliar necrosis ratings for blue oak seedlings for all plot ratings in 1988 through 1990 (Julian day 100 = 10 April, Julian day 200 = 19 July, Julian day 300 = 28 October).

plant mortality. Seedlings that died in 1988 experienced significantly lower levels of chewing damage (P=.026) than those that survived. Although chewing damage was negatively correlated with mortality in 1988, no relationship was detected between chewing damage in 1988 or 1989 and mortality in 1989. Total necrosis ratings in 1988 and 1989 were positively correlated with mortality in 1989 in 2 by 2 contingency table analyses (P=.033 and .053, respectively). Seedlings that were alive in 1990 showed higher average chewing ratings and lower average necrosis ratings in 1988 and 1989 than seedlings that died in those years (table 1).

Although few seedlings (7 percent of total) were located in full sun locations, the relative level of shading had no significant effect on seedling and shoot survival over the course of the study. Maximum average leaf counts in 1989 and 1990 were significantly lower in seedlings under the highest level of shading than in the remaining seedlings. For 1989, least squares means for maximum leaf counts were 10.1 ± 1.5, 9.6 ±.6, and 7.5 ±.6 for the low, intermediate, and high shading levels, respectively. In 1989, chewing damage increased as shading level increased, although this effect was not observed in 1988.

DISCUSSION

Considerable damage to the acorn embryo normally occurs in acorns that have exit holes. Substantial internal damage is also likely in extremely light-weight acorns that lack exit holes, since these acorns normally show severe decay and dehydration of the embryo. However, the results of our study indicate that acorns which do not meet these criteria may also have high levels of internal damage. Since internal damage cannot be reliably predicted from external symptoms, damage may have been under- or overestimated in previous studies where only external damage symptoms were recorded. We found that destructive sampling was the only reliable method for assessing absolute levels of internal damage in acorns. While this method precludes the use of rated acorns in germination tests, we expect that germination and seedling vigor are likely to be adversely affected at internal damage ratings of 3 or greater. Acorns with internal damage ratings of 5 or more are clearly nonviable.

Damaged acorns are prone to early abscission, contributing to the significant disparity between acorn damage levels found in samples collected from the ground and those collected from

Table 1—*Means for chewing ratings and total necrosis ratings by seedling survival class.*

Last year seedling was rated live	Average chewing rating		Average total necrosis rating	
	1988	1989	1988	1989
1988	1.2 A[1]	—	3.9 A	—
1989	1.4 AB	0.7 A	3.8 A	2.8
1990	1.7 B	1.3 B	2.6 B	2.2
Analysis of variance				
F value	3.97	11.70	13.89	3.46
P level	.020	>.001	>.001	.064

[1]Means followed by the same letter within a column are not significantly different at P=.05 (mean separation by LSD following significant F in the analysis of variance table).

tree canopies. Various authors (Griffin 1971, Schettler and Smith 1980, Menke and Fry 1980) have also noted that insect-infested acorns tend to drop before sound acorns. Therefore, the method of acorn collection will significantly affect the estimate of overall damage levels due to insects and disease. However, few authors have stated the method of collection when reporting acorns infestation levels.

Levels of damage in acorns collected from the ground did not decrease as the season progressed, even though the population of damaged acorns on the ground should have been diluted by the less-damaged population from the canopy. It is possible that the supply of sound acorns on the ground is preferentially depleted by vertebrate acorn consumers. Alternatively, insect and pathogen activity may be increasing over this interval, leading to the establishment of new infestations and infections and an increase in damage from established infestations and infections. Regardless of the mechanism, the net result is that a high proportion of the acorns available for recruitment have reduced viability due to insect damage and decay.

Although seed-boring insects are frequently cited as agents affecting acorns in California, the role of microorganisms has received relatively little attention. Our observations suggest that various fungi and possibly bacteria are important pathogens of blue oak acorns in northern California. Acorns are often extensively decayed by these agents even in the absence of significant insect damage. It appears that wounds produced by insects are probably the most common site of entry for the pathogens affecting blue oak acorns. A similar etiology is reported for the "drippy nut" disease of live oak acorns (Hildebrand and Schroth 1967). In addition to effects on acorn germination, various fungi, particularly *Aspergillus* and *Fusarium* spp., produce mycotoxins which may pose a hazard to livestock or wildlife species that consume large quantities of the mast crop.

Direct and indirect effects of water stress appeared to be the most significant factor influencing the growth and mortality of blue oak seedlings in our study. While damage caused by root pathogens, root-feeding insects, and vascular pathogens can be expressed as progressive water stress symptoms, we believe that low soil moisture is the most likely cause of the symptoms we observed. Symptoms consistent with severe water stress, including progressive foliar chlorosis and necrosis and shoot dieback, developed from early June through at least mid-September. Soil moisture levels and blue oak seedling water potentials decrease substantially over this interval (Welker and Menke 1987). The regression analysis of site characteristics also points to water stress as an important mortality factor at our study plots.

Although natural blue oak seedlings are fed upon by a variety of insects, insect herbivory did not significantly affect seedling survival in our study. This is not surprising, given the relatively low levels of damage seen in most seedlings. Furthermore, as indicated by Welker and Menke (in press), some loss of foliage may promote seedling survival by reducing the rate at which seedling water potentials decrease. In 1988, mortality was actually lower in seedlings with high levels of chewing damage. However, mortality rates were also low in seedlings with high leaf counts and low levels of foliar necrosis (Swiecki and others 1990). Therefore, we believe that the negative correlation between chewing and mortality simply reflects the preference of foliar feeding insects for larger seedlings and those with more live leaf tissue.

Although varying degrees of leaf loss due to insect herbivory did not adversely affect seedling survival, loss of the entire shoot did reduce survival. Repeated allocation of stored photosynthate to replace shoot tissues may reduce root growth (Welker and Menke in press), restricting the seedling's access to soil moisture and eventually leading to lethal water stress. However, even though they can be killed by water stress and repeated shoot loss, our data shows that small blue oak seedlings are anything but ephemeral. Overall mortality was only 25 percent over 3 years, and was as low as 5 percent in some plots. Over 60 percent of the seedlings that resprouted in both 1988 and 1989 still emerged in 1990, in spite of drought conditions during these 3 years. Similarly, Griffin (1971) observed 88 percent seedling survival in blue oak 3 years after planting, despite 60 percent shoot mortality in the first summer.

The low percentage of seedlings we located in full sun was the same as that reported by Muick and Bartolome (1987). There were no differences in seedling mortality observed over the course of our study that would account for the low numbers of seedlings away from tree canopies. Lack of dispersal and poor acorn germination in exposed sites (Griffin 1971) could account for the relative lack of seedlings in the open. Open and shaded sites may also differ in the depth of the litter layer, herbaceous plant cover, soil moisture levels, soil condition, soil nutrient levels, temperature, light intensity or other factors that may affect seedling establishment. However, even though the balance of factors under tree canopies is relatively favorable for seedling establishment and persistence, they apparently do not favor the transition to the sapling class. Muick and Bartolome (1987) report that although seedlings are abundant beneath existing blue oak tree canopies, saplings seldom develop in this position.

We believe that persistence in the seedling stage may be part of the reproductive strategy of blue oak, as suggested by Knudsen (1987) for *Q. lobata.* Blue oak seedlings are clearly capable of surviving for a number of years under blue oak canopies. These

persistent seedlings may constitute a reserve of regeneration which is recruited into the sapling stage only when canopy gaps open or entire stands are killed by fire or removed by cutting. We have seen situations in various locations where a relatively even-aged stand of saplings appears to have developed from preexisting seedlings following removal of the canopy by cutting. An analogous situation, referred to as advance regeneration, has been observed for oaks in the eastern U.S. (Beck 1970, Sander and others 1976) where oaks may persist as seedlings or saplings for 6 to 15 years or more, and are still capable of developing into trees following removal of the overstory.

The lack of blue oak saplings in many stands has been cited as evidence of poor regeneration (Muick and Bartolome 1987, Bolsinger 1988). However, if persistent seedlings rather than saplings are the norm for advance regeneration in blue oak, the lack of saplings may be a poor indicator of potential regeneration. Under this scenario, the factors that would have the greatest impact on recruitment are those affecting the establishment and persistence of seedlings and the survival and growth of released seedlings. Although insects and plant pathogens apparently have little impact on the survival of established seedlings, their effects on seedling establishment and the performance of released seedlings remain to be studied.

ACKNOWLEDGMENTS

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The Temporal and Spatial Distribution of Filbert Weevil Infested Acorns in an Oak Woodland in Marin County, California[1]

Vernard R. Lewis[2]

Abstract: Two-hundred shoots contained within randomly selected locations from each of thirty-six coast live oak, *Quercus agrifolia,* trees were sampled to determine the abundance and spatial distribution of acorns infested by the filbert weevil, *Curculio occidentis* in northern California during 1989. The seasonal abundance of infested acorns was highest at 30 percent during mid-September. Overall, 25 percent of all acorns observed on sample trees revealed signs of boring insect activity. Slightly higher infestation rate of 38 percent was obtained from laboratory dissections of field collected acorns (n = 501). Of those acorns dissected in the laboratory found to contain insect larvae, 70 percent contained *C. occidentis* and 30 percent contained the filbertworm, *Melissopus latiferreanus.* Although acorns were numerous on the sunny side of the tree, infested acorns were more abundant on the shady side. The differential distribution of acorns spatially within trees, acorn survivorship, and the impact of insect and other animal acorn predators on acorn production are discussed.

The sweeping branches of a large regal oak is a vision common to all of us. As a single tree or forest stand, our native oaks play an important role in wildlife and human ecologies. In California there are 18 species of oaks, 10 of which reach tree size (Tucker 1980; Griffin and Muick 1990). The total acreage for California's oak species has been estimated at 15-20 million acres (Plumb and McDonald 1981). For thousands of years, native oaks have been a prominent and persistent floral feature in California. Unfortunately, it now appears many of our oak woodlands have been drastically reduced and are poorly regenerating (Mayer and others 1986; Bolsinger 1987; Muick and Bartolome 1987).

Because of poor regeneration and dwindling oak habitats in California, there is renewed interest in factors that restrict or inhibit acorn development. Acorns have many predators, including insects, birds, and mammals (Brown 1980; Griffin 1980; Koenig 1980). However, while acorns are still on the tree, the filbert weevil, *Curculio occidentis* (Casey) (Coleoptera: Curculionidae) and filbertworm, *Melissopus latiferreanus* (Walsingham) (Lepidoptera: Olethreutidae) can play a significant role in the reduction of the acorn crop. The filbert weevil is the more commonly found insect within infested acorns (Brown and Eads 1965). Acorns of all our native oak species are attacked by both filbert pests during the summer and autumn months. Both insects have a single generation per year. However, the filbert weevil can hibernate for several years in the soil as a pupa while the filbertworm overwinters in a single season as a larva (Furniss and Carolin 1977). Acorn crop reduction due to these insects has been reported as high as 80 percent for some locations (Keen 1958; Furniss and Carolin 1977).

These insect species attack acorns differently. The female filbert weevil, after cutting a small hole, deposits her eggs inside of acorns. Filbertworm larvae must bore into acorns unaided by the adult female. The boring into acorns by these insects often results in the oozing of large amounts of sap from acorns. This sap contains a bacterial infection known as dripping nut disease and is commonly associated with insect ovipositional activity on acorns (Hildebrand and Schroth 1967).

The following study was undertaken to quantify the seasonal abundance and spatial distribution of boring insects inside acorns for coast live oaks, *Quercus agrifolia* Née in northern California. The study objectives were: 1) to record the seasonal appearance of insect infested acorns, and 2) to determine the spatial distribution of infested acorns within tree crowns. The reasons for selecting these objectives were the lack of information on the timing of insect attack of acorns and how insects spatial exploit acorns within trees. The reasons for selecting coast live oaks as the host tree included its prominence and importance to wilderness and urban habitats along the coastal belt of California from Baja California Norte to Mendocino County (Griffin and Critchfield 1972). In addition, information gathered from studying this oak may add insight into our understanding of other insect phenologies on more threatened oak species.

MATERIAL AND METHODS

The location for this study was Sky Oaks, Marin County, California. The study area is a 8,000 hectare water shed containing Mount Tamalpais and is maintained and operated by the Marin Municipal Water District. The specific site used for the study was a 22 hectare valley called Bon Tempe meadow. This site is primarily a native oak woodland, composed of coast

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live oak, *Quercus agrifolia*. Historically, the meadow was grazed by cattle up until 1932. The meadow, on a south facing slope at approximately 213 meters above sea level, now con-tains approximately 300 coast live oaks as old as 60 years and varying in height from seedlings to 15 m sized trees. The reasons for using this site over other locations included 1) abundance of coast live oak trees, 2) cooperation by the Marin Water Municipal District, 3) past evidence of filbert weevil and filbertworm activity, and 4) close proximity to the University of California, Berkeley campus.

A 3 by 3 factorial model was used to assess the spatial patterning of acorns within trees. The three vertical locations created within trees were low, mid, and upper crown. Three horizontal locations, northeast, south, and northwest were also created. The total number of sampling locations created from this design was nine. Each of the nine sampling locations was replicated four times resulting in a total of 36 trees being used for the study. This 3 by 3 spatial sampling design was used over 4 by 4 or 4 by 3 designs which use traditional compass designa-tions (north, east, south, and west) because the smaller number of sampling locations enhances significance testing of mean counts for biological systems which are highly variable. Other researchers have shown acorn numbers to vary greatly between trees and years (Carmen and others 1987). In addition, using only three horizontal positions (northeast, south, and northwest) instead of four still allows for sunny versus shady side of tree comparisons.

Individual coast live oak trees were selected from the approximately 300 which occurred at Bon Tempe meadow. The criteria use for selecting trees were: 1) size between 4 - 8 meters, 2) level ground under tree, 3) symmetrical crown, and 4) high potential for producing acorns. High potential of acorn production was determined in March by using only those trees which produced large numbers of catkins. It was assumed trees with high numbers of catkins also produced high numbers of acorns. Average height (±SD) of sample trees was 5.8 ± 1.5 m and average DBH (±SD) at one meter above the ground was 124.8 ± 46.9 cm.

One of the nine possible sampling locations was randomly assigned to each of the 36 trees. Using a 5.5 m ladder, 200 shoots were selected (non randomly) in the center of each sampling location for all trees and labelled for future observations. These shoots were visited once a month from April through December 1989 to collect data on 1) number of female flowers, for April only 2) total number of acorns, 3) number of insect scarred acorns, and 4) number of acorns showing insect oviposition scars and dripping sap.

To better gauge the relative abundance of filbert weevil and filbertworms in acorns on sample trees, 100 acorns were collected from six non-sample trees during each field visit from July to November (501 total acorns). The collection process of these acorns was non random and basically consisted of collecting easily accessible insect scarred acorns at ground level. These field collected acorns were brought back to the laboratory for dissection and insect species determination. It was assumed that the frequency of filbert weevil and filbertworms found in the dissection of non-sample tree acorns would be similar to frequency found for sample trees.

Acorn production, surviorship, and infested acorn counts were graphed through time using Julian Day as the x-axis. Means for undamaged and infested acorns counts among spatial locations were analyzed for significant differences using the Duncan multiple comparisons test (PROC GLM, SAS Institute 1985). Since it was not possible to differentiate filbert weevil ovipositional scarring from filbertworm in the field, all insect scarred acorn data from sample trees was pooled. Differences in the proportions of insect species from laboratory dissected acorns were analyzed using Chi-Squared tests (PROC FREQ, SAS Institute 1985).

RESULTS AND DISCUSSIONS

From the laboratory dissection data, 38 percent of all acorns contained insect larvae. Seventy percent of those acorns containing larvae were filbert weevils and 30 percent were filbertworms. This difference in species composition was significant (X^2 = 138.9, df=1, P < 0.0001). Filbert weevil numbers varied from 1 to 5 within acorns. While filbertworm numbers varied from 1 to 3. However, 12 acorns contained both filbert weevil and filbertworm larvae inside the same nut. Other researchers have shown that it is not uncommon for acorns to be infested by one or more species of insect, even within the same acorn (Kearby, Christisen, and Myers 1986). However, increasing numbers of insects inside acorns probably decreases the success of acorn germination and seedling survival. Griffin (unpublished data[3]) has found that insect infested acorns, although they may germinate, rarely produce vigorous seedlings. Since filbert weevils were found to be more than two time more common than filbertworms, I will restrict my discussion comments to filbert weevils only.

The number of survived acorns declined steadily, almost logarithmically, throughout the season (fig. 1a). The peak period for acorn survival was 60 percent in May (Julian Day 178). By late-December, less than 1 percent of acorns remained on trees. Infested acorns became noticeable on trees soon after adult filbert weevil emergence from the soil in mid-July (fig. 1b). The percentage of infested acorns was seasonally highest at 30 percent by mid-September. Overall, 25 percent of all acorns on sample trees showed external signs of containing beetle larvae. This figure compares favorably to the 38 percent infested rate found from laboratory dissections. Acorn insect infestation rates have been found to vary considerable among sites and years, as much as 80 percent, throughout California (Brown and Eads 1965; Koenig unpublished data[4]).

[3] Data on file, Hastings Reservation, University of California, Carmel Valley, California.

[4] Data on file, Hastings Reservation, University of California, Carmel Valley, California.

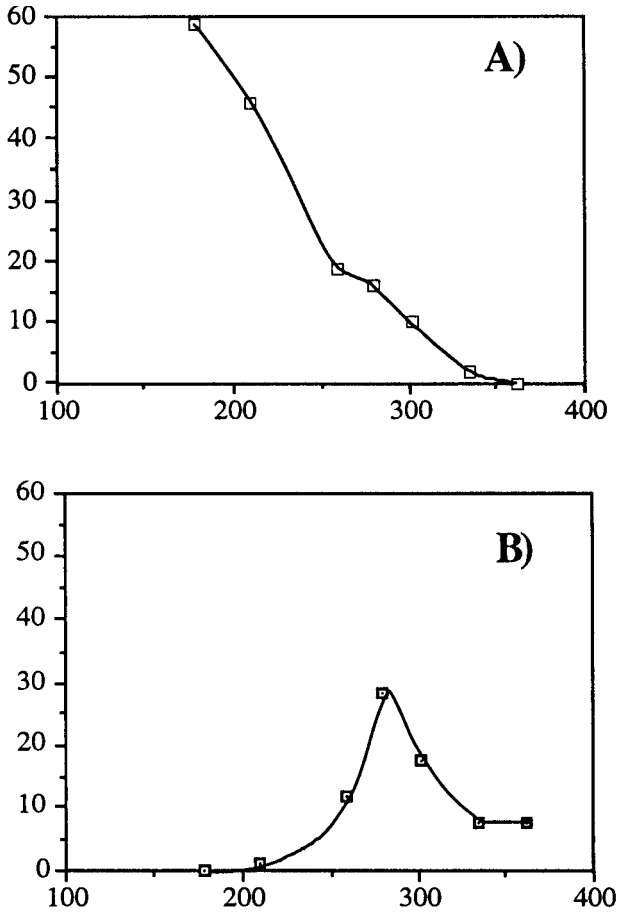


Figure 1—The percentage of survived acorns (A) and damaged acorns (B) from 36 coast live oaks at Sky Oaks, Marin County, California, 1989. Pooled data from observations of 200 shoots per tree. The time axis is expressed in Julian Day.

From the data, it appeared that insects had little impact on acorn survival. Even at peak abundance in mid-September (Julian Day 280), infested acorns only amounted to one third of the acorn crop. However, by this time, only 20 percent of the original acorns from May (Julian Day 178) still remained on trees (figs. 1a and 1b). Other vertebrate predators of acorns (e.g., rodents, deer, woodpeckers, etc.) apparently also had little impact on the acorn production since even before the autumn masting period (mid-July, Julian Day 210) less than 20 percent of the crop remained on trees. The greatest mortality of acorns, approximately 25 percent, occurred during mid- June (Julian Day 210). In June, beetle oviposition activity has not yet commenced and the immature acorns are not developed enough for consumption my vertebrate acorn predators. These results suggest that other factors (i.e., weather, soil condition, or tree physiological condition) impact the survival of immature acorns in early summer.

Vertically within the crown, significantly more undamaged acorns were concentrated in the lower two crown levels ($F = 4.42$, $df = 2, 31$, $P < 0.05$, Table 1). The differences among crown levels was as great as four-fold. This result is not surprising, the crown of oaks is asymmetrically biased with more foliage in the lower two levels. With more foliage in the lower crown you would expect greater numbers of acorns. Insect damaged acorns appeared to be evenly distributed throughout the crown.

Horizontally, significantly more undamaged acorns were found in the south location (table 1). Surprisingly, significantly more infested acorns were found on the northeastern side of trees. These data suggest that the filbert weevil is not exploiting the acorn resource on trees to its fullest. Field observations at the time of sampling provided a possible explanation for this differential partitioning of acorns and weevils.

While conducting the study, it was noticed that acorns on the west side of trees (most exposed to the sun) appeared split, as if bursting from within. These acorns were dripping sap and probably contained dripping nut disease as well as insect larvae. The oviposition stings by weevils and cynipid wasps (Cynipidae) is presumed to be the means of entry of this bacteria pathogen into acorns (Hilebrand and Schroth 1967). As these acorns burst open in late summer, they were soon invaded by ants, wasps, other microbial pathogens, and possibly parasites. It is possible that the fermentation gases produced by the drippy nut disease expand when heated causing the damage seen. Drippy nut disease has been shown to require temperatures of about 29° C for development. These high temperatures are not uncommon on the sunny sides of oaks especially during the late summer. For conifers, significant temperature differences have been shown between sunny and shady sides of individual pine cones (Schaefer 1963). Perhaps the adult female filbert weevil can detect changes in temperatures for varying sides of a tree. Such behavior could enhance larval survival and explain the clumped spatial patterning of infested acorns observed in the field.

The results of this study have important applied implications for pest monitoring and acorn yield studies. Realistically, oaks are sometimes treated for acorn insect pests in urban areas of California. Knowing that filbert weevil infested acorns are

Table 1—*Spatial distribution of total and infested acorns within tree crowns at Sky Oaks, Marin County, California, in 1989*[1].

Within-tree Parameters	Total acorns n[2]	Total acorns $\bar{X}$/100 shoots ± SEM[3]	Infested acorns n	Infested acorns $\bar{X}$/100 shoots ± SEM[3]
Vertical Stratum				
Upper	60	1.2 ± 0.3 a	60	0.6 ± 0.2 a
Mid	60	8.0 ± 1.5 b	60	2.4 ± 0.5 b
Low	60	8.7 ± 2.6 b	60	1.8 ± 0.4 b
Horizontal Stratum				
NE	60	4.6 ± 0.9 a	60	2.4 ± 0.5 a
S	60	8.7 ± 2.7 b	60	1.6 ± 2.8 ab
NW	60	4.6 ± 1.4 a	60	0.8 ± 1.4 b

[1]Pooled data from monthly inspections of 200 shoots/tree (n=36) for August through December.

[2]n, number of vertical (3) or horizontal (3) sampling locations times four replicates times five visits.

[3]Means followed by the same letter within each column and parameter are not significantly different ($P < 0.05$; Duncan multiple range test [SAS Institute 1985]).

concentrated on the shady side of oaks, can significantly reduce pest monitoring time and help locate larval populations within the crown. More accurate pest monitoring decisions often can reduce the use or need of pesticides, which already overburden many of our environments. Currently, acorn yield studies are based on visual ranked categories or timed counts acorn counts (Graves 1980; Carmen and others 1987). For the current study, flower counts in March proved to be a good predictor of immature acorn numbers in mid-summer (fig. 2). However, additional data from larger trees and from other species will be needed to fully evaluate the usefulness of this acorn yield model.

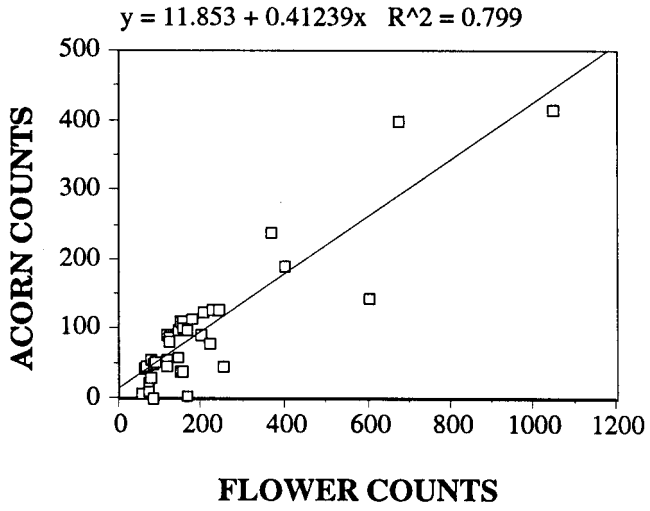


Figure 2—Regression plot of acorn and female flower counts. Data points represent flower counts from 200 shoots for each of 36 coast live oaks from Sky Oaks, Marin County in April 1989 correlated with acorn counts taken from the same shoots and trees in May 1989.

ACKNOWLEDGMENTS

I thank Taufiq Terry and Salvador Gracia-Rubio for technical assistance, Kasey May and his staff of the Marin Water Municipal Water District at Sky Oaks, Marin County, for their cooperation, and Richard J. Brand, Department of Biomedical & Health Sciences, University of California at Berkeley for statistical advice. I also wish to thank Jim E. Milstead, Department of Entomological Sciences, and Flordeliza L. Kala, Department of Education, University of California, Berkeley, for reviewing the manuscript. This research was supported in part by the Department of Entomological Sciences, Chancellor's Postdoctoral Fellowship Program, and Student Opportunity Program, University of California, Berkeley.

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Acorn Yield During 1988 and 1989 on California's Central Coast[1]

Sergio L. Garcia Wayne A. Jensen William H. Weitkamp William D. Tietje[2]

Abstract: In 1988, a study was began to evaluate acorn yield of valley oak (*Quercus lobata*), coast live oak (*Q. agrifolia*), and blue oak (*Q. douglasii*) in three of California's central coast counties: Santa Barbara, San Luis Obispo, and San Benito. The purpose of the study was to examine the degree and variability of acorn production and factors, such as geographic location, individual tree differences, and land-use history, which may contribute to these differences. Data collected during autumn 1988 and 1989 indicate that acorn production was low on the three oak species surveyed; nearly 90 percent of the 266 surveyed trees produced no acorns. Low acorn production in each of the three counties which was surveyed suggests that production may have been quite widespread.

Most (about 80 pct) of California's three million ha of oak woodland is privately owned and used mainly for livestock production. Oak woodland provides habitat for more kinds of wildlife than any other habitat in the state; more than 300 terrestrial vertebrates use this rich habitat for food, water, and cover (Barrett 1980, Verner and Boss 1980, Ohmann and Mayer 1987). Oak (*Quercus* spp.) mast (acorns) is an important component of the diet of many of the kinds of wildlife that inhabit oak woodland-game and nongame alike (fig. 1). In spite of the importance of acorns to wildlife, variations in annual production and factors that affect production are not well understood. Here we report preliminary results of the first two years of a long-term survey of annual acorn production in three central coast counties.



Figure 1—Many kinds of oak-woodland wildlife include acorns in their diet. Productivity of acorn woodpeckers increases during years when acorn production is high. Photograph by Guy E. Connolly.

[1]Presented at the Research Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

[2]Farm Advisors, University of California Cooperative Extension, San Benito County, Santa Barbara County, San Luis Obispo County, respectively; Natural Resource Specialist, Department of Forestry and Resource Management, University of California, Berkeley.

METHODS

During summer and fall 1988, in Santa Barbara, San Luis Obispo, and San Benito Counties, blue oak, coast live oak, and valley oak stands were located. Within these stands, 0.04-ha (tenth-acre) plots were established 6.1 m (200 feet) from a road in the cardinal direction nearest to perpendicular with the road. Plots had a minimum of 10 percent oak canopy cover and at least three oak trees at least 10.2 cm (four inches) dbh (diameter at breast height, or 1.4 m [4.5 ft] from the ground). Any plot not meeting these criteria was excluded.

Thirty-one 0.04-ha plots were established, about equal numbers in Santa Barbara, San Luis Obispo, and San Benito Counties. Within the plots, a total of 266 oak trees over 10.2 cm (4 inches) dbh was marked with numbered aluminum tags for permanent identification. During fall 1988 and 1989, each marked tree was evaluated for mast production (fig. 2) by the method developed by Graves (1980). By this method, trees are ranked 1 to 4 based on number of acorns observed on the tree—1 for no acorns to 4 if the tree is virtually covered (fig. 3). A spherical densiometer (Lemmen 1956) was used to measure canopy cover of each plot. To further characterize the plots, slope, aspect, brush and ground cover present, wildlife sign (droppings and digging), and grazing and tree-harvesting history were also recorded; results of these measurements are not reported here.

RESULTS AND DISCUSSION

There was little difference in acorn production between 1988 and 1989, and between the blue, coast live, and valley oak trees; therefore, years and oak species are combined here. Acorn production was low during 1988 and 1989 (fig. 4). Nearly 90 percent of the surveyed trees had no acorns (class 1). Only about seven percent had a production rating of 3 or 4. This was the case in each of three counties, suggesting that the low acorn production was widespread. Similarly, in a 9-year study (1977-85) of acorn production at the Dye Creek Ranch in Tehama County, conducted by the California Department of Fish and Game (McKibben and Graves 1987), three-fourths of the 363 surveyed blue oak trees produced few or no acorns. Only about three percent of the 363 trees were heavy producers.

In the three surveyed counties on the central coast during 1988 and 1989, there was a trend of increased production with tree diameter. An interesting observation of the study was that mast production on oaks located adjacent to county roads appeared much greater than on trees growing away from the roads. If this observation is real, one would conclude it may be due to greater availability of run-off water along the roads. This difference, even if slight, may be important during a drought such as the central coast has experienced the past four years.

Plans are to record mast production annually on the permanently tagged trees. Long-term data will be used to look further at variation in acorn production by years, trees, geographic location, land-use history, and weather.



Figure 2—Acorn production was assessed by ocular examination of 266 trees during August to October 1988 and 1989.

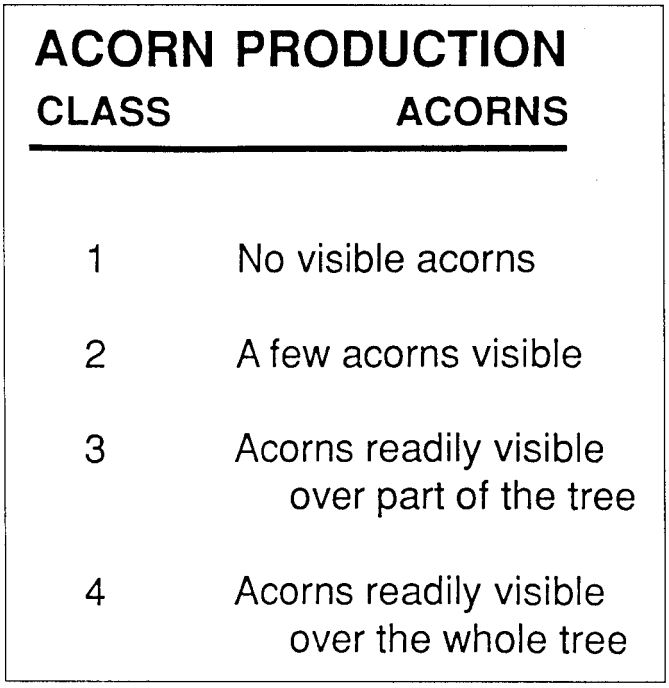


Figure 3—Acorn classification system developed by the California Department of Fish and Game and used for mast production assessment in Santa Barbara, San Luis Obispo, and San Benito Counties during 1988 and 1989.

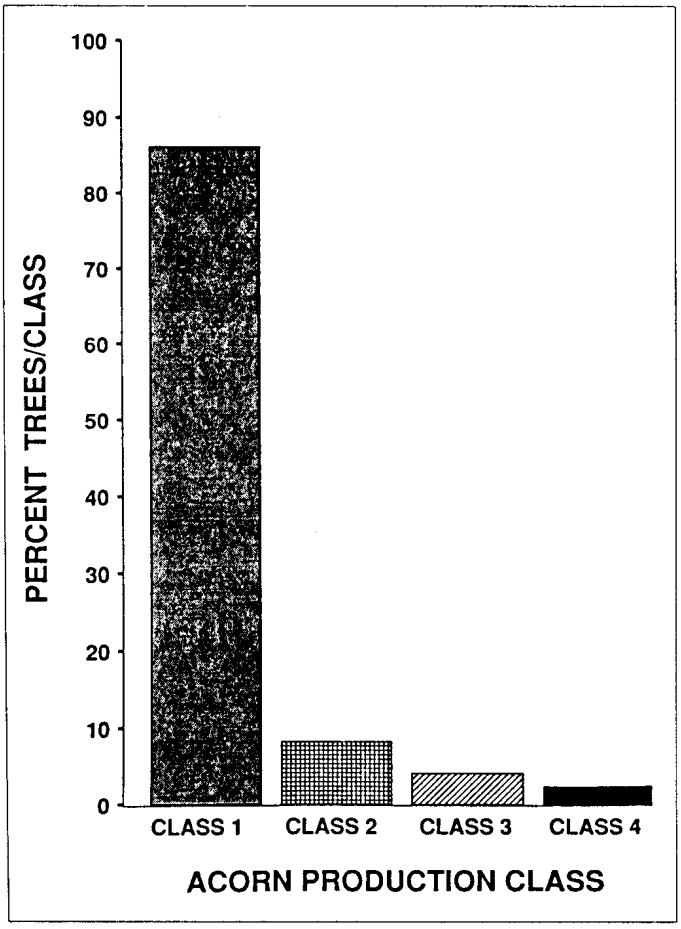


Figure 4—Acorn classification of 266 oak trees in Santa Barbara, San Luis Obispo, and San Benito Counties during 1988 and 1989.

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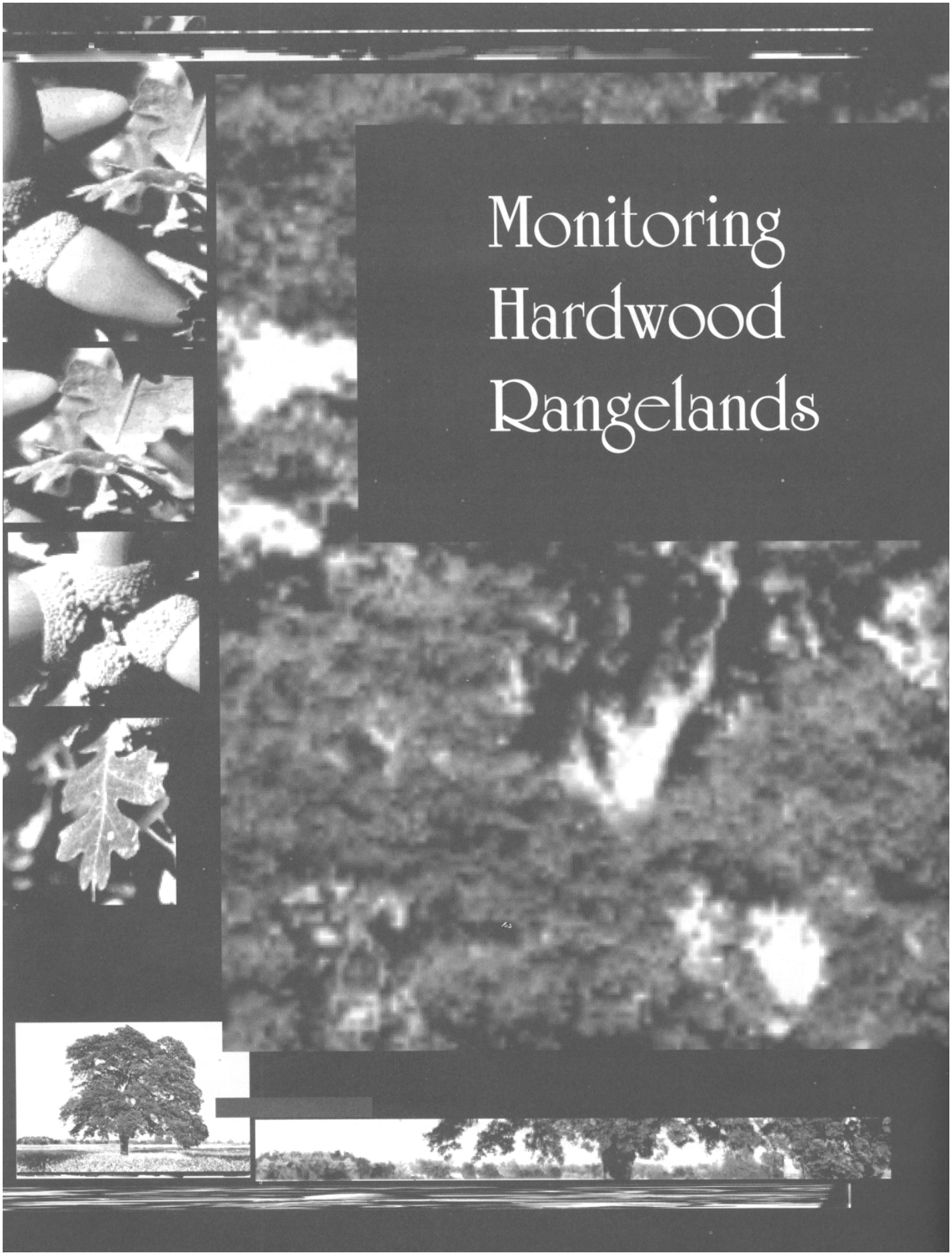
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Monitoring Hardwood Rangelands

Monitoring California Hardwood Rangeland Resources: An Adaptive Approach[1]

Raul Tuazon[2]

Abstract: This paper describes monitoring hardwood rangelands in California within the context of an adaptive or anticipatory approach. A heuristic process of policy evolution under conditions of complexity and uncertainty is presented. Long-term, short-term and program effectiveness monitoring for hardwood rangelands are discussed relative to the process described. The objectives of monitoring include establishing baseline information about the extent, status and condition of hardwood rangelands throughout the state. Baseline information serves as a starting point for detecting change, evaluating the forces driving these changes, evaluating risk and identifying areas where policy actions are needed. Baseline and trend information also serve to invalidate analysis and modeling that has occurred, and improve our understanding of the ecological and social systems involved. Implications for monitoring under conditions of uncertainty and complexity, including what to monitor, how and when, are discussed.

Current policy issues, including those related to oak woodlands and hardwood rangelands, are marked by a high degree of complexity and uncertainty. Uncertainty surrounds our understanding of current and future ecological processes, behavior and response, as well as current and future societal preferences (Holling 1978). Events and responses are often unexpected. Reaction to such unexpected events is often hindered by reliance on information which is not likely to adequately address current issues. Furthermore, the public and private institutions charged with providing information or articulating policy and management response are often incapable of operating within such a complex and uncertain environment by their very design. (Bartlett and Baber 1987; Scott 1987). This paper examines an adaptive or anticipatory approach required by such a policy environment, that explicitly recognizes the uncertainty of information, accepts the need to modify policies based on new information, and includes a component specifically designed for filling important informational gaps.

ADAPTIVE ANALYSIS AND MANAGEMENT

Many of the concepts underlying the adaptive approach to assessment, policy analysis and management are presented in Holling (1978). The premise of the adaptive or anticipatory approach is that the issue of uncertainty pervades the major resource and environmental problems of today; and that resilience based on the variability of the natural and management parts of the system should be the overall criterion of policy design.

Monitoring and the Adaptive Approach

A fundamental, integral part of adaptive assessment and policy analysis is a monitoring and feedback mechanism that allows institutional learning to occur and provide the basis for changes in policy and management. Because of the complex systems involved, the choice of what variables to monitor is extremely important. Structural features, such as distribution, age and linkages are more important than individual variables (Rolling, 1978). Where and when to monitor is important as well, since events in one area can emerge as impacts in another, perhaps distant area, at some unknown later date. Incorrect choices in these areas can result in concluding that no change has occurred when, in fact, it has.

Benefits should be attached to increasing information on unknown or partially known social, economic and environmental effects. One response to high levels of uncertainty and complexity is to attempt to "know everything" before proceeding. By valuing information, the development of it can be focused on those areas that provide the greatest return in terms of increasing our understanding of the issues in a way that facilitates positive policy actions.

While some experimentation and development of new information should be gathered through an integrated research plan, the actual management or policy actions themselves should also be designed to develop new information. Such an approach adds resiliency by diversifying the sources, types and timing of new information. It also provides a necessary "reality check" with those actually involved in management or policy actions, and actively involves them in the adaptive and anticipatory aspects of policy.

[1]Symposium on Oak Woodlands and Hardwood Rangeland, October 31- November 1-2, 1990, Davis, California.

[2]Research Economist, Forest and Rangeland Resources Assessment Program, California Department of Forestry and Fire Protection, Sacramento.

Policy Evolution

A heuristic description of how resource policy might evolve in a complex and uncertain environment is useful for highlighting key areas where information and monitoring come to bear. For simplicity's sake, the process can be broken down into a number of steps.

1. A concern about some environmental attribute or process is raised, often based on a mix of empirical evidence and intuitive reasoning. Neither may be very precise, but are compelling enough to evoke some response.

2. Historical and existing current information is reviewed in light of the concern, with the goal of refuting or substantiating the concern. More likely than not, however, the best available information does not fully answer the questions that have been raised.

3. Models are developed in an effort to decrease some of the uncertainty about the future natural conditions and processes. These range from simple qualitative discussions to more detailed quantitative or mathematical models.

4. Model results will suggest a number of policy alternatives, which are discussed and debated, some of which may be adopted. A comprehensive policy would include aspects of project management and mitigation, research and monitoring, and periodic review.

5. Periodic review of management and policy is made in light of research and monitoring results. Modifications are made, if warranted by the new information. Modifications are also made in light of new environmental or social questions that arise.

This simple description of policy evolution shows that existing information, monitoring and the new information resulting from monitoring all play key roles in adaptive management and assessment, but at different points in the process.

TRENDS AND PROJECTIONS IN HARDWOOD RANGELAND POLICY

The sustainability of California's hardwood rangeland resources is a major concern of the State Board of Forestry. Board policy clearly states that regeneration of the diversity of hardwood species should be assured, soil and water quality protected, and wildlife habitat diversity maintained on hardwood lands. Further, land conversion should be directed away from environmentally sensitive areas, avoiding damage to the viability of wildlife populations and negative effects on resource management (Board of Forestry, 1986). Historical trends and projections of the resources provide a starting point for policy actions, including management and monitoring.

Historical Trends in Oak Woodlands and Hardwood Rangelands

Bolsinger (1988) estimated that hardwood types on woodland decreased by 1,185,000 acres from 1945 to 1985. The estimate, while not precise, does provide an order of magnitude of the change in oak woodlands over the 40 year period. The rate of loss averaged close to 30,000 acres per year. The cause of conversion was not constant, however, over this time period. From 1945 to 1973 the major cause of conversion was rangeland clearing. Most of this clearing was done in the mid-to southern Sierra foothills, the central coast counties and Tehama County. Over a period from 1966-72 to 1981-84 the primary cause was residential-commercial development, followed by road and freeway construction. The rate of conversion increased, as well. Significantly, the study estimated that 279,000 acres of woodlands are in areas being developed for residential and other uses.

An analysis by FRRAP (California Department of Forestry and Fire Protection, 1988) focused on conversion of forest and rangeland cover types to agricultural and urban uses. The analysis found that approximately 27,000 acres of hardwood woodland and 590,000 acres of hardwood woodland-grass were converted to agricultural or urban uses from 1950 to 1980. Most of the conversion occurred in the Sacramento, Central Coast and Central Sierra regions. The analysis looked only at conversion to non-forest and non-rangeland cover types, and did not include, for example, the conversion of oak woodland types to grassland for grazing.

In spite of the differences, the two estimates do provide bounds on the order of magnitude of historical trends in the oak woodlands and hardwood rangelands. While the range of between 600,000 and 1.2 million acres may seem too broad to some, it does indicate that the change has not been trivial. This broad range cannot, by itself, answer the question of whether too much conversion has taken place, but it does serve to contain the initial discussion.

These analyses illustrate two important points that must be considered. First, environmental assessment depends on data that were developed at different times, for different purposes, under different conditions for long term assessment. The luxury of a consistent set of data points that were developed over a forty or fifty year span with the explicit purpose of comparison is rarely the case. In fact, such a set of data should not be expected, given the complexity and changing nature of environmental issues, and the time spans involved.

Second, the dynamics surrounding the particular phenomenon of interest can and do change. In the particular case of oak woodlands, the primary cause of conversion shifted from rangeland clearing to residential-commercial development. The rate of conversion also changed. Developments in process identified by Bolsinger (1988) might indicate that the rate of conversion due to construction is increasing as well.

These insights imply that the design of any data gathering or long term monitoring program must balance the need to be consistent over time to allow for comparison, but must also be flexible enough to accommodate changing circumstances and

dynamics. It is very difficult to know beforehand what the changes will be. Experience indicates that change, however, will occur.

Projections of Hardwood Rangelands

Assessing future trends and the likelihood of changes is fundamental to adaptive management and policy analysis. Whether accomplished by sophisticated computer models, extrapolation of current trends, or obtained through expert opinion, such forecasts or simulations provide a focal point for current policy and management actions, as well as for monitoring efforts.

The future extent and condition of the hardwood rangelands were simulated as part of the CALPLAN model (Davis and others 1987; Marose and others 1988). The model represents an effort to incorporate the best available data sources related to trends in hardwood rangelands, including current distribution, current and future harvest practices and cutting rates, regeneration rates and successional patterns. Current, and especially future harvest practices and conversion rates are based on projections of population and market conditions that are expected to affect hardwood rangeland use.

Results of the baseline scenario for California included acreage of hardwood rangelands by county and seral stage for future decades to the year 2010. Results indicate that about 300,000 acres of the initial 7.5 million acres will be converted to other uses or other vegetation types. Virtually all of the loss is found in young seral stages (0 - 6 inch dbh).

The Central Coast Region is projected to lose about 4 percent, and the Sacramento Region 8 percent. All other regions are projected to lose about 2 percent. These projections are consistent with the historical trends mentioned earlier. The causes of change are also consistent. For example, early seral stages are reduced in areas such as Tehama County due to clearing and burning to increase forage availability for grazing. The driving force behind change in the Central Coast Region is conversion to urban and agricultural uses.

The results provide a pointer to focus short and long term management and monitoring efforts. They indicate the geographic locations where significant changes in hardwood condition and distribution are expected, and the probable causes of such change. The results are also useful for estimating impacts on different wildlife species.

Given this starting point, immediate management and policy actions can be targeted for implementation. A monitoring program can be developed to provide information about the effectiveness of the Board's policy. Monitoring can also provide the information necessary to invalidate the assumptions about both ecological and social responses embedded in the forecasting models.

MONITORING

California's program to protect hardwood rangeland resources includes three types of monitoring: long-term, short-term and program effectiveness (California Department of Forestry and Fire Protection, 1989). Each of these activities focuses on different aspects of environmental and social processes and responses. For each, monitoring involves change detection, understanding the reasons for that change, and an assessment of the risks and benefits change has for the sustainability of the resource.

Long-Term Monitoring

The primary objective of long-term monitoring is to establish baseline information about the extent, status and condition of hardwood rangelands throughout the state. Baseline information serves as a starting point for detecting change, evaluating the forces driving these changes, and identifying areas where policy actions are needed. While the products of the long-term monitoring program are information, the uses are directed towards the continual evaluation and adaptation of hardwood policy.

Long-term monitoring addresses the following questions: Is the condition and extent of hardwood rangelands changing? If so, where is it changing? Is it changing according to our expectations? If not, how is it differing from our expectations, and why?

Long-term monitoring is primarily accomplished through periodic mapping of vegetation cover types. This effort is the responsibility of the Forest and Rangeland Resources Assessment Program. The initial mapping effort was based on 1981 aerial photographs and includes only stands 40 acres or larger in extent. Six cover types (blue oak, blue oak-foothill pine, coast live oak, valley oak, interior live-canyon live oak and montane) and four canopy cover classes (< 10 percent, 10-33 percent, 34-75 percent and > 75 percent) are recognized. This classification scheme is similar to that established within the Wildlife Habitat Relationship database (Mayer and Laudenslayer, 1988), and permits inferences on habitat suitability from the mapped vegetation information.

In order to detect changes in the hardwood resource base, a second project to remap hardwood cover types has recently been initiated. The purposes of this project are to both verify, where possible, the original mapping effort and detect differences due to actual change, not simply those due to differences in classification, scale and boundaries. Changes in technology and need have led to changes in approach. The re-mapping will be done with satellite data, and will use a classification scheme more closely in line with the WHR system. These changes have been made while acknowledging the need for consistency and repeatability over time and scale in order to make meaningful comparisons. All attempts will be made to maintain that consistency,

while still allowing for the incorporation of changes in methods and understanding of the underlying biological system.

Mapping of cover types focuses on the response of the system to the various forces that would lead to conversion. By itself, a periodic, large scale mapping project is only a backward-looking monitoring system. An appropriate adaptive and anticipatory monitoring scheme must also look at the "demand side" of the equation, to track the progress and change in the forces affecting change.

Large scale population growth and resultant conversion to urban and agricultural uses is expected in the Coastal counties and Central Sierra. Population trends and projections are thus a necessary part of the long term monitoring efforts as well.

Large scale conversion to grassland or grazing types due to the application of management practices resulting in changes in seral stage or conversion is expected in the northern areas of hardwood rangeland, such as Tehama County. Whether or not such practices will be applied as projected in the CALPLAN model will depend on a number of factors, including the direction of world commodity markets and the resiliency of the biological system. Applied research projects are underway in a number of these areas. The results of these projects will be useful for invalidating the model projections.

Short-Term Monitoring

Another component of hardwood policy is short term monitoring, under the responsibility of the Forest Improvement Program of the Department of Forestry and Fire Protection. This component is primarily a means of targeting areas for intervention efforts such as the education program of the Integrated Hardwood Range Management Program. While long-term monitoring strives for consistency and repeatability, short-term monitoring is oriented towards field level decisions with less than perfect information. In spite of this, short-term monitoring also provides valuable new information for overall policy development. This information is gathered through a variety of means, including activity reports, networks and overflights of particular areas.

For example, harvesting hardwoods for fuelwood has been raised as an issue affecting the extent and condition of hardwood resources. While it does not appear to be one of the long term driving forces leading to large scale changes, it can have localized, extreme impacts. Research has shown that this activity is difficult to track directly, happens very quickly and can be severe. It is also related to energy costs and the general state of the economy.

The latest trauma in the Persian Gulf has sent oil prices skyrocketing. This would serve to focus short-term monitoring on those areas that have a history or proclivity to harvest fuelwood. The mechanisms of short-term monitoring are particularly suited to pick up sudden changes. Nor is it necessary that the monitoring be completely systematic, consistent or quantitative.

This information will also prove useful in invalidating the assumptions of models used in assessment and planning. If an increase in fuelwood harvesting were not to occur, then the underlying assumptions about the causes of fuelwood cutting would be partially invalidated. On the other hand, some confidence in the models would result from an observed increase in harvesting. Either of these results would have implications for the current hardwood policy.

Program Effectiveness

The third monitoring activity focuses on the effectiveness of the research and education program, under the responsibility of University of California Cooperative Extension. The program attempts to increase understanding and awareness of hardwood resource issues through research and extension. Monitoring the program's effectiveness provides important feedback for more fully understanding and invalidating the assumed responses of both the natural and social systems that have been used to date.

The program may be effective in that information is created and adequately extended to landowners, for example, yet have no impact on changes in hardwood condition and distribution. This would indicate a lack of understanding of how landowners use better information in their decisions.

Focusing Monitoring Efforts: Risk Assessment

Identifying "important" or "critical" areas—places that deserve highest priority for protection or monitoring—can help effectively use monitoring resources, as well as form the foundation of risk assessment. Risk assessment will form the basis for the next round of models, programmatic responses and monitoring.

Current and expected knowledge of the intrinsic ecological factors and responses to events can serve to develop areas of high risk. Such areas serve to increase focus of short-term monitoring and intervention, if needed, and modification of long- term monitoring with regard to what variables are measured. Historical trends and model simulations, mentioned earlier, give some indication about where losses in hardwood extent are expected, and why FRRAP is currently involved in a study to develop the parameters against which relative risk can be evaluated. The ecological factors include the extent, condition and distribution of hardwoods; water quality and soil risks; and wildlife habitat diversity. The social and economic factors, or activities, include probability of conversion to other uses; range management activities, including grazing and clearing; and commercial harvesting.

Research results play a tremendous role in developing both the methodologies and empirical evidence for risk assessment. The ecological factors just mentioned are general, to say the least. But, for example, as understanding of regeneration and recruitment questions improves, estimates of relative risk of losses in extent and distribution, or declining condition, can be improved. As these improvements are made, changes in management and monitoring activities are likely to be needed as well.

CONCLUSIONS

The current policy environment requires that an adaptive approach to resource management and assessment be taken. A key feature of the adaptive approach is to anticipate change, and to actively incorporate learning and responding to change as part of the entire policy design. Monitoring in order to learn, through new information, plays a critical role in the adaptive approach. Monitoring must occur at many different levels, using a variety of tools and information sources. In the case of monitoring trends in California hardwood rangeland resources, it includes long-term, short-term and program effectiveness activities.

The choice of variables—what, where and when—is a major consideration in an anticipatory monitoring program. Experience with hardwood rangelands indicates that some of the important variables, such as extent and condition, are best suited to a long-term, systematic approach. These structural variables also serve as first level approximations for variables that may be important, like regeneration success, but our understanding of which is still evolving. Structural variables, such as population growth and economic activity, must also be tracked in order to understand the social systems involved.

Other variables, such as fuelwood harvesting, are better monitored over the short-term, under less rigorous design conditions. The short-term and program effectiveness monitoring activities also strive to gather new information apart from a structured research plan. Their results can have significant impact on model invalidation and subsequent policy actions. In fact, one of the primary uses of all monitoring information is to test and try to invalidate our assumptions. Feedback from the programmatic level provides a "reality check" based on the growing experience of the people involved in management actions.

Both the ecological and social systems involve guarantee that circumstances and knowledge will change. Consequently, it is reasonable to expect that the monitoring programs themselves will change. The basic design may change due to new technology or, more importantly, the advent of different questions. The variables chosen to measure are also likely to change, as our understanding of the underlying ecological and social processes improves.

Maintaining the connections between the different levels of monitoring, and insuring that feedback with the policy goals, design and implementation strategy occur, are the major challenges in using the adaptive approach.

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Ownership Patterns on Hardwood Lands[1]

Sam C. Doak[2]

Abstract: The pattern of land use and ownership—including sizes of ownerships, types of landowners, and their various management objectives—affects the level of benefits available from the California's hardwood resource. Geographic information system (GIS) databases of ownership and population characteristics were developed for two California counties using local assessors' data, Census data and existing vegetation maps. The utility of these spatial data sets is demonstrated in preliminary comparisons of hardwood land ownership patterns in Nevada and Shasta Counties. Refinement of these data capture techniques and the addition of other data layers will greatly increase the potential for more detailed analysis of ownership patterns.

California's oak woodlands and hardwood rangelands provide a variety of benefits including wildlife habitat, biological diversity, range forage, wood products, open space, and scenic beauty. The quality and availability of these benefits from hardwood lands is not determined by the mere extent of tree cover, but is also a function of human interaction with the hardwood landscape. Over 70 percent of California's hardwood forest land is privately owned (Bolsinger 1988) and, therefore, subject to a wide range of management objectives and practices. The particular juxtaposition, or spatial nature, of different sizes of ownerships, types of landowners, and land management objectives—as well as ecological conditions—dictates the nature of benefits available from the hardwood resource.

Demand for land for residential and commercial development has been a major force of change across California's hardwood landscape. Urban expansion and development of high density subdivisions have obvious and direct effects on the extent of hardwood land. Shifting patterns of ownership across rural lands, however, may have more extensive, albeit less visible, ramifications on hardwood resource-related benefits (Doak and Stewart 1986).

The process of changing ownerships, decreasing parcel sizes, and residential occupation, particularly dispersed, rather than high-density development, alters the character of hardwood lands by introducing multiple new owners and their often conflicting management activities. Wildlife habitat is compromised by land clearing, new roads, fences and roaming dogs. Soil stability is endangered by construction and land clearing. And, the introduction of new homes complicates rural fire protection responsibilities and further burdens local infrastructure (Doak and Stewart 1986).

The management objectives of new landowners are often quite different from those of traditional owners of California's rural hardwood areas. New owners generally relocate from urban areas to enjoy a different lifestyle in a natural setting, and they are less likely than established residents to rely on natural resources as a source of income (Fortmann and Huntsinger 1985). Many are absentee owners with little interest in active land management. Often they are more educated and wealthier than their long-standing rural counterparts (Blakely 1984; Romm and others 1983; Fortmann and Huntsinger 1985). Conflict over land use is more likely to occur in areas of fragmented ownership and management, and near wealthy and highly educated landowners (Doak and others 1988). A clearer understanding of these spatial ownership patterns and their relationships to resource management and conflict is needed to help further the State's objectives of stabilizing hardwood resource values through research, landowner education and monitoring.

HARDWOOD COVER AND LAND USE

Remotely sensed imagery such as aerial photography or satellite imagery is well suited for describing the extent and structure of hardwood stands, as well as detecting changes in cover over time. Vegetative cover alone, however, is not a good indicator of land use. Shifts in land use are not always accompanied by perceptible changes in vegetative cover. For example, dispersed residential development, while a major change in land use, may have little effect on total hardwood canopy closure.

Although remotely sensed data can describe the hardwood resource in a physical sense, it alone cannot answer compelling questions about the use and management of hardwood lands. Who owns these lands? Are they resident or absentee owners? What are their management objectives? How large are management units and how much do they vary in size? How rapidly is land ownership changing? What is the potential for conflict over use and management of hardwood lands? The implications of different types of vegetative cover and changes in cover must be assessed within the context of relevant social, economic, political and physiographic factors that affect land use and management.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31 - November 2, 1990, Davis, Calif.

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SPATIAL DATA LAYERS OF OWNERSHIP AND POPULATION

Geographic information systems (GIS) provide a framework in which various sources of data can be combined to model spatial patterns of land use and ownership. With a GIS, computerized maps, or layers, are linked to databases describing various attributes of particular locations. Data sets can be combined and enhanced by developing attribute relationships both within and between individual data layers. Physiographic characteristics of hardwood areas can be combined with ownership, demographic, and infrastructure characteristics, to create powerful tools for analysis of land use.

County assessors' property records contain extensive information on the ownership and use of individual parcels such as parcel size, landowner name and address, assessed improvement values, and historic deed recordation dates. Although these data are developed for assessment and taxation purposes, they do provide opportunities for describing ownership characteristics and patterns. With some manipulation, assessors' data can be used to indicate landowner wealth, ownership unit size, parcel ownership transfer rates, landowner residency status, land use fragmentation and other characteristics (Doak and Stewart 1986). Census data provides additional information on population/household characteristics such as age, employment, education, income, tenure, and living conditions.

To test the utility of these sources of data in characterizing ownership patterns in hardwood woodlands, GIS[3] databases describing ownership and population characteristics were developed for two California counties: Nevada and Shasta. Three GIS layers were developed for each county: (1) ownership, created from county assessors' property data; (2) population characteristics, based on Census data; and (3) vegetation type.

Assessors' mapbooks were selected as the primary analysis unit for the ownership layers. Although assessors' records contain detailed information on individual parcels, the cost of digitizing all parcels in a county is prohibitive.[4] Fortunately, the structure of assessors' parcel identification numbers provide alternative, although somewhat arbitrary, units for spatial analysis. Assessors' parcel numbers generally describe three to four spatially nested units. The largest unit is the mapbook; mapbooks contain multiple pages; and pages, which are sometimes divided into blocks, contain groups of individual parcels.

Ownership layers were digitized from each county's assessors' mapbook index map. Using digital tapes of the 1988 secured property roll purchased from each county assessors' office, individual parcel records were manipulated to provide summary statistics of parcel and ownership characteristics at the mapbook level. These summary variables were then related as attributes to each ownership layer. Mapbook attributes developed for the Nevada and Shasta County layers included variables describing: average parcel size; variation of parcel size; estimated average ownership size; assessed improvement value per acre; estimated number of houses per acre; number of owner-occupied houses per acre; and percent of area by parcel transfer rate.

An attempt was made to identify ownership units based on combinations of parcels. Assessors' data are parcel specific, and while parcels may conform to legal property divisions, they do not necessarily represent total ownership or management units. Many landowners own multiple parcels but manage them together as single units. Ownership units were defined in this study by summing parcels by owner name within each mapbook polygon. This method tends to underestimate actual ownership unit size since: (1) if the owner's name is misspelled, the two (or more) spellings are interpreted as separate ownerships; (2) a single ownership that crosses two mapbooks will be defined as two separate ownership units; and (3) some management units may actually be composed of multiple parcels owned under the names of different family members.

Census tracts were selected as the primary analysis unit for the population characteristics layer. A digital file of summary 1980 Census data was purchased from the California Department of Finance.[5] These data were manipulated and condensed into variables which where used as attributes to a digitized Census tract layer. Attributes included population density by various age, education, personal income, and residency status classes; and household characteristic such as average home value, household income and tenure.

An existing CALVEG GIS layer was used as the vegetation layer.[6] The CALVEG maps were created by the USDA Forest Service at a scale of 1:250,000 from manual interpretation of satellite imagery. Minimum polygon sizes vary between 400 and 800 acres. While a fairly generalized vegetation map, the hardwood species designations in CALVEG provide a general definition of hardwood extent sufficient for demonstrating general ownership patterns on hardwood lands. Other vegetation maps and data may provide more accurate and more detailed estimates of hardwood extent and structure (Tosta and Marose 1986).

PATTERNS OF OWNERSHIP

The three GIS layers were used to describe ownership patterns on hardwood lands in Shasta and Nevada County through a series of overlays. The vegetation layer was first used to develop separate layers of hardwood land in each county.

[3]The geographic information system used here was PC-ARC/INFO.

[4]Based on 1988 assessor's property rolls, there are 42,879 parcels in Nevada County and 76,681 parcels in Shasta County.

[5]U.S. Department of Commerce, Bureau of Census Summary Tape File Number 3 (STF-3).

[6]The California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program provided county level ARC/INFO coverages of CALVEG.

Hardwood land was identified, using CALVEG attributes, as non-urban land dominated by blue oak (*Quercus douglasii*) in Shasta County and interior live oak (*Q. wislizenii*) in Nevada County. These county hardwood layers were then combined with the other layers and used as "cookie cutters" to create separate ownership, and population layers for hardwood lands in each county. Summary attributes within each new polygon[7] of the ownership and population layers were then used to develop estimates of a variety of characteristics describing ownership patterns in each county's hardwood land. Some of these characteristics are presented in table 1.

Table 1— *Patterns of Land Use and Ownership in Hardwood Lands in Nevada and Shasta County*[8]

	NEVADA	SHASTA
Hardwood Area (acres)[9]	128,986	278,231
Privately owned Area (acres)	117,874	247,599
Privately owned Area (pct)	91	89
Total Parcels	18,536	8,532
Average Parcel Size (acres)	7	33
Total Ownerships	14,066	4,764
Average Ownership Size (acres)	9	58
Assessed Improvement Value	$771,720,38	$ 235,106,709
Average Assessed Value per acre	$5,983	$845
Total Houses[10]	10,797	3,257
Houses Per 1,000 Acres	84	12
Resident Landowners[11]	7,329	2,966
Percentage of Owner Occupied Units	68	91
Acres Transferred > 3 Times in 15 Yrs.[12]=	13,613	NA
Percentage Transferred > 3 Times in 15 Yrs.	11	NA
Population (1980)	20,458	13,145
Population (#) New to County since 1975	10,376	4,486
Population (pct) New to County since 1975	51	34
Households (#, 1980) Heating with Wood	3,878	861
Households (pct, 1980) Heating with Wood	19	20

[7]The final Nevada hardwood ownership layer had 46 polygons, the Shasta hardwood ownership coverage—56 polygons, the Nevada hardwood Census coverage—14 polygons, and the Shasta hardwood Census coverage—18 polygons.

[8]For purposes of this analysis, hardwood lands were identified from the CAL VEG coverages as blue oak woodlands in Shasta County and live oak woodlands in Nevada County. This excluded some areas of riparian and montane hardwoods.

[9]These acreage figures are based on a simple definition of hardwood lands used for demonstration purposes. Other sources may provide more accurate acreages of oak woodland (Tosta and Marose, 1986).

[10]This estimate may be low. Since houses are not defined as such on the assessor's property rolls, an assessed improvement value of at least $10,000 on any parcel was assumed to be a house.

[11]Resident landowners were inferred from homeowner's exemptions on the assessor's property roll.

[12]The number of acres transferred more than three times in 15 years were estimated from deed recordation dates on the assessor's property roll. All such recordations were assumed to indicate a transfer of ownership.

The results provide some interesting contrasts between the ownership patterns of Shasta and Nevada Countys' hardwood lands. Nevada County is characterized by small parcel and ownerships sizes, high assessed improvement values per acre, and a large percentage of new residents. Shasta County has larger average parcel and ownership sizes, lower improvement values per acre, and a higher percentage of resident homeowners.

The relative degree of land use fragmentation was estimated using the coefficients of variation (CV) in average parcel and ownership size. Using CV as a proxy, the level of fragmentation increases considerably when the primary unit changes from parcels to ownerships. Ownership units may be a more useful variable for depicting fragmentation since they more closely resemble the way land is actually managed. Table 2, showing the percentages of hardwood land in Nevada County by CV of average parcel and ownership size, illustrates the relative difference between these units as measures of fragmentation.

POTENTIAL USES

The potential utility of the GIS data layers developed here far exceed simple overlays and data queries. These type of data have applications for a variety of research, landowner education and monitoring efforts related to California's hardwood resource.

GIS ownership and population attribute layers can be used to test hypotheses regarding relationships between ownership characteristics and: landowner goals; land use conflict; resource production; and environmental degradation. For example, GIS layers of vegetation, ownership and population characteristics could be used as a framework for implementing landowner surveys designed to test relationships between hardwood landowner and ownership characteristics (e.g., age, residency status, ownership size) and owner management objectives. Specific categories of landowners could be identified based on vegetation and ownership characteristics. Individual names and addresses could then be drawn from the basic assessors' data. Finally, survey results could be related back to the spatial framework for more detailed analysis.

These databases might be used in a similar fashion to target certain types of landowners with specific types of extension

Table 2—*Fragmentation of Hardwood Land in Nevada County as Measured by the Coefficient of Variation (CV) in Parcel Size and Ownership Size*

	Pct of total area	
CV	Parcels	Ownerships
1-2	28	1
2-3	57	32
3-4	15	40
4-5	0	9
> 5	0	18

programs. Small residential hardwood landowners, for instance, are likely to respond to a different array of programs than are owners of large management units.

With the addition of other data layers such as slope, zoning, soils, roads, fire hazard, or hydrography, spatial models can be developed to simulate or predict a multitude of natural an cultural processes. Wildlife habitat suitability models, for example, could be developed as functions of a canopy closure, distance to streams, elevation, density of major roads, average parcel size, and density of houses.

Predictive models could be developed to estimate the level and intensity of future residential development. These models might estimate the likelihood of parcelization and development based on current ownership (private vs. public), zoning (allowable parcel density and use), existing infrastructure (road networks), slope (related to construction suitability) and distance from community centers.

These types of models could also be used for land use planning and resource allocation. High densities of housing development, for example, are thought to have negative effects on wildlife species associated with oak woodlands, while low home densities covering a broader area may both complicate fire protection efforts and increase risk of habitat loss due to destructive fires. Use of GIS modeling can help local planners minimize development impacts on habitat and assist fire agencies in efficiently allocating resources to protect both new development and existing habitat.

GIS data layers of ownership and population characteristics have applications in hardwood monitoring efforts, both in directly assessing changes in land ownership, and in providing a context in which to assess changes in vegetative cover on hardwood lands. Changes in the hardwood canopy that occur in areas of large isolated ownerships, for example, are likely to have different resource implications than canopy changes that occur across areas of multiple small parcels.

The use of smaller analysis units may result in more refined ownership and population data layers in future data development projects. While assessors' mapbooks are useful units due to their relative homogeneity, rural mapbooks often cover very extensive areas. Future development of ownership layers may benefit by dividing these larger mapbooks along page lines or groups of pages. Smaller units, of course, will tend to increase development costs. Census blocks are smaller spatial units than tracts and will be available in the 1990 Census TIGER line files.

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Monitoring Values and Practices of Oak Woodland Decision Makers on the Urban Fringe[1]

William Stewart[2]

Abstract: Concern over oak woodlands has shifted away from ranch management towards residential areas. This shift has been accompanied by the involvement of decision makers who previously had little involvement with rangeland policies and practices. A survey of three recent Cooperative Extension workshops illustrates a number of important patterns regarding interest and activities of small landowners, landscape professionals, local government employees and concerned neighbors. The process of addressing these potential decision makers through existing professional or issue based interest groups offers significant efficiencies regarding communication and monitoring strategies.

Over the past two decades concerns over oak woodlands have changed dramatically. Previously, activities which led to the removal of large numbers of oaks were related to subsidies for range improvement or large scale firewood harvesting. Now they are more often related to new housing developments, expansion of existing buildings and the overall impact of urbanization. At the city and county level this has led to ordinances and requirements which typically focus on specific cases of tree removal and attempts to trade a certain number of new saplings for each tree removed. Few if any of the measures deal with more difficult issues such as wildlife habitats or how to ensure that there will be a next generation of the existing plant species.

One major consequence of this shift in concern from ranch management to a more `open space' perception of the land is the involvement of a new set of decision makers. When framed in the context of a rural resource, groups concerned with oak woodlands were mainly large landowners, state or federal agencies, and statewide environmental groups (Ewing 1990). When framed in the context of a suburban resource, a new set of profession- or issue- based interest groups enter. Landscape professionals such as arborists, gardeners, and landscape architects, local planners, concerned neighbors and local environmental groups are increasingly involved with new projects and local debates over development and ordinances. Although considerable research has been done on the views and practices of landowners (Huntsinger and Fortmann 1990, LeBlanc and others 1989) there is much less information on more "suburban" interest groups. Existing patterns and experiences with local ordinances and policies (Doak and others 1988), surveys of county planners (Pillsbury and Oxford 1987), Realtors (Diamond and others 1987), and initial recipients of Cooperative Extension oak woodland management literature (Easton 1987) provide insights into some but not all of these groups.

Whatever the state policies regarding oak woodlands will be, most actions will be taken by private landowners, often assisted by consultants. Local government officials will be involved in the planning and approval processes for some of these actions. Given the inherent difficulties of predicting the future on existing geographic and demographic patterns of change, a more effective strategy could be to focus on the decision makers themselves. One lens with which we can reduce the heterogeneity is through existing profession- and issue-based interest groups.

This paper reports on how monitoring and communicating through interest groups could offer significant economies and more importantly could promote more effective working arrangements for discussing new problems, information and strategies.

NEW APPROACHES OF IHRMP EXTENSION PROGRAMS

Since 1986, the University of California Cooperative Extension and the California Department of Forestry and Fire Protection's have jointly funded the Integrated Hardwood Range Management Program. Research, extension, and monitoring activities were initiated to accomplish the goals set out in the 1986 policy statement of the California State Board of Forestry. In the last few years the Program has broadened from its initial focus on large landowners and resource professionals to include other groups such as small landowners, local planners, schools, and conservation organizations.

An example of this more inclusive approach was a series of three workshops organized by regional hardwood specialists of the University of California Cooperative Extension in the spring of 1990. Workshops were held in San Luis Obispo, Sonoma and Tuolumne counties and attracted 400 participants from more than thirty counties. Participants included small landowners, arborists, landscape architects, local planners and concerned neighbors. During the workshop, participants responded to a survey which dealt with their values, problems and practices regarding oak woodlands.

To reduce the number of potential categories, participants were grouped according to what they felt was their main reason for attending the workshop—landowner, consultant, government employee or concerned neighbor. Even though the sample

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31 - November 2, 1990, Davis, California.

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was biased by requiring individuals to attend the workshop to become part of the survey, it provided a professionally and geographically diverse sample of individuals who are interested in oak woodlands and most probably will be involved in future decisions. Table 1 categorizes the participants in terms of their self-defined major interest in the workshop.

Most landowners at the workshops owned 10 acre or smaller parcels. Few large landowners or land developers attended the workshops. Consultants were predominantly landscape architects in San Luis Obispo, arborists and professional gardeners in Sonoma, and professional gardeners and developers in Tuolumne. Government employees were roughly half planners and half technical staff from parks, roads or planning departments. "Neighbor" was a catch all term which included members of conservation organizations, college educators, retired individuals and other members of the public.

Table 1—*Participants at three regional IHRMP workshops*

			Self- defined major reason for attending			
			Landowner	Consult.	Govt.	Neigh.
Workshop	Total	Surveyed	pct	pct	pct	pct
San Luis Obispo	90	56	12	50	34	4
Sonoma	240	147	11	41	29	19
Tuolumne	80	65	18	31	39	12
Total Percent			12	40	32	16

Note: Total—estimated total participants Surveyed—number of returned surveys pct—percent of surveys from each self defined group at different workshops.

VALUES, PERCEIVED PROBLEMS AND PRACTICES

If we want to have a more realistic handle on how to provide assistance to these new oak woodland "managers" or decision makers, we need to ask some basic questions about how they relate to the land. The most basic question is why do these people value oak woodlands? There was a surprising degree of consistency across all groups. Figure 1 illustrates the relative ranking of important values with equal weight given to each workshop.

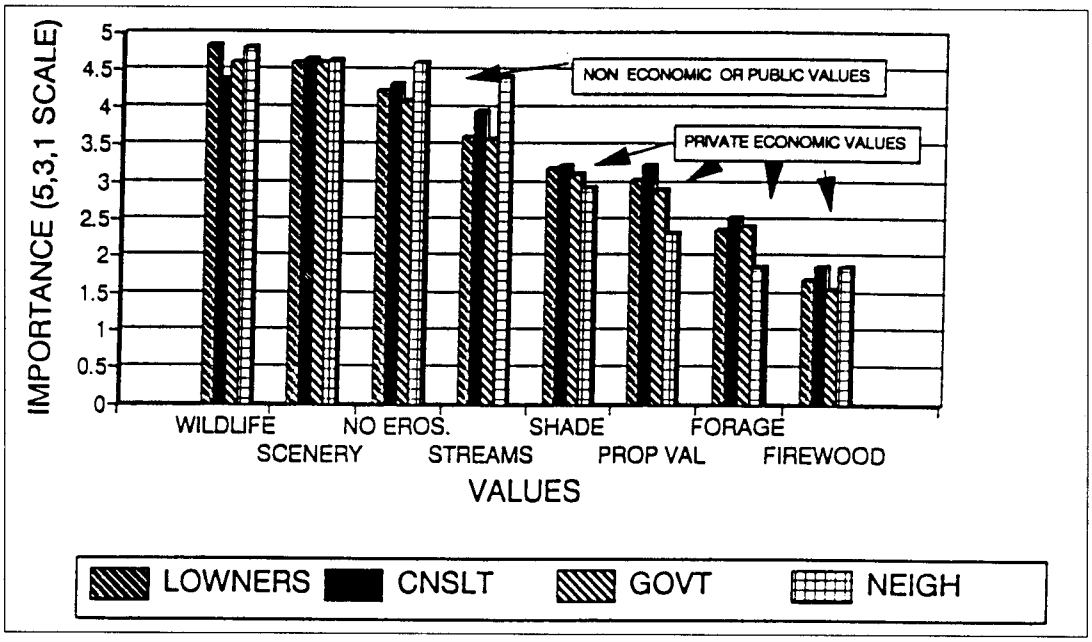


Figure 1—Oak woodland values—a summary of three workshops.

Legend

IMPORTANCE WEIGHTING
5— "very important"
3—"fairly important"
1—"not too important"

VALUES

Wildlife	wildlife habitats
Scenery	scenic beauty
No eros.	prevent soil erosion
Streams	preserve quality of riparian corridors
Shade	shade for people and animals
Prop val	Increased property value associated with oaks
Forage	Improved forage underneath oaks
Firewood	source of firewood

A general distinction can be made between two types of values—public and private. The high value placed on wildlife habitat and scenic beauty as well as the strong concern to protect against degradation of soil and stream resources all represent a concern for good land stewardship and protection of the natural qualities of the land. The values we conventionally associate with management—making income off the land by either increasing the real estate value or annual cash flow—are given significantly less credence.

Though there is general agreement on values there is less agreement on what problems exist and how serious they are. As with values, the pattern of responses was relatively similar across all three regions (figure 2). The loss of oak woodlands to large scale development projects was the first or second concern for nearly all groups. Problems commonly associated with "bad" ranch management — damage to riparian areas, excessive firewood harvesting, and over grazing—were considered to be relatively minor problems by all groups. For nearly all other topics, small landowners had significantly different perceptions than consultants, government employees, and neighbors. Except for diseases, small landowners generally reported lower levels of problems. Other groups concentrated on problems related to individual trees rather habitats or larger groups or populations of trees. Although blue and valley oak have the least regeneration and highest percentage of older trees among all the major species in California (Muick and Bartolome 1987), there was no statistical difference between the participants who had blue or valley oak on their parcels of interest (N=171) and those who did not (N=126) in terms of regeneration, planted acorn survival, diseases or loss of stately trees.

The most significant difference between groups and regions concerned recommended practices (figures 3 through 5). Saving individual living trees was suggested by more than 80% of most groups. Although nearly all groups felt wildlife habitat was the most important value of oak woodlands, they were usually not able to translate this into concrete actions. For only two groups—landowners in San Luis Obispo and government officials in Tuolumne—did retaining corridors or groves during any clearance operation garner a significant majority. Likewise, saving snag and cavity trees, some of the most important habitat niches within the oak woodlands, was rarely mentioned by a majority of any geographic or interest group. Finally, the preparation of land management plans was not a familiar or widely practiced approach among this sample.

COMMUNICATION NETWORKS

One inference from their responses is that decision makers on the urban fringe often do not have sufficient awareness of planning or management techniques to effectively address the problems they see. An aim of extension is to provide information so individuals can more effectively achieve their goals. This aim is easy to achieve with full time farmers and ranchers who will most likely be farming and ranching during the next few years. It is more difficult to do when dealing with much diverse populations, who may or may not be making significant deci-

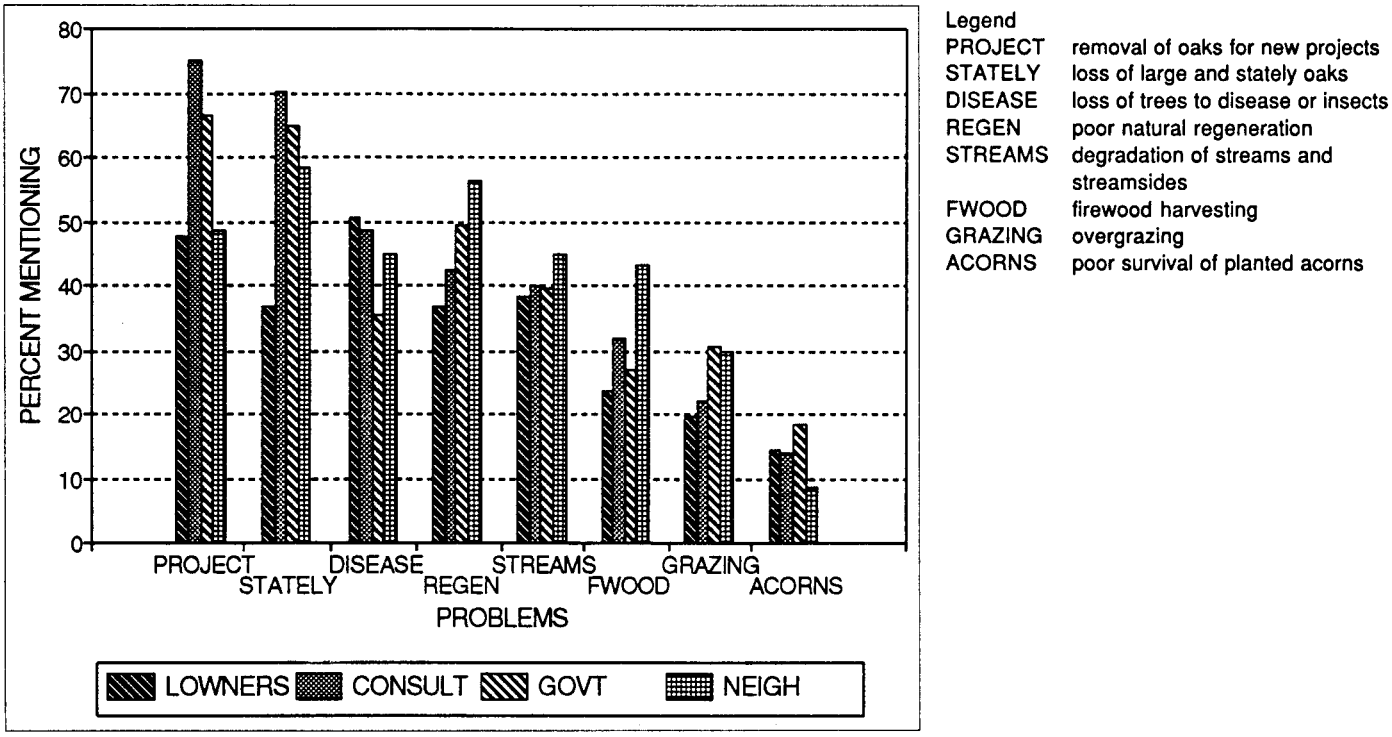
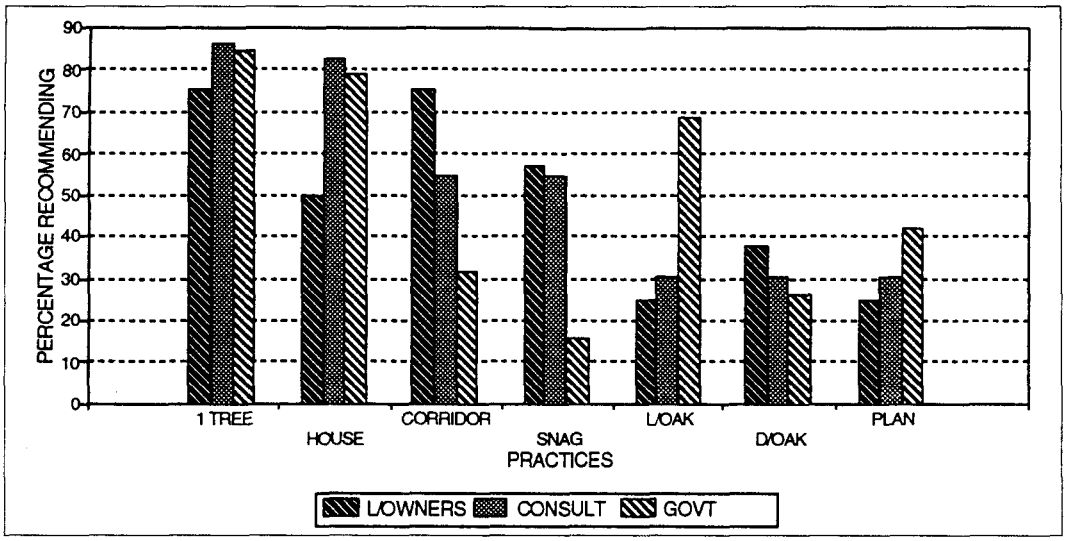


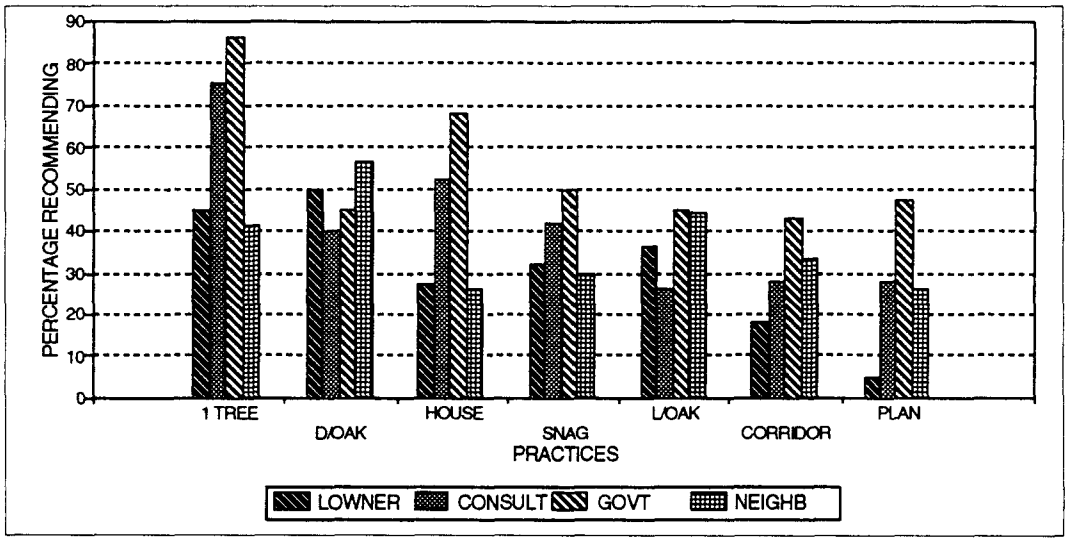
Figure 2—Problems with oak woodlands - a summary of three workshops.



Legend

1 TREE	save one tree
HOUSE	alter plans for new house or road to preserve trees
CORRIDOR	leave corridors or groves if thinning oaks
SNAG	leave snag and cavity trees
L/OAK	plant live oaks
D/OAK	plant valley or blue oaks
PLAN	have a land management plan prepared

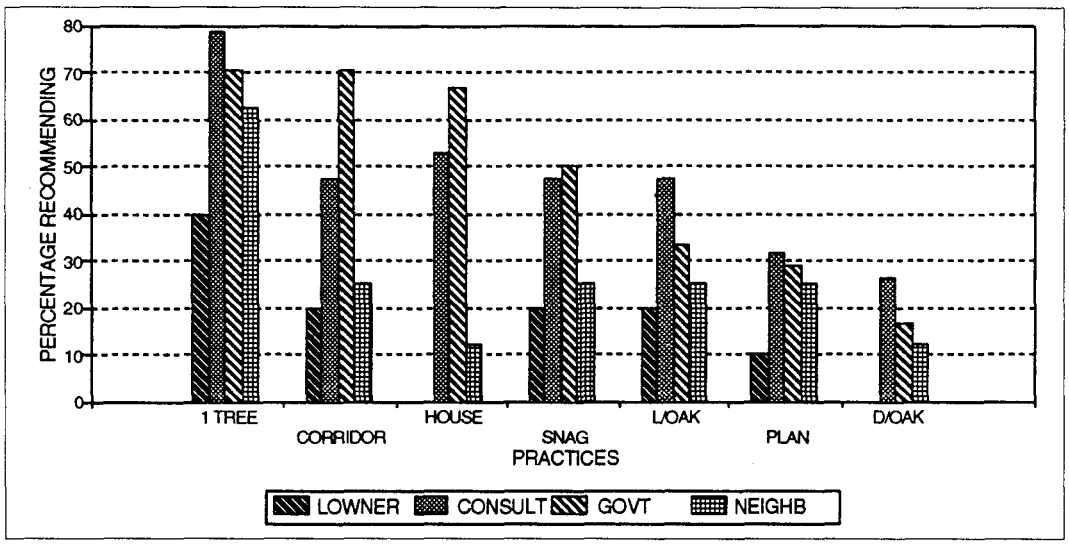
Figure 3—Oak woodland practices as preferred by San Luis Obispo participants.



Legend

1 TREE	save one tree
HOUSE	alter plans for new house or road to preserve trees
CORRIDOR	leave corridors or groves if thinning oaks
SNAG	leave snag and cavity trees
L/OAK	plant live oaks
D/OAK	plant valley or blue oaks
PLAN	have a land management plan prepared

Figure 4—Oak woodland practices as preferred by Santa Rosa participants.



Legend

1 TREE	save one tree
HOUSE	alter plans for new house or road to preserve trees
CORRIDOR	leave corridors or groves if thinning oaks
SNAG	leave snag and cavity trees
L/OAK	plant live oaks
D/OAK	plant valley or blue oaks
PLAN	have a land management plan prepared

Figure 5—Oak woodland practices as preferred by Tuolumne participants.

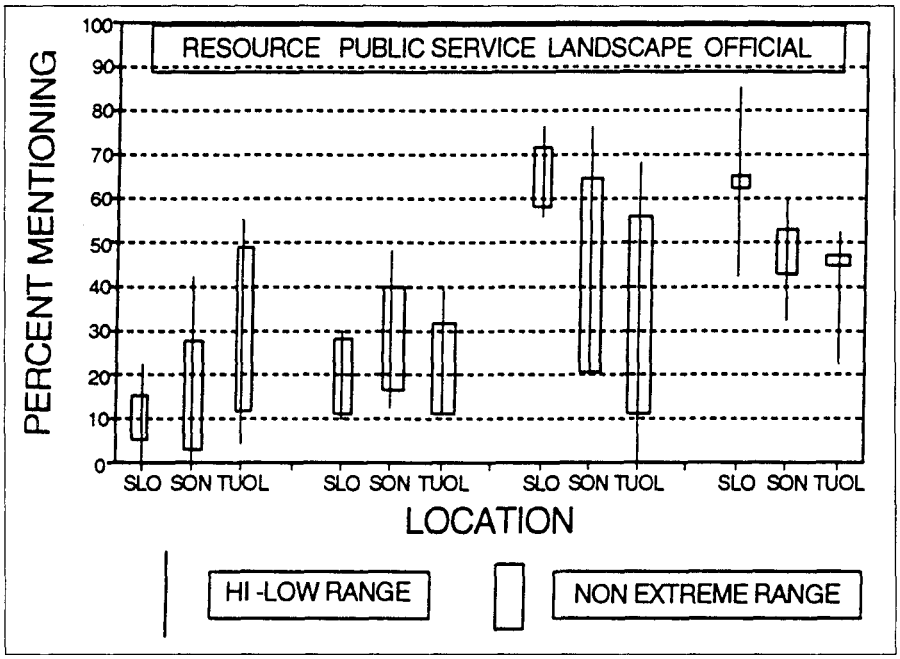


Figure 6—Oak management discussions by location and type of contact.

sions regarding oak woodlands over the next decade. To understand the broader communication networks within which this sample is connected they were asked a number of questions concerning who they talk to, what they read and what they see in the field regarding oak woodlands.

Discussions with other knowledgeable individuals is probably the most important source of new information for most of the participants. Figures 6 summarizes some of the communication patterns. The workshops in San Luis Obispo and Sonoma attracted participants from the widest number of counties and generally illustrated a stronger influence of urban and suburban related issues. The communication patterns of the Tuolumne participants, on the other hand, had more similarities to those reported in Huntsinger and Fortmann (1990) and LeBlanc and others (1989). Although the patterns vary considerably by location and profession, a number of general inferences can be drawn.

Contacts can be broken down into four general categories: (1) local officials—planning or technical department staff as well as elected officials; (2) landscape professionals—landscape architects, arborists, and gardeners; (3) "public service" professionals—Cooperative Extension, conservation organizations and University faculty and (4) resource professionals—foresters, wildlife biologists, agricultural consultants, and range consultants. Local government officials and landscape professionals are numerous in the absolute sense and were contacted by a high proportion of the participants. Cooperative Extension personnel and conservation organization representatives appear to be the most active networkers of information since representative of these relatively small groups were contacted by a significant number of the participants. State and Federal agency personnel as well as forestry or agricultural consultants were rarely contacted outside of Tuolumne sample. Although resource professionals should possess much of the technical knowledge concerning wildlife habitats and vegetation dynamics they appear to be "out of the loop" for many land use decisions in or near suburban areas.

The most common approaches used by organizations to disseminate new information are publications, workshops and other types of meetings. Published information on oak woodland management is available from a number of sources. Table 2 illustrates the importance of different publications for information on oak woodland management. Since this series of workshops were sponsored by University of California Cooperative Extension it is not that surprising that their publications were the most widely read. This represents an enormous increase from 1985 when Cooperative Extension farm advisors were the least important source of oak related information (Huntsinger and Fortmann 1986). Professional journals represent an apparently under utilized channel for providing new information to professionals who may not normally receive Cooperative Extension literature.

Another important source of ideas concerning oak woodland management is actually seeing "good" examples. The percentage of participants who had seen good management ranged from 56 percent in Sonoma to 77 percent in Tuolumne. Approximately two thirds of those people were also able to

Table 2—*Useful sources of new information regarding* **oak** *woodland management*

Information Source	Percent of participants reading for oak information
Cooperative Extension publications	81
Agricultural or forestry journals	49
Gardening journals	43
US Forest Service publications	42
Other magazines	32
Newspapers	28

discuss management with the owner or land manager. When people can read about better oak woodland management in their own terminology and see it on the ground, we will be getting closer to more effective strategies for these fringe areas.

The wide variety of concerns of different interest and professional groups suggests that forums to discuss oak woodland management before serious conflicts arise would be useful. When asked to rank the usefulness of potential forums for discussing oak woodland related information and policies the participants felt Cooperative Extension would be the most useful and gave slightly lower ratings for professional associations, county agencies and state agencies.

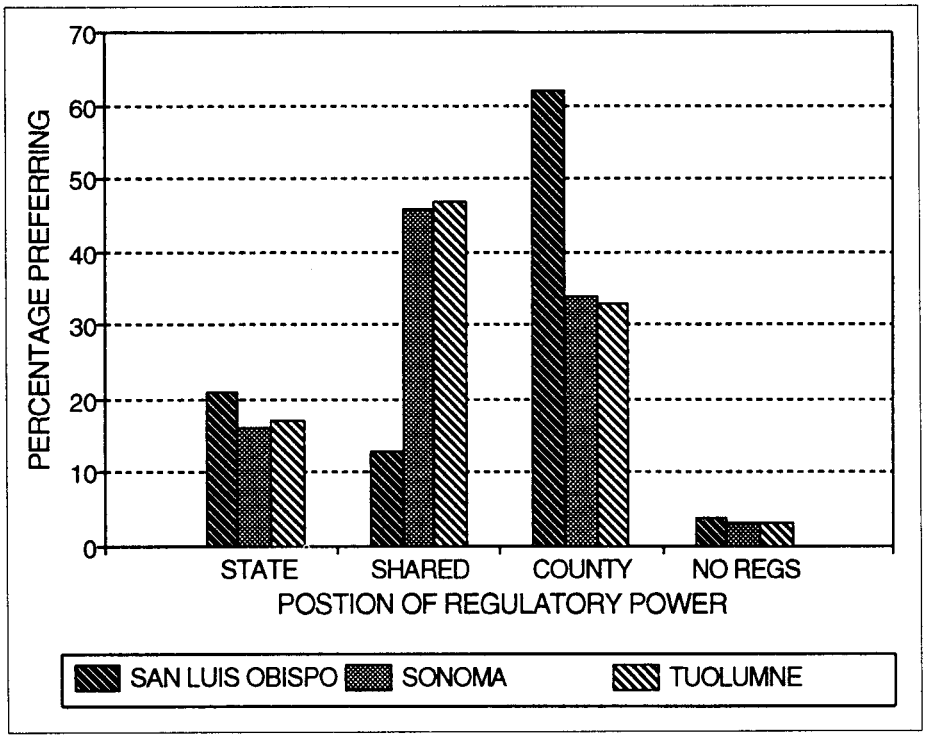
PUBLIC POLICIES

The participants of these three workshops came because they feel there is a role for public involvement in oak woodland policy. What individuals consider to be appropriate involvement varies from the traditional provision of "extension messages" to more expansive, and expensive, approaches such as workshops, local or state regulation, subsidies and outright purchase of partial or full development rights. Although most policy discussions concerning public intervention have centered on regulation and at the State level through laws and the local level through zoning (Huntsinger and Bleier 1990), a number of recent initiatives concerning wildlands have mandated state purchase of all or some development rights for wetlands, parks, or wildlife habitats. In addition there has been discussion on whether a more proactive use of various state and federal subsidy programs could promote certain land management practices which would further generally agreed upon social goals. To get an initial idea of how much support exists for these approaches with respect to oak woodlands, participants were asked two simple yes/no questions: (1) did they approve the use of State funds for the purchase of development rights in ecologically sensitive oak woodland areas; and (2) would they support the use of landowner subsidies to promote land use practices beneficial to wildlife and scenic beauty? A surprisingly high rate of approval of these two issues was common to all groups (table 3).

Although the participants responded favorably to the use of state funds for oak woodlands, figure 7 illustrates a strong preference for a significant level of city or county involvement. Support for financially expensive state funded programs and the desire for local control (which usually consists of zoning and regulation) represent two very different and often conflicting types of government involvement.

Table 3 — ***Approval of state funds to protect unique oak woodland habitats***

Workshop	Purchase Development Rights	Provide Subsidies for Habitat Preservation
San Luis Obispo	91 pct	87 pct
Sonoma	92 pct	84 pct
Tuolumne	91 pct	81 pct



Legend

Location of workshop

SLO San Luis Obispo County

SON Sonoma County

TUOL Tuolumne County

Type of contact

RESOURCE foresters, wildlife biologists, agr. and range consultants

PUBLIC SERVICE Cooperative Extension, conservation organizations and University faculty

LANDSCAPE landscape architects, arborists and gardeners

OFFICIAL planners, technical department staff, elected officials

Figure 7—Regulatory power concerning oaks preferred by participants at regional workshops.

CONCLUSION

When serious discussions began at the state level concerning interventions on oak woodlands, the focus was oriented mainly towards ranch lands. Recent conflicts and ordinances have been localized and oriented towards residential areas (Doak and others 1988). A new set of professional and interest groups are being brought in who often have very different values and approaches. This requires that extension programs, such as the IHRMP of the University of California Cooperative Extension, use strategies which address both the physical problems and the decision makers who will be involved. Many of the actors influencing decisions regarding oak woodlands are not landowners and do not necessarily hold similar values to landowners, especially large landowners. Strategically, it could be much more effective to deal with these diverse actors through interest groups, be they professional or issue oriented. Interest groups have their own journals and newsletters, continually share ideas and experiences, and are easier to track.

These three workshops attracted a large number of non-landowners who previously had little involvement with Cooperative Extension or state agencies concerned with rural resources. The participants illustrated a strong underlying agreement on values of these lands, the use of government funds to further those values, and a significant degree of local government control. Preserving living individual trees was the most common practice suggested of the participants. It is mainly done with private funds but is also the underlying rationale for many local ordinances. While they strongly support the value of wildlife habitat, scenic beauty and riparian zones, these features do not directly provide income to landowners. Consequently, these are often considered as constraints rather than goals for income producing land managers. How programs to protect these "public values" which occur on private land could be paid for may become a major issue in upcoming years. In terms of preserving habitats or relatively rare tree species, planning appears to be rare which takes into account larger areas and younger trees

Many of the technical programs and publications of the IHRMP focus on how to monitor and manage resources to achieve habitat and aesthetic goals within the economic limitations of the landowners. The challenging task facing Cooperative Extension and other concerned organizations is how to transmit the knowledge to the individuals who will be involved in the decision making process, both as landowners and non-landowners. Although traditional resource professionals have the strongest technical background regarding wildlife and vegetation management, they are often not involved in decision making on the urban fringe. If state or local policies to promote the shared values are to be effective, the multitude of decision makers must become better acquainted with the relevant information. Contacting and monitoring these decision makers through their respective professional or interest groups appears to be an effective strategy.

TOWARDS AN INTEREST GROUP BASED MONITORING AND EVALUATION SYSTEM

One purpose of this research was to better define the important actors at the urban interface. Residential expansion and rapidly changing land uses have significantly increased disagreements over oak woodland management in this area. Strategically it is efficient to deal with large number and diversity of potential actors through interest groups, be they professional or issue oriented. Interest groups have their own journals and newsletters, continually share ideas and experiences, and are easier to track.

We realized that if this sampling approach was to have any practical use, it must include rural interest groups and the approach used for all groups must be comparable. As a follow-up to this first set of surveys, we conducted a larger state wide survey which used random samples for a number of identifiable interest groups. The groups sampled included some of those identified in the first survey as well as the California Cattlemans Association, range professionals, and consultants to large scale developers. Samples from the different interest groups were taken from the four areas—San Diego, the Central Coast, the San Joaquin Valley foothills and the northern Sacramento Valley foothills—to capture but not be overwhelmed by geographic variation.

Initial analysis shows very similar values across rural and urban groups. Natural beauty, habitat for all wildlife species, and protection from soil erosion were the most important values for all groups. Compared to people who went out of their way to spend a full work day at a Cooperative Extension workshop, the respondents mentioned relatively fewer problems and were less concerned with habitat loss to development. Ranchers focused on the loss of forage from tree and brush growth. Most other groups concentrated on the loss of individual trees, poor regeneration and overgrazing. All groups ranked planning and management techniques similarly but landowners practice techniques less often than professionals recommend them.

The purchase of development rights and the provision of subsidies for wildlife habitat improvement had considerably less support than it did among the sample which attended the three workshops. There was strong, across the board support for the provision of information and advice and, with the exception of ranchers, very strong support for more parks. When asked to respond as taxpayers, however, the respondents gave significant support only an income tax check off and special fees on new subdivisions. Regulation in terms of zoning, permits and ordinances was more widely supported. The percentage of ranchers willing to accept carefully crafted oak related ordinances was considerably higher than reported in Huntsinger and Fortmann (1986).

Compared to earlier surveys of landowners and other decision makers, there is considerably more communication about

oaks with government, consultants, and other groups. Professional associations were important for within-group communication. Conservation organizations and Cooperative Extension were the only types of organizations with a high level of cross membership. The concern for non-game wildlife habitat has increased while concern over firewood harvesting has gone down. Overall there appears to be a convergence on what is desired but less clarity on how do it or how to pay for it. If we are to bridge the gap between values and actions it will be necessary to translate scientific principles into workable approaches and make sure that the messages are spread through the effective channels. I submit that profession- and issue-based interest groups must be involved early if we are to avoid the costly polarization that has occurred over forestry and agriculture practices in California.

ACKNOWLEDGMENTS

Richard Standiford, John Le Blanc, William Tietje, Robert Schmidt, and Ellen Rilla all provided considerable support and helpful comments.

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Holocene Changes in the Distribution and Abundance of Oaks in California[1]

Roger Byrne Eric Edlund Scott Mensing[2]

Abstract: Our knowledge of the long-term history of oaks is primarily based on biogeographical analysis of anomalous distribution patterns and paleobotanical macrofossil evidence. Neither of these provide a continuous record of change. In this paper, we present fossil pollen evidence which records significant changes in oak abundance over the last 10,000 years. Between 10,000-5,000 years ago, oaks in the Sierra Nevada increased at the upper altitudinal limit of their range. Since the mid-19th century, oaks at low elevations in the Coast Ranges have increased. We believe that the early increase represents an upward migration of oaks in response to climatic warming and changes in the fire regime, while the recent change reflects an increase in woodland density following a cessation of burning by Indians, a change in grazing pressure, or both record of vegetation change over time. This record can be interpreted to identify causal factors associated with changes in species composition useful in predicting what impact management decisions or future climatic change may have on oak woodland distribution and composition.

This paper reports how pollen evidence from the Sierra Nevada and the Coast Ranges can be used to reconstruct changes in the distribution and abundance of oaks during the past 15,000 years. The Sierran record covers the whole of this time period and shows significant increases in oak abundance during the early and mid Holocene 10,000 to 5,000 years ago. The Coastal record provides high temporal resolution of the last 500 years. It shows a significant increase in oaks during the period of European settlement.

Prior to the publication of Adam's first paper on the Clear Lake pollen record (Adam and others 1981), our knowledge of the long-term history of oaks in California was based almost entirely on biogeographical and paleobotanical evidence. The former involved the analysis of anomalous distribution patterns, such as disjunctions and zones of hybridization where both parent species no longer coexist (Axelrod 1981, Griffin and Critchfield 1976); the latter was heavily concerned with macrofossils, especially fossil leaves and acorns (Axelrod 1983, Wolfe 1979). Both of these lines of evidence have provided useful information, but it is information that is inherently discontinuous, both in space and time. In contrast, as Adam convincingly demonstrated at Clear Lake, fossil pollen can provide a continuous record of change, a record which in this case reflects changes in oak abundance on a regional scale.

Pollen analysis is an important paleoecologic tool and has been used to reconstruct vegetation history associated with climatic change and human induced environmental change (see Birks and West 1973, and Huntley and Webb 1988 for comprehensive reviews). Analyses of the contemporary pollen rain have shown that modern pollen distribution generally corresponds with the distribution of wind pollinated taxa (Anderson and Davis 1988, Bradshaw and Webb 1985, Heusser 1983, Wright 1967). Not all species produce sufficient quantities of pollen to leave a reliable record. However, oak is a prolific producer. Although taxonomic resolution for pollen is not as good as macrofossil evidence, pollen provides a continuous

PREVIOUS CALIFORNIA POLLEN STUDIES

Pollen studies in California have primarily been applied to paleoclimatic reconstruction based on shifts in distributions of indicator taxa (Adam 1985). Of all paleoecological sites in California, the record from Clear Lake (fig. 1) presents the best evidence of long-term changes in the distribution of oak woodlands (Adam 1988). This record shows that the modern distribution of oak woodlands is a recent development in evolutionary time. The full glacial record indicates the virtual absence of oaks from the drainage basin. Under these colder conditions, pines were dominant, with sagebrush and Cupressaceae (incense cedar, cypress, juniper, etc.) more abundant than at present. With postglacial warming, oak reestablishment commenced ca. 13,000 years ago. Pollen percentages suggest that oaks were more abundant than at present during the early and middle Holocene (approximately 10,000-6,000 years ago).

Other records since the last glacial maximum are scarce in California, particularly within the present and/or past range of oak species. In the North Coast Ranges and the Sierra Nevada, work by Byrne (1988), Davis and Moratto (1988), Mackey and Sullivan (1986), Reed (1984), and West (1985) indicates that some lower elevation taxa increased in importance at higher elevations in the early and middle Holocene (approximately 10,000-5,000 years ago). These records show similar but not identical shifts in oak.

At Tule Lake and Lily Pond in the Mendocino National

[1] Symposium on Oak Woodlands and Hardwood Rangeland Management, Oct. 31- Nov. 2, 1990, Davis, Calif.

[2] Associate Professor and graduate students respectively, Department of Geography, University of California, Berkeley

Forest, oak began to increase in importance approximately 7,000 years ago, reaching maximum percentages around 5,000 years ago, and declining slightly to the present (West 1985). A similar pattern was revealed at Dogwood Pond (Reed 1984), where oak was uncommon before 7,000 years ago, but then increased to high levels in the middle Holocene. Most of the oak pollen at this site was identified as Canyon live oak (*Q. chrysolepis*).

At Gabbott Meadow in the central Sierra Nevada, oak pollen present at higher-than-modern values from approximately 9,000-5,000 years ago led Mackey and Sullivan (1986) to infer a warmer and/or drier climatic interval at this time. This interpretation was supported by other sites in the Stanislaus drainage analyzed by Byrne (1988); Swamp Lake and Lake Moran both show elevated levels of oak during the early and middle Holocene. Farther south, paleoecological work on Exchequer Meadow (Davis and Moratto 1988) also suggests an increase (less pronounced than at the Stanislaus sites) in oak at elevations above its modern range, reaching a maximum approximately 9,000-7,000 years ago.

Several pollen analyses of short cores have examined changes within the last few hundred years. Analysis of two midden sites in Tuolumne County near New Melones Dam found evidence that suggests oak woodland was more open in the late 18th and early 19th centuries, but that oak and pine expanded into formerly open areas in the late 19th and 20th centuries (Byrne and others, in press). Expansion is attributed to less frequent fires in the post-Indian period. West and Mossberg (1978) analyzed a short core from a sag pond near Tejon Pass. They found fluctuations in oak pollen, but were unable to interpret the significance without data on sedimentation rates. A sedimentation and pollen study of Zaca Lake in Santa Barbara County indicated a general increase in oak over the last two centuries (Peterson 1980). However inquiry into this vegetation change was not the focus of the analysis.

THE PRESENT STUDY

In this study, we have selected sites potentially sensitive to changes in oak abundance and distribution during the Holocene. Our study has two temporal foci: the early- and middle Holocene (10,000-5,000 years ago), a period of climatic warming; and the last 500 years, a period of major vegetation change associated with changes brought by European settlement. Examples include the introduction of livestock and alien plant species, and the decimation of the native Indian population. The long term record focuses on sites at the current upper elevational limit of black oak (*Q. kelloggii* Newb.) in the Sierra Nevada. In this paleoecologically sensitive zone we have identified evidence of altitudinal shifts in oak distribution associated with climatic warming. Sites in the northern and southern Sierra are being examined to identify possible regional trends (fig. 1).

Evidence for the more recent, pre-European period is from the Central Coast Ranges. These sites are located within the sphere of influence of Spanish missions and early settlement in areas affected by grazing and agriculture. The actual distribution of sites is constrained by the paucity of naturally occurring permanent lakes.

Lake sediments are extracted with a Livingstone piston corer, hand operated by two or three people from a small floating platform centered over the deepest section in a lake. Sediments are recovered in 1-meter sections with stratigraphy intact. Sediment analysis is done at the University of California Berkeley Palynology Laboratory. The sediment cores are sampled at intervals (typically 10 centimeters), and samples are chemically processed to concentrate the pollen and remove other organic and inorganic material (Faegri and Iversen 1975). A spike of a known quantity of *Lycopodium* spores is introduced as a control to calculate absolute pollen concentration and influx. Glass slides are prepared and examined under a Leitz microscope at 400x magnification. Approximately 250-400 grains are identified and counted, using photographic keys and reference specimens compiled in the Pollen Lab. Chronologic control is obtained with carbon-14 dates, identification of ash layers (Sarna-Wojcicki and others, 1983) and with introduced European pollen types which act as stratigraphic markers in sediments deposited in the past 200 years (Mudie and Byrne 1980, West and Mossberg 1978). Pollen diagrams (fig. 2-3) are produced using the CalPalyn software package (Bauerand Orvis 1990).

DISCUSSION OF PRELIMINARY RESULTS

Previous paleoecological work in the Sierra Nevada has pointed to early Holocene climatic warming as an important factor in vegetation change. In particular, at several (but not all) sites oaks seem to have expanded upslope beginning about 10,000 years ago. To examine this phenomenon more closely, we are undertaking work at several sites positioned near the upper limit of California black oak, between 1,500-2,000 meters (see fig. 1).

Lake Moran shows the strongest oak signal (Byrne 1988, Edlund and Byrne in press). Figure 2 shows that from about 10,000—5,000 years ago, oak pollen is present at above-modern levels, in association with increases in bracken (*Pteridium*), sagebrush (*Artemisia*) and dwarf mistletoe (*Arceuthobium*). Macrofossil and charcoal analysis of a second core from this site documents a shift from lodgepole—western white pine—sugar pine—mountain hemlock to a ponderosa pine dominated forest (Edlund and Byrne in press). The timing of the increase in ponderosa pine coincides with the increases in oak and dry understory species, and with an increase in charcoal influx to the lake sediments.

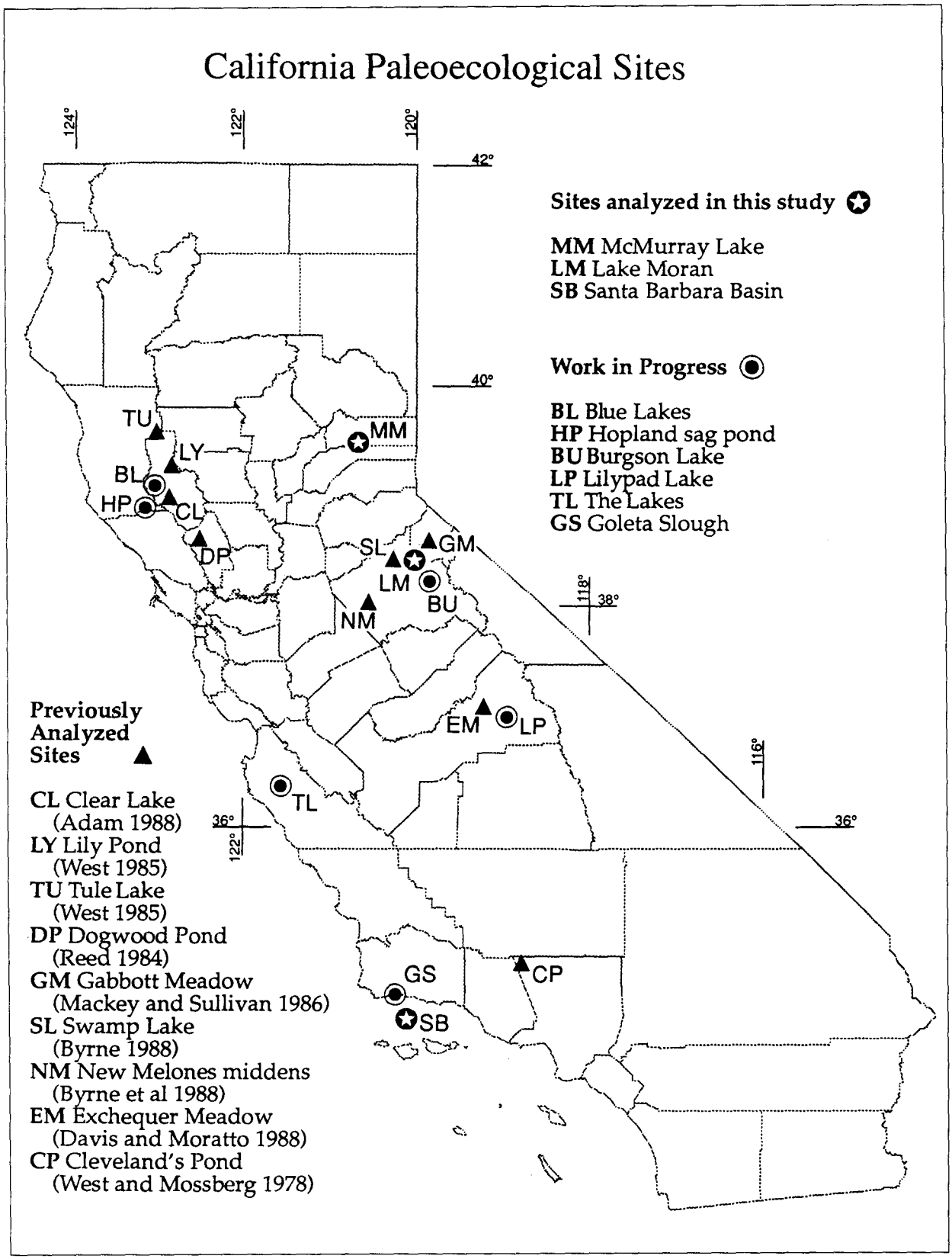


Figure 1—Site map of previously analyzed pollen sites, sites analyzed in this study, and work in progress.

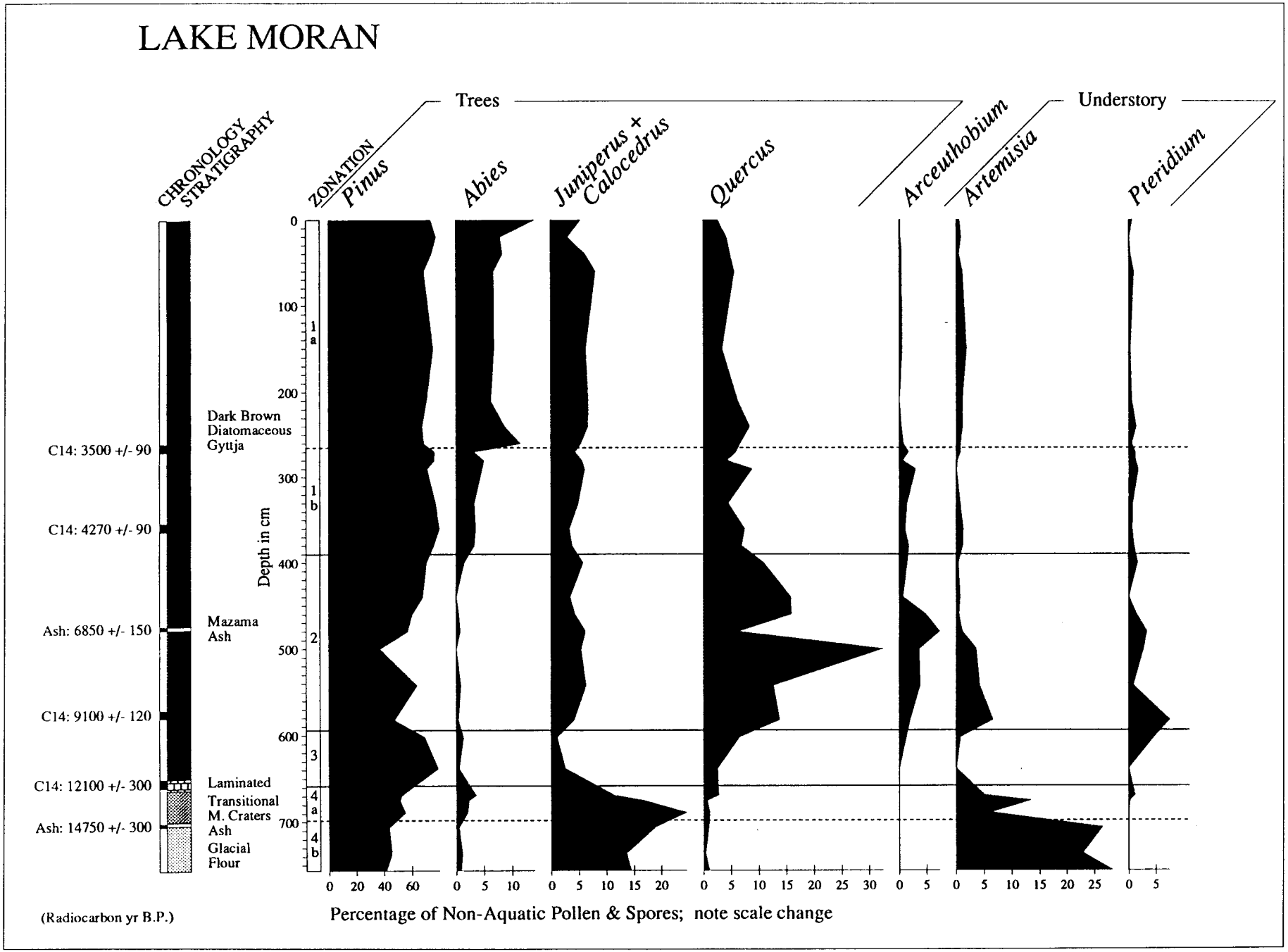


Figure 2—Pollen diagram for Lake Moran, Tuolumne County, California.

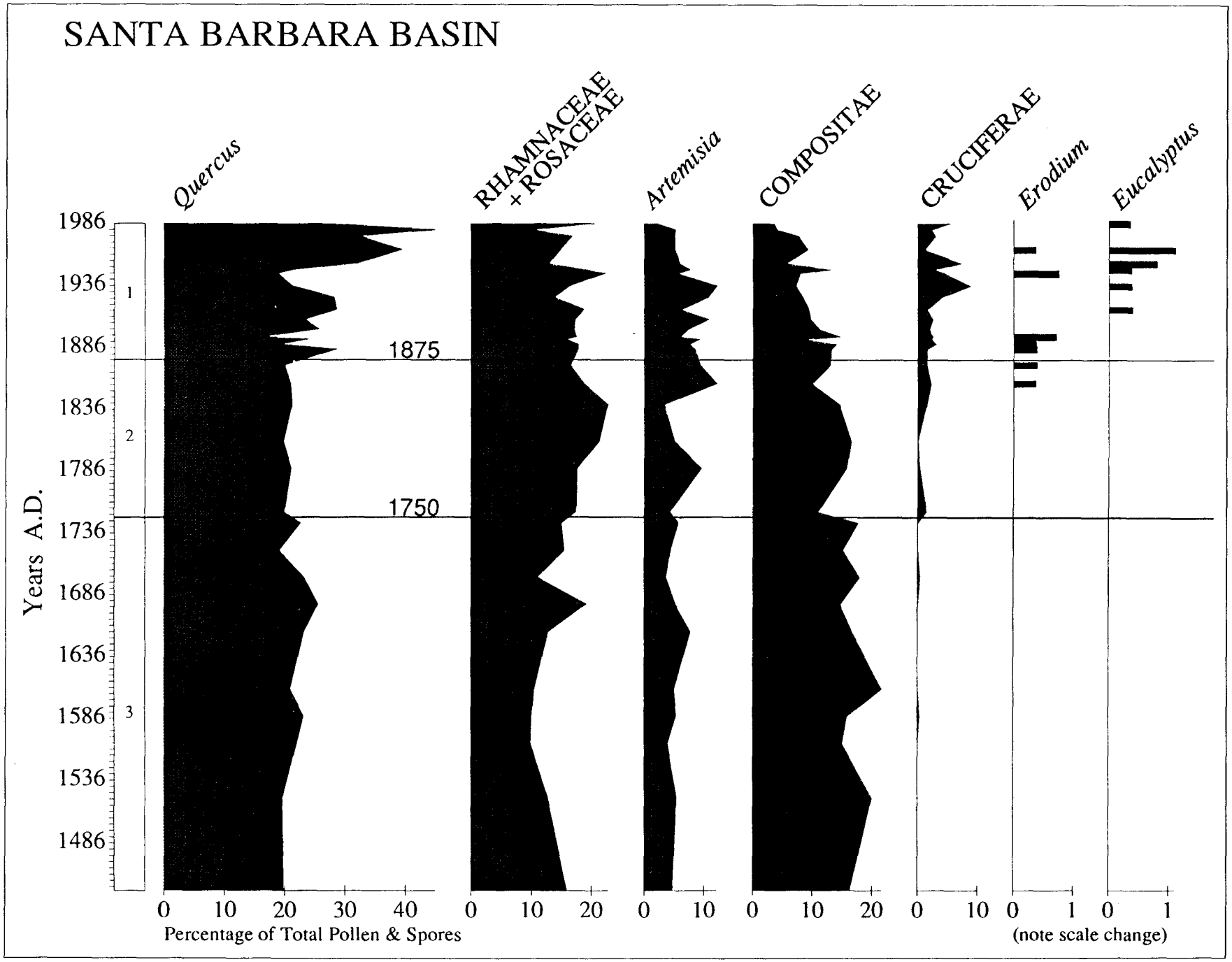


Figure 3—Pollen diagram for the Santa Barbara Basin, California.

Our interpretation of the Moran oak record is that dramatic changes commenced about 10,000 years ago. For at least a thousand years prior to this date, a dense, closed canopy forest included species whose distributions no longer overlap in the Sierra Nevada. Summers were sufficiently warm to support sugar pine (limited to <2100 meters elevation in the central Sierra today), while moisture was adequate for the survival of mountain hemlock, today restricted to high elevation sites (generally > 2500 meters) with abundant snowpack. Oaks were not important at this time.

We hypothesize that climatic warming at the close of the Pleistocene Epoch forced a change in the role of fire in the montane Sierra Nevada. The dense white pine/lodgepole pine canopy was consumed by fires, providing openings for bracken and sagebrush, and allowing ponderosa pine and black oak to out-compete the more poorly fire-adapted species which preceded them.

Work on changes in oak woodlands for the recent period has largely been confined to age structure analysis focusing on the last 200 years (Anderson and Pasquinelli 1984, McClaran 1986, Mensing 1988, Vankat and Major 1978, White 1966). Age structure analyses have identified potential changes in oak regeneration prior to European settlement (Mensing 1988) but are generally restricted to the historic period because of losses through cutting and natural mortality. Palynological work in the Coast Ranges has been frustrated by the difficulty in finding suitable sites with a sensitive pollen record. Recently, researchers at Scripps retrieved a core from the sediments of the Santa Barbara Basin which is continuously varved for the last 1,000 years (Schimmelmann and others 1990). The annual nature of the Santa Barbara varves has been confirmed by isotope dating (Bruland 1974, Koide and others 1972, Krishnawami and others 1973) and by sampling the near-surface sediments (Soutar and Crill 1977). Sediments consist of a dark, silt rich winter layer and a light diatomaceous spring layer. An unusually high sedimentation rate of 1.0 -2.0 millimeters per varve makes it possible to sample at yearly intervals, providing an accurate chronology spanning the period of European settlement. Sediment mineralogy has identified the Santa Clara and Santa Inez River drainages as the primary sources of material (Fleischer 1972). Vegetation in these drainages is a mosaic of oak woodland, chaparral, coastal sage scrub, grassland and conifer woodland. Previous pollen analysis from basin sediments found that the pollen record is primarily one of changes in the area adjacent to the channel, and not from long distance transport (Byrne and others 1977, Heusser 1978).

Approximately 500 years of the Santa Barbara core have been analyzed at intervals of 10-20 years. Core chronology has been worked out for the period 1760 to the present (Schimmelmann, unpublished data). For the period 1450-1760 a constant rate of sedimentation has been assumed, giving a figure of 1.2 years per varve. The results (fig. 3) indicate an increase in the importance of oak beginning about 1875. Prior to this period, oak averages 20 percent of the total pollen. It increases to an average of 27 percent in the late 1800s, and reaches as high as 45 percent in the late 1900s, more than twice the pre-European figure. This continued increase occurs at a time when oak distribution was probably decreasing due to clearing for agriculture and development.

Although further work is needed in analyzing this evidence, our tentative hypothesis is that oak woodland density has increased since the mid-19th century. We believe increased density may be the result of cessation of regular burning by Indians, or changes in grazing and woodcutting practices associated with population increases in the 1850s. If this hypothesis is correct, the present oak woodlands are more dense than the woodlands under Indian settlement. The increase in canopy and stem density may contribute to the present lack of regeneration in some areas.

We are testing the validity of these results through further analysis of the Santa Barbara Basin core, as well as analysis of a core we plan to retrieve from Goleta Slough. To test our hypothesis on a regional scale, we are analyzing core material from The Lakes in Monterey County, and from a short core out of Headquarters Lake, a sag pond at Hopland Field Station in Mendocino County. We also plan to collect cores from Blue Lakes in Lake County and Cleveland's Pond in Los Angeles County.

CONCLUSION

Our preliminary results reveal changes in oaks during the Holocene. First, 10,000-5,000 years ago, oaks in the montane Sierra Nevada increased in importance at the upper altitudinal limit of their range. We believe this environmental change was a response to climatic warming and to changes in the fire regime. More recently, following Spanish settlement and the introduction of exotic plant species, oak again increases. We hypothesize that this rise may reflect increased oak woodland density following a cessation of burning by Indians, or changes in grazing and woodcutting practices associated with intensified land use during the mid-19th century. Further analysis of microscopic charcoal and records from additional sites are needed to test these hypotheses and further clarify regional trends.

ACKNOWLEDGMENTS

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Vegetation Change in Blue Oak Woodlands in California[1]

Barbara A. Holzman Barbara H. Alien-Diaz[2]

Abstract: A preliminary report of a statewide project investigating vegetation change in blue oak (*Quercus douglasii*) woodlands in California is presented. Vegetation plots taken in the 1930s, as part of a statewide vegetation mapping project, were relocated and surveyed. Species composition, cover and tree stand structure data from the earlier study were compared with the current survey to determine the changes that have occurred in these woodland habitats. Twenty one plots were surveyed from south San Benito and eastern Monterey county rangelands. Changes of note included a general increase in total basal area of blue oak and foothill pine (*Pinus sabiniana*), particularly due to an increase in small trees (4-11 DBH class). An increase in the percent cover of understory annuals including Avena species and *Bromus diandrus,* and a decrease in *Bromus mollis* and *Poa* species were noted.

Oak woodlands form a reservoir of biological diversity and provide resources for human use. This study focuses on changes within blue oak *(Quercus douglasii* (QUDO)) woodlands due to human modification and succession. This study documents changes in blue oak communities over time to project future trends and provide stand information for current assessment and management of blue oak woodland communities within California. Of particular interest are differences in plant species distribution, stand characteristics and associated plant species. The data reported here are the first in a continuing study of changes within blue oak woodlands throughout the state.

Blue oak occurs in a continuous ring around the Central Valley of California from 100 to 1200 meters elevation, from north Los Angeles County to the head of the Sacramento Valley in Shasta County (Munz and Keck 1968, Griffin and Critchfield 1972). It is prominent in the foothill woodland areas of the state and forms a transitional zone between the valley grassland and the higher elevation mixed coniferous forest. Blue oak woodlands cover approximately 10 percent of the state of California; 75 percent is privately owned; 14 percent is in the National Forest system and the remaining in state, county or miscellaneous federal ownerships (Griffin and Critchfield 1972, Griffin 1977, Bolsinger 1988).

Blue oak vegetation forms two layers. The overstory contains blue oak and regional associations of other deciduous and evergreen oaks and pines (particularly *Pinus sabiniana*) (Griffin 1977). Codominance with other overstory species is influenced by water table, slope and location. In many blue oak communities there is little understory shrub cover, instead annual grasses and native annual and perennial forbs account for greater than 80 percent of the ground cover (Griffin 1977).

Griffin (1977) describes the "foothill woodland" as the major oak community in California. The Coast Range and Valley types within the Blue Oak Phase of the foothill woodland are represented in this study. The Coast Range type is often associated with foothill pine (PISA2) and other oak species. The Central Valley type is a savanna-like community where blue oak is the prominent tree with grass species dominating the understory (Griffin 1977).

Allen and others (1989) further refined blue oak types in a classification system that described 10 subseries within the blue oak woodland. These subseries differ in associated overstory codominants, understory species and environmental parameters (Allen and others 1990). Using this classification, four subseries (Blue oak/Grass (QUDO/GRASS), Blue oak-Foothill Pine/ Grass (QUDO-PISA2/GRASS), Scrub oak (*Quercus dumosa*)-Blue oak/Grass (QUDU2-QUDO/GRASS) and Valley oak (*Quercus lobata*)/Grass (QULO/GRASS) are represented in this study.

Succession within blue oak woodlands is thought to proceed from grassland to tree stages, with associated shrubland communities occurring in locally favorable sites (Mayer and Laudenslayer 1988). Disturbance by fire, grazing or harvesting alters this simple scenario of community change. Blue oak occurs throughout most of California and changes within the communities are expected to vary regionally and locally based on differences in climatic, edaphic and historical use regimes. Because blue oak is typically the longest lived tree within the community, its presence in the climax or mature community is expected.

METHODS

Allen and others (1989) described 7 series and 57 subseries of rangeland cover types for California's hardwood rangelands based on Vegetation Type Map (VTM) data from the 1920-30's. From these classified types, blue oak subseries were selected for further study. The first area selected for study was the Priest Valley USGS 30 minute topographic quadrangle, located in southern San Benito and northeastern Monterey counties. Twenty one one-fifth acre plots were chosen randomly from the original

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VTM plots within this quadrangle and investigated for historical vegetation changes.

The landscape of this area is rolling grasslands and oak woodland hillsides with agricultural crops grown in the valleys. Annual rainfall in the area varies from 10 to 45 inches (254 to 1143 mm). Rainfall in the past year has ranged from 20 to 100 percent of normal. The study plots were located on 10 to 70 percent slopes on all aspects. Elevations ranged from 700 to 3500 feet (213 to 1067 meters). Soils also varied, ranging from sandy to clay loams, all easily erodible. Water holding capacity of the soils ranged from 1-8 inches (2.5 to 20.3 cm), with root penetrability from 10-60 inches (25.4 to 152.4 cm) (USDA SCS 1969 and 1978).

All 21 plots were privately owned with several plots owned by the same family. Twenty percent of the plots were held by absentee owners, but were managed as part of working ranches. Only one of the 21 plots had evidence of conversion; a road was built in the middle of the plot. The surrounding vegetation remained similar so the plot was included in the analysis (the new plot only included the vegetation west of the road). All the remaining plots have a history of livestock grazing. All are currently or were recently grazed by cattle or horses.

The data consist of U.S. Forest Service VTM plots collected as part of a statewide effort to map vegetation (Wieslander 1935). These historic records collected by crews in the 1920s and 1930s contain data regarding tree stand structure, percent cover of dominant understory vegetation by species, soil type, parent material, and environmental elements for each site. Along with these data, photographs of representative plots were taken and the location of the sites were noted on U.S. Geological Survey topographic maps. The twenty-one plots chosen were relocated and resurveyed for evidence of change. Data collection methodologies used in the earlier survey were repeated. Additional data were also collected as described below.

VTM plots were initially sampled to provide a validation of the vegetation mapping project and to include information regarding understory species associated with the vegetation type being mapped. The plots selected were representative of the vegetation subtypes encountered. The VTM plots were randomly selected within the boundaries of "well-defined natural associations" (Wieslander and others 1935). Initial site location, county, township, range and distance from a selected reference point were recorded. Slope, aspect and elevation were estimated. Parent material, soil depth and "character" (structure), and penetrability (ability to walk through the vegetation) were recorded. Plot history (fire, harvesting, disturbance and use) was also recorded if known.

In the initial study, tree, shrub and ground cover were recorded using one- tenth acre rectangles (0.5 by 2 chains), divided into 100 squares. The dominant species within each square was recorded. When less than 50 percent of the square was occupied by shrubs or grasses, ground surface characteristics such as bare ground, rock outcrops or tree trunks were noted. In plots where trees over four inch diameter at breast height (DBH) occurred, the trees were tallied, noting species and DBH class. For the tree tally, the sampling strip was 0.2 acres (1 by 2 chains). Plots were surveyed between March and May of 1932.

The procedures above were repeated in the current study to allow for a direct comparison between earlier and current samples. Data were collected in June and July of 1990. Additional data collected included an estimate of plant cover by species from a 100 foot linepoint transect, with species recorded at 1 foot intervals. Stand structure was measured using a standard relascope from three points, one at plot center, one perpendicular to the slope and one parallel to the slope (Avery and Burkhart 1983). The presence of seedlings and saplings within the plot was also recorded. The plots were also located on county soils maps to determine soil series and capability unit designations.

The data were analyzed to determine what changes occurred in the vegetative overstory and understory since the initial survey. The dominant species present on the site in 1932 were compared to those present in 1990. Changes in overstory basal area and understory species percent cover were also compared. The data were first analyzed using all plots, for an overall view of change. Then the newly surveyed plots were classified using the Hardwood Rangeland Type Descriptions (Allen and others 1989). Changes in type classification of the plots were noted. The data were analyzed by cover type to determine what changes could be detected within the various types.

Initial measures of central tendency and dispersion were conducted. Tests for matched pairs, comparing the differences of means, for surveyed vegetation variables were used to determine whether significant differences existed between the early VTM and current data. These tests were stratified to determine if significant differences occurred in tree overstory (basal area, stand structure and composition), tree understory (cover and composition), shrub and/or herbaceous (cover and composition) layers.

RESULTS AND DISCUSSION

The resurveyed plots were classified using Hardwood Rangeland Cover type keys (Allen and others 1989). Four cover types were recognized. Of the 21 plots; 11 were classified as QUDO/GRASS, 5 as QUDO-PISA2/GRASS, 3 as QUDU2-QUDO/GRASS and 2 as QULO/GRASS. Of the original plots classified during the VTM analysis by Allen and others (1989), 71 percent of the plots remained classified as the same type. The 29 percent that changed resulted from a change in the overstory species, such as the appearance or disappearance of foothill pine, scrub oak or blue oak.

Plots were initially compared regardless of cover type designation. Overall differences between the 1932 and 1990 data included an increase in total basal area for all tree species (figure 1). These increases were significant for blue oak and foothill pine. This overall increase in basal area is expected due to growth of trees over time.

Comparing understory cover between the 1932 and 1990 data, a significant increase in the percent cover of bare ground

and litter was also noted. An increase in some annual grasses such as ripgut (*Bromus diandrus*) and wild oats (*Avena* species) and a decrease in the percentage of cover of soft chess (*Bromus mollis*) and bluegrass (*Poa* species) (since the initial survey) were apparent (figure 2). Other genera not noted in the 1932 study which formed a significant cover in the 1990 survey were barley (*Hordeum*), fescue (*Festuca* and *Vulpia*) and needlegrass (*Stipa* species). Total species composition by plot increased on average by two new species per plot between 1932 and 1990.

All of the 21 plots surveyed were currently being grazed. Several plots in the study area were heavily grazed and the land was completely denuded by July. The increase in bare ground is probably due to a combination of the timing of sampling and current heavy grazing, as well as four years of drought in the state. Further sampling of the understory will be taken during the Spring to verify the understory changes noted above.

Of the 21 plots surveyed, only one plot was altered by construction or development. A road was built through the middle of the plot, yet the surrounding vegetation could still be classified into the QULO/GRASS cover type. The remaining 20 plots were classified as blue oak woodlands and largely used for livestock grazing and as wildlife habitat.

After the overall comparisons were made the plots were evaluated by cover type to determine if patterns of change within types could be detected.

Blue Oak/Grass (QUDO/GRASS)

The 11 plots within the QUDO/GRASS type showed an increase in total species composition from 11 in 1932 to 17 species in 1990 (an average increase of 2 new species per plot). Most of this change was in understory vegetation. There was a significant loss in percent cover by *Poa* sp. and *Bromus mollis.* Other grass species including *Avena* and *Hordeum* species and *Bromus diandrus,* not noted as dominant cover in the 1932 survey, were now present. Bare ground also increased in percent cover on several plots.

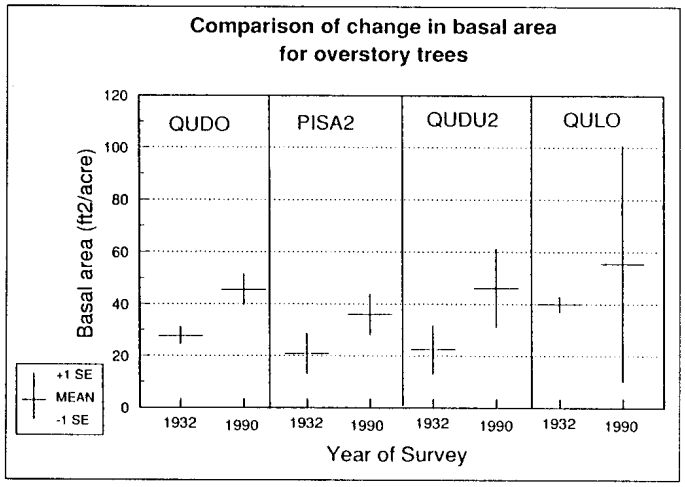


Figure 1—A comparison of total mean basal area (ft^2/ac) by overstory species on plots taken in 1932 and 1990. Means are based on total basal area per species per plot for the 21 plots.

A significant increase in total basal area of blue oak was also apparent. Average total mean basal area increased from 34.6 (± 5.0) ft^2/acre to 50.4 (± 7.1) ft^2/acre in 1990 (for an annual growth of 0.7 percent). A comparison of tree stand structure showed an increase in trees within the small tree size class (4-11 DBH). Average number of trees in the 4-11 class increased from 3.6 (±.53) trees per.2 acre to 7.09 (± 1.18) trees per.2 acre (figure 3). An increase in the number of trees at the larger DBH classes were not significant. Six of the eleven plots had blue oak seedlings present on the plot, averaging 7(± 3) seedlings per plot.

This increase in basal area of blue oak is due to growth over time and an increase in the number of trees in the 4-11 DBH class. The increase trees at the 4-11 DBH classes as well as the presence of smaller trees and seedlings on 50 percent of the plots represents some recruitment of new trees into the area.

Blue Oak-Foothill Pine/Grass (QUDO-PISA2/GRASS)

Within the 5 plots classified as QUDO-PISA2/GRASS cover type, *Bromus mollis* decreased and *Bromus diandrus* and *Avena barbata* increased in percent cover within the plot. Overall understory species present as dominants increased from 10 to 17, (average increase of 2 species/plot) due to an increase in grasses and forbs.

Blue oak total basal area increased significantly. Average total basal area increased from 28.6 (± 2.4) ft^2/acre to 53.2 (± 12.8) ft^2/acre (annual growth rate of 1.5 percent). Foothill pine also increased significantly, from 15.6 (± 5.9) ft^2/acre in 1932 to 40.4 (± 11.0) ft^2/acre in 1990 (annual growth rate of 2.7 percent). These increases were due to an overall increase in the number of trees at all DBH classes (figure 3). Blue oak seedlings were present on 3 of the 5 plots, averaging 10 (± 5) seedlings per plot.

An increase in basal area and total number of blue oak and foothill pine trees since the 1932 study was evident in the

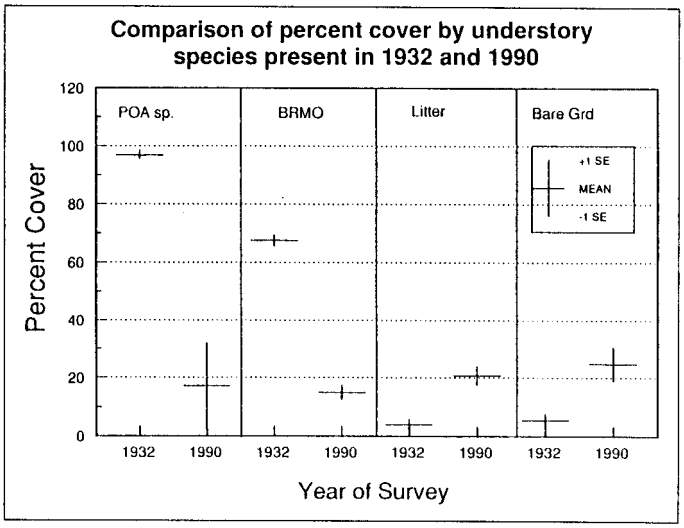


Figure 2—A comparison of percent cover of understory species present on the VTM plots in 1932 and 1990. Note that all have changed significantly since 1932.

QUDO-PISA2/GRASS cover type. With the presence of seedlings and an increase in the number of blue oaks and foothill pines at all DBH classes, this type appears to be stable.

Scrub Oak-Blue Oak/Grass (QUDU2-QUDO/GRASS)

In the three plots in the QUDU2-QUDO/GRASS cover type surveyed in 1932, *Poa* (a perennial grass) was the only dominant understory species, covering 98-100 percent of the plots. In 1990, bare ground, litter and *Hordeum* (an annual grass) are the understory dominants. An increase in overstory cover may be a factor in the decrease in understory vegetation.

In the overstory, an increase in the total basal area of scrub oak was apparent, while blue oak remained similar to the earlier survey. This increase in scrub oak is due to an increase in the number of trees in the 4-11 DBH class (figure 3), particularly on one site, a large number of these represent trees forked at the less than four feet high (thereby counted as two or more trees). No blue or scrub oak seedlings were present, but several shrub size scrub oaks were present on the plots.

In this type, we may see future changes that could include the continued loss of blue oak and an increase in scrub oak leading to change in cover type from QUDU2-QUDO/GRASS to a QUDU2/GRASS type as described by Allen and others (1989).

Valley Oak/Grass (QULO/GRASS)

This type was included in the study because these two plots initially contained blue oak. Upon resurvey no blue oak trees were found, although seedlings were present on one of the two plots. A road was constructed in the middle of one plot. Understory dominant species within these plots also increased due to the increased variety of grasses and forbs. Yellow star thistle (*Centaurea solstitialis*) was also present on the plot where the road was constructed. Numbers of valley oak (*Quercus lobata*) did not increase significantly on these plots. Although the trees present did increase in size, the overall increase was not significant. Few trees in the 4-11 DBH class were present. Blue oak and valley oak seedlings were present in small amounts (averaging 2 and 3 per plot respectively) on both plots.

No trend is apparent from these two plots, the amount of valley oak varied widely, increasing in one plot and decreasing in the other. Future study of this cover type as well as the others mention is needed to further assess the significance of these findings.

Tree Health

Many of the blue oaks in the area were infested with mistletoe (*Phoradendron flavescens* var. *villosum*). Discussion with the landowners indicated an increase in mistletoe growth in the last three years. Ranchers indicated that tent caterpillars (*Malacosoma* sp.) reduced tree foliage in 1988 and 1989, but

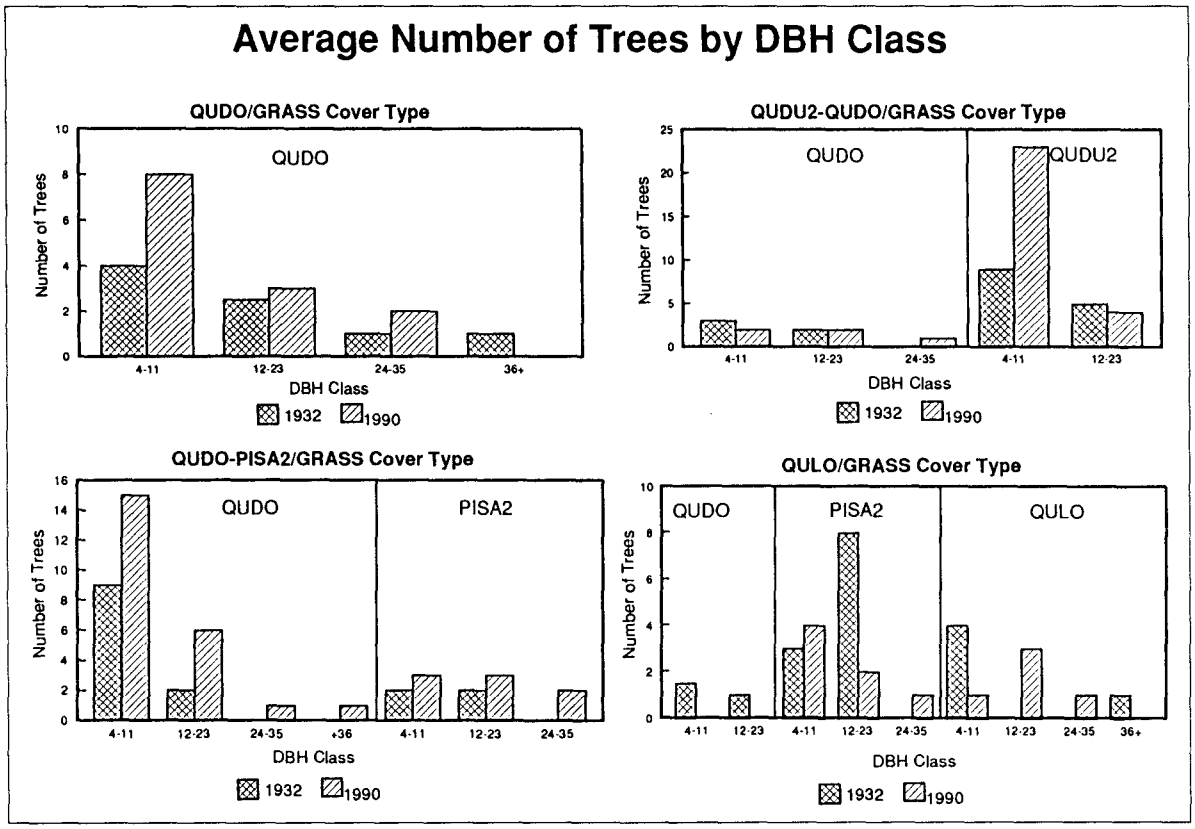


Figure 3—Average number of trees per plot by cover type and DBH class.

there was little evidence of caterpillar presence in 1990. Yellow star thistle was present on one plot which was disturbed by a road. Star thistle is present in the general study area primarily on the valley floor and is a concern to ranchers. It was rarely observed on the blue oak dominated hillsides.

CONCLUSION

Floristically, these initial results show an increase in understory species diversity, favoring species less palatable to livestock. Changes in overstory include an increase in blue oak basal area and an increase in trees present for plots within the QUDO/GRASS and QUDO-PISA2/GRASS types. The only significant mortality was in large trees (DBH 36+) in the QUDO/GRASS type, however these were replaced by increases in other size classes. Foothill pine and scrub oak basal area also increased. No recruitment of valley oak was evident but its inclusion in this study was incidental. Further study of this region during the growing season may include other understory species and show new understory patterns.

Only one plot in this survey showed evidence of conversion or disturbance (i.e. road construction), the remaining plots under private ownership were less affected. This area may not be representative of land use changes in the blue oak woodland statewide since this area is currently not significantly affected by suburban encroachment. Further study in four other regions of blue oak woodlands in the state, including the north coast, north central, northern Sierra foothills and the southern Sierra foothills may provide a different vision of blue oak changes.

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Winter-Deciduous versus Evergreen Habit in Mediterranean Regions: A Model[1]

Mark A. Blumler[2]

Abstract: Although winter-deciduous species are presumed to be "out-of-phase" with the mediterranean climate regime, distributional evidence suggests some taxa may be more tolerant of summer drought than evergreen sclerophylls. Deciduous species possess several features that confer advantage in extreme summer dry regions: drought-deciduousness, an efficient response to severe seasonal drought; high photosynthetic rates especially during the optimum late spring period; and a phenology similar to evergreens (but with more rapid growth) during the critical first year. I present a preliminary model of the relative importance of deciduous and evergreen plants in relation to climate, soils, and biotic influences.

The association of broadleaved evergreen sclerophyllous shrubs and trees with mediterranean-type (winter-wet, summer-dry) regions is generally regarded as the classic example of convergent evolution in plant physiognomy in relation to climate (Box 1981, Cody and Mooney 1978, Schimper 1898). Paradoxically, winter-deciduous species also grow where summer drought is severe, although this fact is scarcely recognized; in fact, the association of mediterranean climate with evergreen sclerophyllous habit is so strongly engrained that deciduous taxa are sometimes misclassified as evergreen (Specht 1969). At first glance, winter-deciduous species appear to be "out-of-phase" with the mediterranean climate, since they are leafless during part of the rainy season. On the other hand, it is often argued that evergreen sclerophylls have a growth rhythm that is in tune with and evolved in response to the mediterranean climatic regime (Cody and Mooney 1978, Mooney and Dunn 1970a). But most sclerophylls evolved prior to the development of summer-dry climates (Axelrod 1973, Minnich 1985), and many of the important mediterranean sclerophylls, or their nearest relatives, grow also where summer rain is significant (Minnich 1985, Suc 1984); so it is probably more accurate to speak of them as pre-adapted (Minnich 1985).

This paper describes how winter-deciduousness can be an effective adaptation to extreme summer drought, and examines a preliminary model of the relative likelihood of occurrence of evergreen and deciduous species, depending on climatic, edaphic, and biotic conditions.

DISTRIBUTIONAL EVIDENCE

Surprisingly, winter-deciduous species are often dominant where summer drought is especially severe. In California, the blue oak (*Quercus douglasii*) is distributed on sites that are often below, i.e., more xeric than, the chaparral belt (Baker and others 1981), and that also tend to be too dry for all other tree species (Barbour 1988, Griffin 1971, 1977, Vankat 1982). Shrubby evergreen oaks also grow in dry regions, but usually where there is a certain amount of summer rain. The "semi-evergreen" engelmann oak (*Q. engelmannii*) may be analogous to blue oak, as it is found primarily in interior regions that are hotter in summer than the southern California coast that supports the evergreen coast live oak (*Q. agrifolia*) (Barbour 1988, Lathrop and Osborne 1990). Even the valley oak (*Q. lobata*) may be more tolerant of summer drought than evergreen trees (Cooper 1926, Griffin 1971, 1973, 1976).

An even more striking pattern occurs in the Fertile Crescent and in Near Eastern mountain ranges generally. The region is vegetated almost exclusively by deciduous species, including oaks as well as many other genera (Zohary 1963, 1973). Yet summer drought is often even more severe than in California (Naveh 1967). The Fertile Crescent, especially its southern tips, experiences the hottest, longest, and driest summers of any winter rain region. Hence, in a sense, it has the most mediterranean climate on earth — although it is sometimes regarded as non-mediterranean simply because sclerophylls are rare (Blumler 1984). Winter-deciduous oaks and other taxa also can be found within the Mediterranean Basin in areas that experience relatively severe summer drought, such as southwestern Turkey (Quezel 1986), southern Italy, southern Spain, and North Africa. In interior central Chile, which has a long, dry, but relatively cool summer, deciduous legumes are sometimes dominant; but these maybe phreatophytic (Rundel 1981).

The suggestion that mediterranean winter-deciduous species must be phreatophytic (Box 1981) could apply to some taxa in the Old World, such as *Styrax officinalis,* and to the valley oak in California (Cooper 1926, Griffin 1976, 1977). However, it clearly does not apply to the blue oak, which does not need to rely upon the water table (Griffin 1973); nor does it apply to important Mediterranean/Near Eastern oaks such as the tabor (*Q. ithaburensis), Q. brantii,* and *Q. macrolepis* (Eig 1933, Oppenheimer 1950). On the other hand, evergreen sclerophylls often grow where they can tap ground water year-round (Arkley 1981, Griffin 1973, Mooney 1983). An alternative hypothesis that winter cold limits dominance by evergreens (Larcher 1981, Raven and Axelrod 1978) cannot apply where deciduous and

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evergreen species are sympatric, as in Israel and California. For instance, evergreen chaparral is often found upslope from blue oak woodland (Baker and others 1981, Vankat 1982), where conditions are cooler and wetter. In Israel, the tabor is thought to be less cold tolerant than the evergreen kermes oak (*Q. calliprinos*), which ranges to higher elevations.

Blumler (1984) pointed out that the "edaphic climate" exerts a critical control on plant distribution where summer drought is extreme. If edaphics moderate drought seasonality (as on coarse, rocky, or infertile substrates), one typically finds evergreen shrub associations. If not, one encounters deciduous park forest, bunchgrass/annual communities, or, in the most extreme cases such as vernal pools, pure stands of annuals. For instance, although evergreen sclerophylls often grow intermixed with blue oak, the latter is more important on relatively fine-textured soils and open slopes that dry out most completely in summer (Gartner and others 1957, Griffin 1977). On the Santa Rosa Plateau, coast live oak is more common around rock outcroppings and less common in open soil than the engelmann oak (Snow 1972). In Israel, the major control on distribution in the lowlands is edaphic: the tabor and other winter-deciduous species occur primarily on heavier, more fertile soils that often dry out to a greater degree in summer than those supporting maquis (Eig 1933, Kutiel and others 1979, Litav and Orshan 1971, Oppenheimer 1950, Rabinovitch-Vin 1983).

ADVANTAGES OF DECIDUOUS HABIT

How is it possible that winter-deciduous species could achieve a competitive advantage under severe summer drought conditions? First, they seem to be drought-deciduous, dropping their leaves in late summer or even earlier if under extreme stress (Diamantoglou and others 1989, Griffin 1973, McCreary 1990). Sclerophylls do not lose their leaves so readily (Griffin 1973), perhaps because there would be a greater cost to the plant than in a deciduous species that is programmed to withdraw nutrients prior to abscission; but once the deciduous species has lost its leaves, it is in a better position to resist drought than the evergreen. Where summer drought is severe, optimum growing conditions prevail in late spring, and conditions become progressively less favorable until soil moisture recharges with the next winter's rains; fall-winter photosynthesis in evergreen species may be limited not only by low light but also by low moisture, and a positive carbon budget may not always be possible. Thus, leaf loss in late summer or fall may be more efficient than sclerophylly (Griffin 1973). This is especially likely if cool winter temperatures further reduce potential photosynthetic rate (even if there is no actual damage to plant tissue from frost).

Second, deciduous species inherently have more rapid maximum photosynthetic rates (Mooney 1983), and may be able to grow as rapidly on an annual basis as evergreens, despite being leafless for part of the year (Mooney and Dunn 1970b). Deciduous oaks typically produce soft leaves in spring, which become progressively tougher (more drought resistant) over the course of the summer. Thus, they are able to take full advantage of the abundant moisture and warm temperatures of late spring. Evergreen sclerophylls necessarily photosynthesize less rapidly at that time, although they are able to maintain a relatively stable rate throughout the year. This suggests that evergreens are best adapted to relatively mild temperature fluctuations and absence of a pronounced, predictable, annual boom and bust cycle of potential photosynthesis. If this is so, they also should be best adapted to semi-arid conditions in which dry spells are relatively short, while deciduous taxa may be better adapted to long, seasonal droughts. Hence, one can find sclerophyllous shrublands also in non-mediterranean, subtropical semi-arid climates (e.g., Freitag 1971, Keeley and Keeley 1988, Minnich 1985).

Finally, deciduous taxa, unlike some evergreen sclerophylls, seem to germinate and grow through the critical first winter (Griffin and Muick 1990, Matsuda and McBride 1986, Matsuda and others 1989). Their high growth rate probably increases their competitive ability against fast-growing herbs. Most woody seedlings do poorly in direct competition with annual grasses on fertile soils (Blumler 1984, da Silva and Bartolome 1984, Gordon and others 1989, Kaplan 1984, Litav and others 1963, Schultz and others 1955), but evergreen sclerophylls presumably are even weaker seedling competitors than deciduous taxa. Hence, one might predict that they could be completely excluded if summer-dry woodlands are open enough to support a vigorous, herbaceous vegetation. For example, Griffin (1976) found that valley oak seedlings were killed primarily by browsing and only slightly affected by grass competition, while evergreen oaks were little affected by browsing but established primarily in shade. Because it has very large acorns, valley oak is probably more competitive than blue oak (studied by Gordon and others). However, it is a plausible hypothesis that even the blue oak is more resistant to herbaceous competition than are evergreen species.

Environmental history (climatic change) also has probably played an important role. Much of the Near East would have experienced extremely cold winters during glacial periods (van Zeist 1967, Wright 1962), and perhaps sclerophylls would be more widespread today if they had not been eliminated at those times. Similarly, the present distribution of California oaks may be partly a function of Pleistocene climates. However, environmental history cannot explain the failure of evergreen species to replace deciduous ones where distributions have been sympatric for thousands of years. For instance, evergreen and deciduous oaks were both present in Israel by the Late Pleistocene (Henry 1989, Horowitz and Gat 1984). In any event, it is unlikely that winter-deciduousness evolved in response to extreme mediterranean climate; rather, species such as the blue oak were presumably pre-adapted to summer drought, just as were the evergreen sclerophylls that make up the chaparral and maquis.

Additional considerations determine sclerophyll distribution. Sclerophylls are stress-tolerators in Grime's (1977, 1979)

tripartite system. Thus, photosynthetic rate in shade is higher than that of deciduous species, while it is much less in sun. Also, as is well-known, sclerophylly is associated with soil infertility (Beadle 1966, Chapin 1980, Mooney 1983). Of course, summer drought is moderated in shade and on infertile soils (Blumler 1984). Finally, adult sclerophylls have much better sprouting ability than deciduous species; however, this may not be true of seedlings (Snow 1980).

A PRELIMINARY MODEL

A preliminary model of the conditions favoring winter-deciduous and broadleaved evergreen sclerophyllous shrubs and trees in mediterranean regions is presented here:

Environment	Deciduous	Evergreen
Cold winters	x	
Mild winters		x
Hot summers	x	
Mild summers		x
Summer rain		x
No summer rain	x	
Heavy soil texture	x	
Coarse soil		x
Fertile soil	x	x
Infertile soil		
Rock		x
Herbaceous cover	x	
Shade		x
Sun		x
Browsing of dense stands	x	
open stands	x	
Fire in dense stands		x
open stands	x	

The predictions of the model can be treated as a series of hypotheses to be tested, since only a few have been verified sufficiently. Deciduous plants are predicted to perform well where summers are hot, winters cold, summer drought severe, soil fertile or heavy, competition from herbaceous vegetation intense, and/or stand density is low; evergreen sclerophylls should be favored if summers and winters are mild, some summer rain occurs, soils are infertile, herbaceous competition is limited, and/or seedlings are shaded. In addition, fire in dense stands should favor sclerophylls because adults resprout better than deciduous plants. Fires may favor the latter if woody vegetation is sparse because adult mortality will be low and because immature deciduous plants may resprout as well as or better than evergreens. Browsing or cutting should favor adult sclerophylls, but may also favor immature deciduous plants.

MANAGEMENT IMPLICATIONS

The major management implications of the model are that dense woodlands are likely to become dominated by evergreen species, while frequent fire may be a means of maintaining deciduous park forest. These conclusions seem to be in line with available evidence on regeneration patterns in California (Griffin 1971, 1976, 1977, McClaren and Bartolome 1989, Muick and Bartolome 1987). At the same time, it is also possible that establishment occurs primarily during recruitment "windows" that open when conditions suddenly change. For instance, removal of cattle from an area that had been heavily grazed might be followed by an interval of several years during which herbaceous vegetation recovered and browsers and acorn seed eaters increased in numbers. During that short period of time, establishment might be excellent. Such possibilities are ignored in this model.

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Thematic Mapper Analysis of Blue Oak (*Quercus douglasii*) in Central California[1]

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Abstract: Digital Thematic Mapper (TM) satellite data from September 1986 and December 1985 were analyzed to determine seasonal reflectance properties of blue oak rangeland in the La Panza mountains of San Luis Obispo County. Linear regression analysis was conducted to examine relationships between TM reflectance and oak canopy cover, basal area, and site topographic variables. September reflectance in TM3 was strongly negatively correlated with oak canopy cover (r^2=0.62), less strongly related to oak basal area or density (r^2=0.2-0.4). December reflectance was not as strongly correlated as September reflectance. These results indicate that late summer TM data can be used effectively to monitor oak cover in California's rangelands, even in rugged environments.

California Blue Oak (*Quercus douglasii* H. & A.) is the dominant overstory species over a large portion of rangelands in California. In recent years, the long-term viability of this species under modern land use regimes has been called into question. Regeneration of blue oaks appears to be impeded by a combination of factors (Borchert and others, 1989), and management of the rangeland where blue oak is most common is being reviewed. A detailed inventory of the current status of the species is necessary for future management planning, as well as to provide a baseline for monitoring.

Digital satellite imagery is the most economical and objective source of data currently available for mapping and monitoring oak woodland over large areas. There are presently four satellite-borne sensors providing synoptic coverage of California. These are the NOAA Advanced Very High Resolution Radiometer (AVHRR), the French satellite SPOT, and the Landsat Multi-Spectral Scanner (MSS) and Thematic Mapper (TM). The data provided by AVHRR is not of sufficient spatial resolution (1.1 Km) for detailed analysis of the highly variable landscapes typical of blue oak habitats. Landsat MSS provides coverage at 80 m. resolution with four spectral bands, and SPOT HRV provides coverage at 20 m. resolution in three multispectral bands, as well as a panchromatic channel with 10 m. resolution. Landsat thematic Mapper data has been used successfully to map blue oak woodlands (Brockhaus and Pillsbury, 1987). The 30m spatial resolution of TM is well suited for mapping complex vegetation mosaics and its high spectral dimensionality, including three visible, one near-infrared, and two mid-infrared channels, allows good discrimination of natural vegetation types. Although the use of TM data for mapping blue oak stand types has been demonstrated, the sensor also has the potential to provide quantitative information on stand characteristics such as basal area and crown closure. Much work is needed to test and calibrate TM data for this purpose. In this paper we evaluate the potential of TM data for estimating basal area and crown closure over rugged terrain.

STUDY AREA

The study area is located in the La Panza Range of southern San Luis Obispo County, California, and covers two diagonally adjacent 7.5 minute USGS quadrangles, Pozo Summit and Los Machos Hills (figure 1). Over 90 percent of the study region lies within Los Padres National Forest. The climate is Mediterranean, with warm, dry summers and mild, wet winters. Average annual precipitation at Pozo, on the western edge of the study region, is 527 mm, most of which falls between November and March. Temperatures range from 0 to 25 degrees Celsius. Elevations range from 300 - 1175 m, with the lower elevations characterized by long rows of steep, rolling hills incised by lower-order intermittent streams and drainage gullies. Study plots were selected to include the entire range of slopes and aspects present in the region. Regional vegetation is a mosaic of mixed chaparral, chamise chaparral, coastal sage scrub, grassland, valley oak savanna, blue oak woodland and blue oak/digger pine woodland and forest.

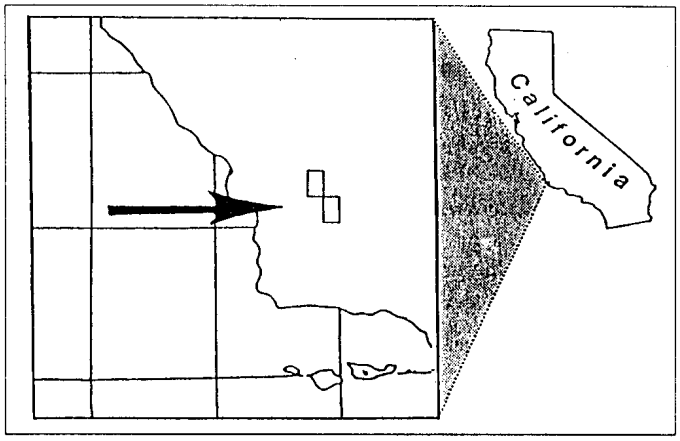


Figure 1—Location of Study Area.

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Oak woodlands and grasslands, which occupy approximately 40 percent of the area, have been grazed by cattle to varying degrees throughout most of this century. Most private and public lands are still grazed, and grazing intensity is highly variable spatially and from year to year. Management of the area is oriented toward rangeland production, wildlife habitat protection, and watershed protection.

FIELD METHODS

Field measurements of slope angle, slope aspect, and tree basal area were collected during spring and summer, 1987 in 84 plots 60 by 60 m scattered throughout the project area. Forty-six plots were sampled by U.S. Forest Service ecologists for a related project, and 36 additional plots were collected for this study. Plots were located to sample the range of stand densities (including non-wooded grassland) and terrain conditions in the study area, and were centered in stands of relatively homogeneous physical and vegetational characteristics. Shrub cover did not exceed 10 percent in any of the sample plots.

Diameter at breast height was measured for all trees that occurred within a 0.1 acre (407 m^2) circular subplot centered in the 60 by 60 m plot. Estimates of overstory crown cover were obtained from 1:24,000 color stereo air photos acquired September, 1983. Crown cover within each plot was measured by magnifying the air photos to 1:8,000 and estimating total tree canopy cover (5 percent cover classes) by dot count of a 10 m grid.

Image Processing

Satellite data available for use in the study were from Landsat 5 Thematic Mapper path 42, row 36, for two dates: one scene from December 14, 1984, and the other from September 15, 1986. Both scenes were of good quality; however the September 1986 scene had some cloud cover, with approximately 10 percent cloud cover within the study area. Two subimages were extracted from each date of imagery corresponding to the Los Machos Hills and Pozo Summit topographic quadrangles. Twelve ground control points were used to register the subimages to each of the two 7.5 minute topographic maps using a first-order linear transformation. Radiance data were corrected for atmospheric effects by dark pixel subtraction (Moik 1980) based on near-IR reflectance from a nearby reservoir. We used this somewhat crude correction method because our analyses were concerned chiefly with relative pixel radiances in single bands rather than absolute radiance or reflectance values. Median radiances in all bands except the thermal band (TM 6) were extracted for a 2 by 2 window centered on each field plot.

DATA ANALYSIS

Correlation analysis and stepwise multiple regression were used to measure the association between oak canopy cover or basal area and the following variables: DN values for TM bands (excluding TM 6) in September and December, the first four principal components of the original spectral data for each data (based on the correlation matrix for sampled pixels), the Normalized Difference Vegetation Index (NDVI, (TM4 - TM3)/(TM4 + TM3)), and plot slope orientation. Slope orientation was expressed as (sin(slope angle))x(cos(slope aspect)), with aspect measured in degrees from north. This index ranges from -1 for a vertical south-facing slope to 1 for a vertical north-facing slope.

RESULTS

In September all TM bands and the first principal component of the bands were negatively correlated with oak canopy cover, with r-values ranging from -0.76 to -0.82. Correlations were slightly lower but still highly significant between tree cover and December spectral data (table 1). NDVI was positively correlated with oak canopy cover in September when oaks were in leaf and the understory was senescent, and weakly negatively correlated with oak cover in December when oaks were leafless and the understory was greening up.

Table 1— ***Correlations (r) of spectral data and oak canopy cover and basal area for September and December TM imagery. All correlations are significant at p<0.01.***

Spectral Band	Oak Canopy Cover	Oak Basal Area	Northness
September			
TM1	-0.79	-0.52	-0.46
TM2	-0.81	-0.53	-0.45
TM3	-0.83	-0.55	-0.44
TM4	-0.76	-0.46	-0.41
TM5	-0.82	-0.47	-0.45
TM7	-0.79	-0.46	-0.44
NDVI	0.73	0.47	0.42
PC1	-0.82	-0.41	-0.46
December			
TM1	-0.77	-0.41	-0.65
TM2	-0.72	-0.40	-0.68
TM3	-0.73	-0.38	-0.67
TM4	-0.67	-0.37	-0.67
TM5	-0.73	-0.37	-0.67
TM7	-0.74	-0.39	-0.65
NDVI	-0.28	0.13	0.17
PC1	-0.72	-0.40	-0.68

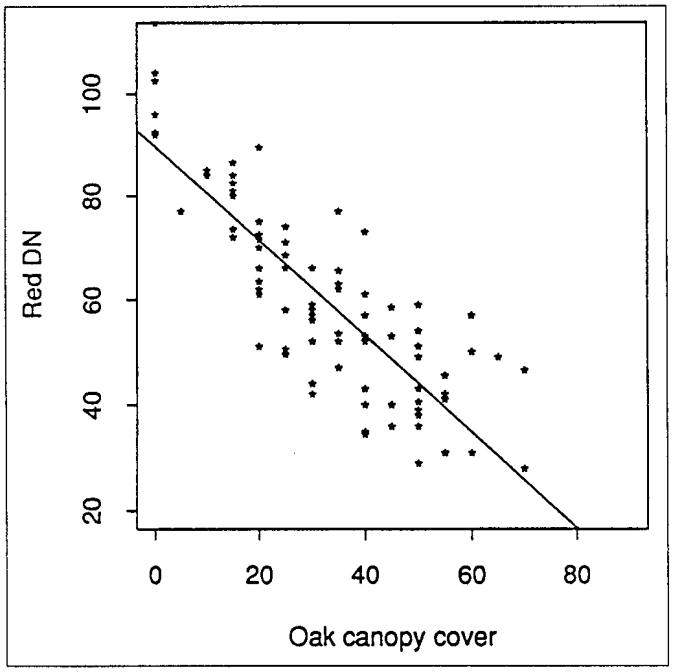


Figure 2—Regression of September TM3 radiances against photointerpreted oak canopy cover.

Spectral data were not as highly correlated with plot basal area as with tree canopy cover (table 1). This is due to the relatively weak relationship between tree canopy cover and basal area ($r = 0.62$, $p<0.01$).

Tree cover was significantly positively associated with slope orientation ($r=0.52$, $p<0.01$), with highest cover on steep north-facing slopes. TM DN values were negatively correlated with slope orientation, especially in the December scene, when topographic variation in illumination was relatively high (solar zenith angle = 66 degrees, solar azimuth = 146 degrees at the time of scene acquisition). Thus the strong negative correlations between TM data and oak cover could be partly due to the association of oak cover and topography.

Multiple regression analysis indicated that there was little predictive skill added by using more than one spectral band to predict oak canopy cover or basal area. This was mainly due to the high intercorrelation among the spectral channels (e.g., the first principal component accounted for 89.2 percent of the total variance in the September TM data). Thus, a simple regression of September TM 3 (red) versus cover proved to be the best model for predicting crown cover from the spectral data (Figure 2). No improvement was obtained through the use of multi-data imagery. The results were also not improved by transformations of the data.

DISCUSSION

Satellite monitoring of tree canopy cover in California's blue oak woodlands is feasible using simple correlative models, even in relatively homogeneous terrain with variable ground layer conditions. Tree cover is highly correlated with radiance in all TM bands in summer and winter imagery, without any compensation for varying illumination on sloping terrain. The high correlation can be attributed to a number of effects that vary depending on the season of image acquisition. In late summer, oak canopies are in leaf and the herb layer is dry and highly reflective. Canopy light absorptance and shadowing of the understory combine to create a strong negative relationship between pixel brightness and tree cover. The relationship is strengthened by the tendency for greater tree cover on north-facing slopes, where shadowing of the understory by tree canopies is greater.

In early winter, the leafless tree canopies are relatively dark against a background of thatch and emerging herbs. Light interception by the tree canopies is presumably much reduced, but tree shadowing of the understory is proportionally greater at the lower winter sun angles. Perhaps more important is the positive associations of tree cover with slopes receiving less sunlight at low winter sun angles.

A number of factors may have operated to reduce the correlation between tree cover and spectral data, most importantly: errors in registering imagery to field measurements, low precision and errors in estimating tree canopy cover in the air photos, spectral variation in the understory layer due to differences in composition, condition and illumination, and variations in tree canopy reflectance associated with leaf density and condition. Field reflectance measurements of the blue oak woodlands and grasslands are needed to isolate the relative importance of these sources of error.

In conclusion, our results are highly promising and indicate that both distribution and canopy structure of blue oak woodlands can be monitored with single-date TM data. Late summer imagery appears especially well-suited to meet these objectives.

ACKNOWLEDGMENTS:

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Historical Mortality of Valley Oak (Quercus lobata, Nee) in the Santa Ynez Valley, Santa Barbara County, 1938-1989[1]

Rodney W. Brown Frank W. Davis[2]

Abstract: The range and abundance of valley oak (*Quercus lobata*, Née) have steadily decreased in the last 100 years due to low rates of regeneration during this period. Documented low rates of sapling recruitment must be compared to adult mortality rates in order to evaluate the severity of this decline. The purpose of this research is to measure and analyze the mortality rate of established valley oaks in different habitat types over the past 51 years. Valley oak stands of the Santa Ynez Valley in Santa Barbara County were mapped and stratified into three major habitat types: valley floor alluvium, lower hillslopes and swales, and rolling uplands. Mortality rates of canopy individuals in each habitat type were determined for a sample of 600 valley oaks censused in 1938 aerial photography and re-censused in 1954,1967,1978, and 1989.125 of 600 (20.8 percent) sampled individuals disappeared during the 51 year period. No new individuals were recruited into the canopy layer during this time. The average mortality rate between 1938 and 1989 was 0.45 deaths/100 trees/year. Mortality rates were highly variable within and among habitat types, and were not strongly associated with precipitation or human population increases in the Santa Ynez Valley during the study period. High mortality between 1967 and 1978 coincides with the lowest groundwater levels in the 51 year study period.

Jepson (1910) and other botanists in the early 1900's first noted that the valley oak produced the most abundant crops of acorns of the western oaks, yet was the least successful in regeneration. The reasons proposed for this failure are varied and complex, and will not be reviewed in this paper (see Borchert and others 1989, Dutzi 1979, Griffin 1971, 1976 & 1980, and Rossi 1979). Whatever the causes for low sapling recruitment rates of the valley oak, these rates must be compared to the rates of adult mortality in order to evaluate whether the species is declining within its range, and if so, to measure the rate of decline. Valley oak stands in the Santa Ynez Valley, like many others statewide, exhibit a skewed size distribution. Populations are dominated by scattered large individuals (which we refer to as "established trees"). Rare saplings tend to occur at the margins of stands, in fence rows, or neighboring shrublands (Bolsinger 1988, Calloway 1990). Mortality of established trees thus represents, at least for the present, a thinning process ultimately resulting in a treeless grassland.

Scheidlinger and Zedler (1980) used aerial coverage from 1928 and 1970 to measure change in canopy cover of coast live oak stands in southern San Diego County. We have analyzed historical aerial photography to measure the mortality rates of valley oaks in different habitat types over the past 51 years and to investigate how mortality varies among sites, habitats, and time periods.

METHODS

Valley oak stands of uniform vegetation composition and environmental conditions in the upper Santa Ynez Valley of Santa Barbara County were first identified and mapped on U.S. Geological Survey 1:24,000 7.5 minute quadrangle maps using 1:24,000 color and 1:40,000 color infrared air photos from 1978. We used recent photography to delineate stands in order to exclude areas converted to other land use or land cover types. The mortality rates reported here are thus conservative and assumed to be due to natural death rather than removal by humans. All areas mapped as valley oak stands from the air photos were verified in the field. Only pure valley oak stands were retained in the analysis.

The non-contiguous study area encompassed 3,171 hectares located on the following four topographic quadrangles: Figueroa Mountain, Lake Cachuma, Los Olivos, and Santa Ynez. Stand density varied from a high of 1.40 trees/acre to a low of 0.23 trees/acre. This study area contained several habitat types including valley floor alluvium, lower hillslopes and swales, and rolling uplands. Elevations ranged from 158 m to 427 m. Most of the area is underlain by Quaternary deposits dominated by alluvium, terraces, and Paso Robles conglomerates (Dibblee 1950, 1966).

We used a stratified random design to sample 600 trees in 12 stands. The study area was divided into the three habitat types of valley floor alluvium, lower hillslopes and swales, and rolling uplands. Plastic overlays were made for the photos from the 1938 base flight (Fairchild Aerial Surveys flight C-4950, 1938, 1:24,000 black and white paper prints) and the study area outline was transferred to these overlays. Twelve stands were sampled at random, including five in valley floor alluvium, four in lower hillslopes and swales, and three in rolling uplands. Three stands

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in the valley floor alluvium were cultivated cropland, and two were used for pasture.

We identified and mapped the 50 valley oaks closest to a point located randomly in each stand (the minimum size of trees that could be reliably detected was between 10 and 15 meter crown diameter). Once trees were mapped in the 1938 images, frame overlays were constructed for the 1954 photos (U.S. Department of Agriculture flight BTM-PMA-6-53-DC item 3, 1954, 1:20,000 black and white paper prints, flown by Pacific Air Industries). Each sampled individual from the 1938 flight was noted as alive or dead/missing in 1954.

The above procedure was repeated using photos from 1967 (U.S. Department of Agriculture flight BTM, invitation #ASCS 9-67 DC item 6, 1967, 1:20,000 black and white paper prints, flown by Western Aerial Contractors, Inc.), 1978 (U.S. Department of Agriculture flight USDA-24-615070, solicitation #ASCS/FS-11-78 SLC item 3, 1978, 1:24,000 natural color paper prints, flown by Pacific Aerial Surveys; and U.S. Department of Agriculture flight USDA-40-06083, invitation #ASCS 12-78 SLC item 1, 1978, 1:40,000 color infrared positive transparencies, flown by Pacific Aerial Surveys), and 1989 (Pacific Western Aerial Surveys flight PW-SB 7,1989,1:24,000, natural color positive transparencies, flown by I.K. Curtis).

Mortality rates were expressed as deaths per 100 trees per year. We calculated mortality rates for each period by dividing the number of deaths by the number of individuals at the start of the census period and by the number of years in the period, and multiplying that number by 100 (this is a conservative estimate of mortality, as the denominator neglects the decrease in number of trees over the census period). Two models of mortality were used to project future decreases in population: 1) mortality independent of population size, in which the number of survivors was modeled as a linear function of time ($N_t = N_0$ d*t, where N_t is the number of survivors at time t years from the 1938 census, N_0 is the number of individuals at the start of the period, and d is the decrease in number of remaining individuals per year). This model implies an increasing mortality rate as the number of remaining individuals decreases linearly through time; 2) constant mortality rate ($N_t = N_0 * \exp(rt)$). This model implies a curvilinear decrease in trees through time.

The Kruskal-Wallis non-parametric statistic was used to test for significant differences in mortality rates among time periods and habitat types. Also, mortality rates for each period were qualitatively compared to precipitation, ground water and Bureau of Census population data.

RESULTS

During the 51 year time span of this study, 125 of the 600 sampled individuals disappeared, for an overall mortality rate of 0.45 +/- 0.22 deaths/100 trees/year (table 1). By habitat type, individuals in valley floor alluvium fared the worst, with a mean mortality rate of 0.54 +/- 0.33 trees/100/year. Mortality rates were extremely variable among stands in this habitat type (fig. 1a) and did not differ systematically between cropland and pasture land use. Individuals within the lower hillslopes and swales and rolling uplands habitats showed similar and less variable mortality rates of 0.33 +/- 0.15 and 0.29 +/- 0.13 trees/100/year respectively (fig. lb). Differences in mortality rates among habitat types were not significant based on rank statistics.

There was considerable variation in mortality rates both within and between sampling periods (fig. 2). Differences among periods were not significant based on rank statistics. A larger

Sample	Habitat		1938-1954	1954-1967	1967-1978	1978-1989	Mean	SD
1	Valley alluvium	Cropland	2.00	0.45	0.85	0.31		
2	Valley alluvium	Cropland	0.75	0.35	1.08	0.00		
3	Valley alluvium	Cropland	0.38	0.16	0.20	0.20		
4	Valley alluvium	Pasture	1.00	1.65	0.55	1.17		
5	Valley alluvium	Pasture	0.13	0.16	0.19	0.39	0.54	0.33
6	Lower Hillslopes		0.00	1.08	0.63	0.68		
7	Lower Hillslopes		0.00	0.15	1.67	0.00		
8	Lower Hillslopes		0.00	0.15	0.56	0.00		
9	Lower Hillslopes		0.50	0.33	0.21	0.00	0.33	0.15
10	Rolling Uplands		0.25	0.48	0.00	0.00		
11	Rolling Uplands		0.75	0.17	0.42	0.44		
12	Rolling Uplands		0.13	0.16	0.57	0.20	0.29	0.13
Mean (SD)			0.49 (0.58)	0.44 (0.46)	0.58 (0.46)	0.28 (0.36)	0.45	(0.22)

Table 1—*Summary mortality statistics for 12 valley oak stands in the Santa Ynez Valley between 1938 and 1989, organized by habitat type and time period. Rates are expressed as mean deaths/100 individuals/year (SD-standard deviation).*

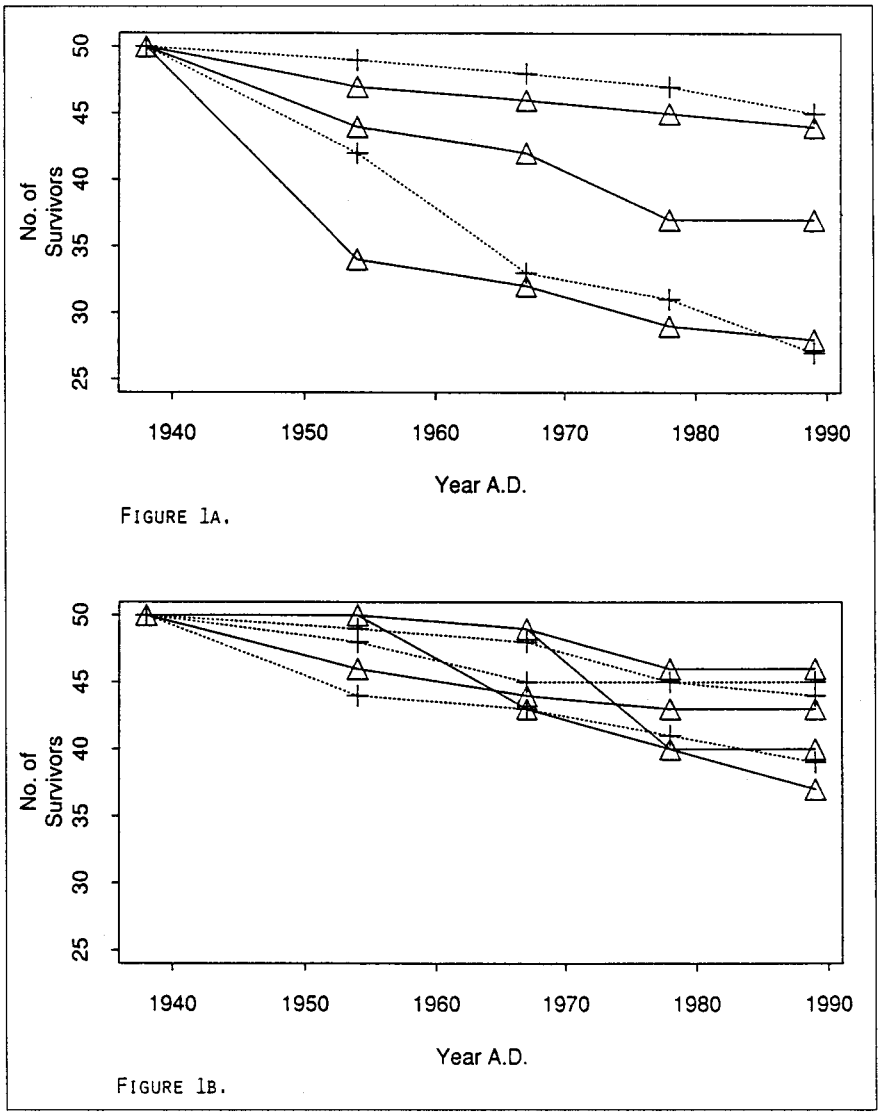


Figure 1—Survivorship curves for valley oak stands (50 trees per stand) in the upper Santa Ynez valley between 1938 and 1989. Habitat types include valley floor alluvium (Figure 1a; cropland (triangles) and pasture (crosses)), lower hillslopes and swales (Figure 1b (triangles)) and rolling uplands (Figure lb (crosses)).

sample size would be necessary to isolate any apparent interaction between habitat type and time period. Average annual and seasonal precipitation did not vary significantly among the sampling periods (mean annual precipitation = 39.3 cm). Ground water data collected within the study area between 1941 and 1990 did show fluctuations, though these fluctuations varied considerably depending on the location of the test well (fig. 3). Both wells closest to the sampled stands gradually declined to minimum elevations in the mid to late 1960's. The historically low ground water levels of this period (94 feet and 111 feet below the surface) may have contributed to the high valley oak mortality rate between 1967 and 1978. The distances to ground water at the minimum well elevations greatly exceeded the estimated maximum depth of valley oak tap roots of 66 feet (Griffin 1973).

It is interesting to examine human population growth in the upper Santa Ynez Valley during this century (fig. 4). This region has shown remarkable growth in population especially since 1950. However, this population growth is not associated with the mortality rates in valley oak stands that have remained under the same land use.

Variable mortality rates among stands make it impossible to determine with certainty whether valley oak mortality during the period 1938-1989 was density-dependent or density-independent. However, the best fit to all of the survivorship data (12 stands, 4 census periods per stand) was obtained using the simple,

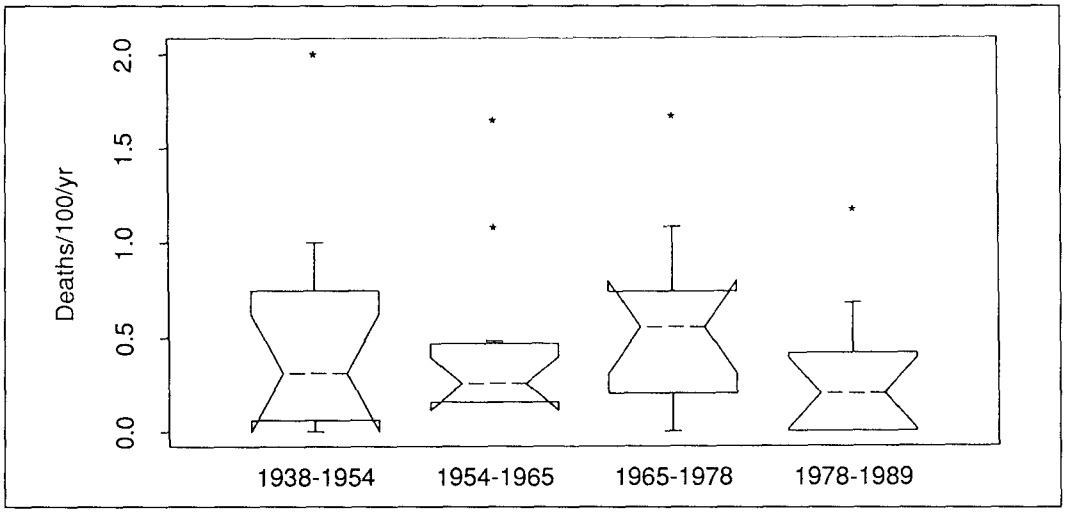


Figure 2—Box plots showing the distribution of valley oak mortality among 12 stands during four time periods. Boxes show the median (dashed line) and quartiles (upper and lower horizontal lines) of of the data, the ranges (vertical lines) and outliers (asterisks). Overlap between notched portions of the boxes indicates no significant difference among the means for each period at the 95% level.

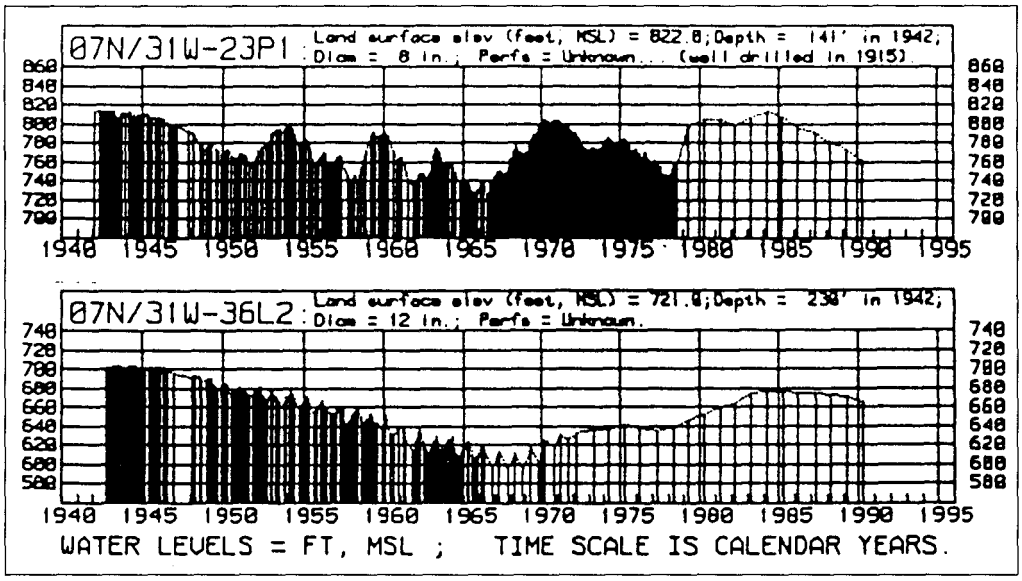


Figure 3—Ground water elevations (feet above mean sea level) in two wells near Los Olivos in the upper Santa Ynez valley between 1940 and 1990 (data courtesy of the Santa Barbara County Water Agency).

density-independent model, which was obtained by least squares regression: N_t= -0.21 *t - 49.7 (r^2 = 0.38, p < 0.01). The density-independent mortality for the 12 stands, with a starting stand size of 50 trees, ranged from 0.90 trees/year/stand to 0.16 trees/year/stand, averaging 0.41 trees/year/stand. At the higher loss rate, which applied to 2 of 12 stands. the 600 trees censused in 1938 would decline to 0 by the year 2026 (fig. 5a). At the average loss rate, the population would be reduced by *50%* by the year 2060. Different results were obtained with the density-dependent model: the maximum mortality rate for a stand was 1.09 deaths/100 trees/year, and the average was 0.45 deaths/1 00/year. Using this standard demographic model, the maximum rate yielded a population decrease by a factor of two every 64 years (fig 5b), and the mean rate yielded a similar decrease every 156 years.

DISCUSSION

Mortality rates reported here may underestimate actual rates for some periods due to the censusing of standing, recently dead individuals. Also, the analyses here presume no age depen-

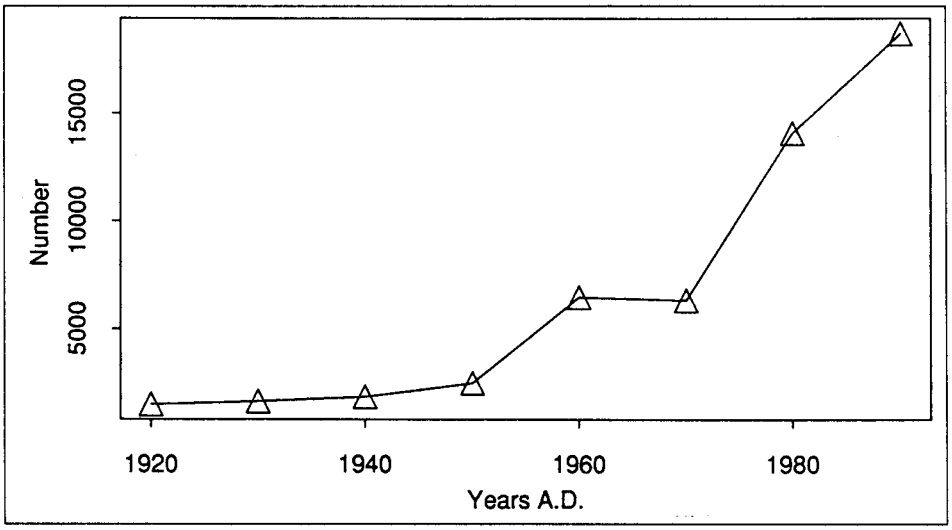


Figure 4—Human population growth In the upper Santa Ynez valley between 1920 and 1990 (U.S. Bureau of the Census). 1990 population is projected by the Santa Barbara County Cities Area Planning Council.

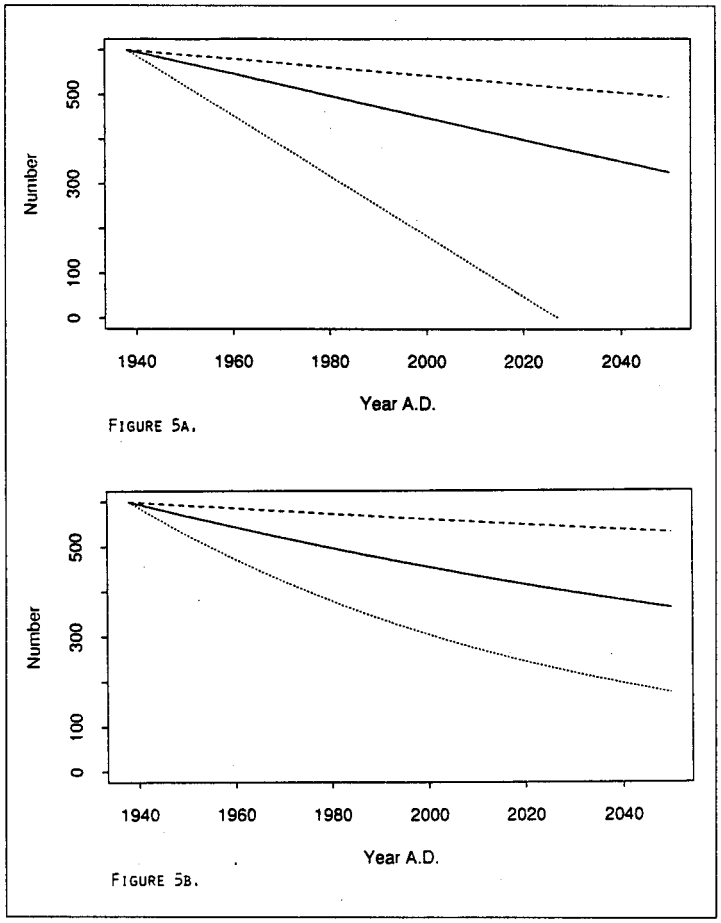


Figure 5—Projected numbers of the sample of 600 valley oaks from 1938 to 2050 based on simple linear decrease of trees through time (Figure 5a), and constant mortality rate through time (Figure 5b). Solid line is based on the average mortality rate as measured in 12 stands, and dotted and broken lines are based on the maximum and minimum rates respectively.

dence in mortality. It would be useful to conduct actual age structure analyses of these stands. However, many of the large valley oaks in the upper Santa Ynez valley are hollow and therefore their age cannot be determined precisely. Finally, due to the wide variation of mortality rates among the stands, a much larger sample size may be necessary to detect significant environmental associations with mortality. There is a strong need for comparative studies in other valley oak habitat areas.

Presumably, the mortality rates for very young and very old individuals are considerably higher than those shown here. Given the best estimate of valley oak life span at 350 years (Elias 1980, Jepson 1910), density and age independent mortality in a sample of 600 valley oaks would be 1.71 trees/year, or 87 individuals over the 51 year period. The actual decline of 125 individuals of the sample population was 44 percent over this expected mortality.

This study shows a steady decline in the valley oak population with no obvious, consistent trend in mortality rates between 1938 and 1989. Given the relatively high mortality and lack of recruitment of canopy individuals over the past 50 years, it appears that an active program of sapling propagation is necessary to maintain or increase the size of the existing valley oak populations of the region.

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Monitoring Insect and Disease Impacts on Rangeland Oaks in California[1]

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Abstract: We developed methods to assess the impacts of diseases and arthropods on sapling and mature rangeland oaks, and applied these methods at 18 sample plot locations in northern California. The impact of arthropod damage was generally rated as minor. Leafy mistletoe (*Phoradendron villosum*) was found on 5 percent of the rated trees. There was a slight correlation between mistletoe infestation levels and dieback ratings. Characteristic canker rot symptoms were seen in 9 percent of the trees surveyed, and 16 percent of the trees had at least 20 percent of the bole volume decayed by fungi. In *Quercus douglasii,* the percentage of trees showing more than 20 percent wood decay in the bole differed significantly between locations, ranging from 0 to almost 43 percent. Canker rot fungi and other wood decay fungi were the most significant agents affecting health and survival of rangeland oaks.

Significant insect and disease impacts were noted in some of the earliest treatises on oaks in California (Sudworth 1908, Jepson 1910), and have been reviewed by Brown (1980) and Raabe (1980). More recently, we completed an extensive review of the published literature and unpublished collection records on diseases and arthropods reported to attack oaks in California (Swiecki and others 1990). Data on the geographic distribution, characteristics, and taxonomy of the agents, symptomatology of the oak-agent interaction, and bibliographic information on the source of each report has been compiled into a computerized database, the California Oak Disease and Arthropod (CODA) Host Index. This database presently contains information on 780 arthropods, 200 disease agents, and over 200 saprophytic fungi known to occur on oaks in California (Swiecki and others 1990).

Even though information on the occurrence of diseases and arthropods is extensive, little information has been compiled on the relative importance and overall impacts of diseases and arthropods on rangeland oaks. Since California oaks have generally not been considered commercial timber species, most of the existing information on the diseases and arthropods that affect California oaks is based on trees in landscape settings.

The purpose of this study was to provide baseline data on the levels of damage and mortality associated with diseases and arthropods in undeveloped oak woodlands and savannahs. It is essential to have such baseline data to monitor changes in the condition of oak resources that occur over time as the result of either natural conditions or cultural practices. We developed, adapted, and tested sampling and rating methods to assess the impacts of diseases and arthropods on rangeland oak stands containing blue oak (*Quercus douglasii* Hook. & Am.).

METHODS

Two series of plots, located in northern California, were surveyed in this study. One series of plots were permanent inventory plots established by the Forest Inventory and Analysis (FIA) Research Work Unit of the USDA Forest Service Pacific Northwest Research Station (Bolsinger 1988, McKay 1987). In 1989 we surveyed eight of these plots, which were selected for the presence of blue oak.

In addition to the above plots, nine plots were surveyed at locations where we had established seedling study plots (Swiecki and others, these proceedings). These plot locations were selected for the presence of blue oak seedlings, without consideration of the tree overstory. Therefore, while not a truly random sample, these plots constitute a relatively unbiased sample with respect to overstory tree condition. One additional plot (2001001) in Alameda county was specifically selected to document the very poor condition of the stand in the area. Data from this plot have been excluded from certain analyses as noted. Locations of all plots are shown in figure 1.

To ensure compatibility with existing survey data, the layout of all new plots was based on the methods used by the FIA. Each field plot consists of five subplots distributed across 2 ha. We normally collected complete tree data on at least two 16 m (0.08 ha) fixed-radius subplots for each plot. Complete tree ratings were usually limited to the first 20 trees in each subplot, and only mortality was rated for the remainder of the subplot. Trees in the remaining three subplots in each plot were rated only for mistletoe and dieback. Data on key site characteristics were collected following FIA methods with some minor modifications and additions, or compiled from published sources (Swiecki and others 1990).

Data on tree characteristics, condition, and injury factors were collected on standardized data sheets. Characteristics noted for each tree included species, age class (mature or sapling), form class (seedling or sprout origin), canopy class, and diameter at 1.37 m height (diameter at breast height, DBH) for mature trees or basal diameter for saplings. Oaks with basal diameters of at least 1 cm and DBH of 1 cm or less were assigned

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to the sapling age class. Canopy classes were the same as those described in the FIA methods. In order of increased shading by other trees, the canopy classes used were: open grown, dominant, codominant, intermediate, and overtopped. Dead trees within each plot were also tallied, and were categorized by visual estimate as having died within the past 10 years or not.

For symptoms that could be rated on the basis of the percentage of the tree which was affected, the following 0 - 6 pretransformed percentage scale (Little and Hills 1978) was used:

Rating:	Percentage interval	Interval midpoint (pct)
0	None visible	0
1	Trace to 2.5	0.6
2	>2.5 to 20	9.5
3	>20 to 50	34.5
4	>50 to 80	65.5
5	>80 to 97.5	90.5
6	>97.5	99.4

For some characteristics that could not be readily estimated on a percentage basis, we used the following scale to rate the probability that symptoms would have a significant negative impact on tree health or survival:

Rating:	Probability of significant negative impact
0	no apparent impact
1	low probability
2	moderate probability
3	high probability

In plots where complete tree ratings were taken, symptoms rated and scales used were as follows:

Characteristic rated:	Rating scale	Location within tree
Mistletoe density	0-6	Canopy
Live and dead mistletoes clumps	count	Canopy
Density of epicormic branches	0--none 1= infrequent 2= numerous	Canopy, trunk
Canopy thinning	0=no, 2=yes	Canopy
Overall dieback	0-6	Canopy
Branch flagging (current season)	0=none, 1=present	Canopy
Impact of cankers	0-3	Canopy, trunk
Wood decay	0-6	Canopy, trunk
Impact of wounds	0-3	Canopy, trunk
Foliar arthropod damage	0-6	Canopy
Impact of other arthropods	0-3	Canopy, trunk
Twig and stem gall density	0-6	Canopy
Impact of woody galls	0-3	Trunk

The identity of causal agents associated with damage was coded when known. Trunk data was not collected for oaks in the sapling age class.

For purposes of data analysis, a composite injury index variable was calculated for each individual tree as the sum of all of the above ratings except the number of mistletoe plants. The injury index was not calculated if data from any of the included ratings were missing.

For categorical data, we used Fisher's exact test or the chi-square statistic to test the significance of differences in contingency tables. General linear model analysis of variance (SAS Institute, Inc. 1988) was used to test for differences between oak species, plot locations, age classes and crown classes for pretransformed ratings and the composite injury index. Regression analysis was also used to test for correlations between selected variables. Unless otherwise noted, significant differences and effects are significant at $P < 0.05$.

RESULTS

Approximately 75 percent of the trees rated were *Q. douglasii,* including a small percentage (2.1 percent) of suspected hybrids with other white oaks. Approximately 20 percent of the oaks rated were in the black oak subgenus, the majority of which were interior live oak (*Q. wislizenii* A. DC.) and coast live oak (*Q. agrifolia* Née). Basal area varied significantly with canopy class, and was greatest in dominant and open grown trees, and smallest in overtopped trees. Saplings comprised 12.9 percent of the sampled trees. The live oaks were more commonly scored as being of sprout origin (46 percent for *Q. wislizenii,* 18 percent for *Q. agrifolia*) than was *Q. douglasii* (5 percent). Approximately half of the 1035 trees sampled received complete ratings, while the other half were scored for mistletoe and dieback only.

Visible fungal sporulation was relatively uncommon on sampled trees, but species of *Stereum, Inonotus,* and *Hypoxylon* were occasionally identified within plots. Foliar damage caused by insects and/or mites was present on virtually every tree examined, and symptoms included chewing, window feeding, stippling, blotch and serpentine mines, and galls caused by cynipid wasps and eriophyid mites. Insect groups directly observed on rated trees were primarily Homoptera, including aphids, whiteflies, and pit scales, although Tussock moth pupae and lepidopterous larvae were occasionally observed. However, the percentage of leaf area affected by foliar feeding insects was normally quite low, and was usually rated as less than 2.5 percent. Levels of foliar damage did not differ significantly between saplings and mature trees.

Twig galls, usually caused by cynipid wasps, were also commonly observed but very seldom involved enough of the canopy to have a significant impact on tree health. Wood boring by buprestid and cerambycid beetle larvae and other insects was common, but was usually restricted to dead or dying branches in the canopy. Arthropod damage to the trunk was primarily due to wood borers and termites. These insects most commonly invaded through wounds or cankers, and were often associated with decayed wood. In most cases, their impact was rated as minor (fig. 2A) but occasionally their activities were sufficient

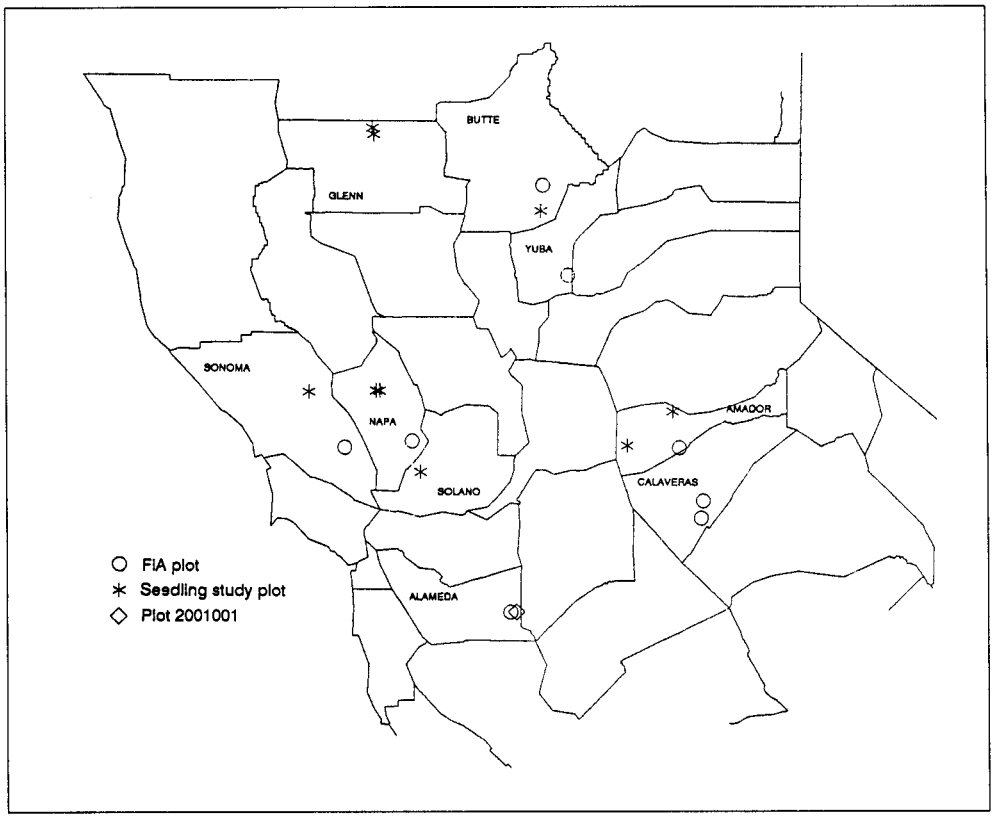


Figure 1—Locations of surveyed plots by type.

to cause significant structural weakening of affected trees. Significant levels of insect damage to the trunk were more common in the live oaks than in blue oak (fig. 2A).

Leafy mistletoe (*Phoradendron villosum* [Nutt.] Nutt.) occurred in the vicinity of 14 out of 18 plots surveyed, but was found in only 5 percent of over 1000 trees rated. It was not found in any of the 107 saplings rated. Mistletoe did not occur in any of the 50 *Q. agrifolia* trees we sampled, but was found at similar frequencies in *Q. douglasii* (4.6 percent, n=777) and *Q. wislizenii* (7.3 percent, n=138). More than one mistletoe clump was present in about 75 percent of infected trees, and up to 30 live mistletoe clumps were found in a single tree. Average mistletoe density ratings and numbers of mistletoe plants were significantly greater ($P<.01$) in open grown and dominant trees than in codominant, intermediate, or overtopped trees. Among mistletoe-infested trees, there was a slight positive correlation between mistletoe density rating and dieback rating ($r^2=.105$, $P=.039$), and heavy mistletoe infections were frequently associated with dieback. Dead mistletoe plants were found in about half of the infected trees.

Dieback rating varied significantly by plot, oak species, and crown class. Among the three oak species best represented in our sample, the average dieback rating was greatest for *Q. wislizenii* (fig. 2B). Unlike many other damage variables, the distribution of dieback ratings approximated a normal distribution. No obvious geographic trends were seen in dieback ratings. Average dieback ratings differed significantly between canopy classes, and were greatest in overtopped trees. Overall, average levels of dieback were significantly higher in the mature tree size class (2.5 ± 1.1) than in the sapling class (2.2 ± 1.5).

Although it was not possible to definitively diagnose the causes of canopy dieback for all trees rated, our field observations do not implicate any single cause overall. Shading in dense stands and overtopped trees appeared to be a major cause of branch decline and dieback in blue oak. Dieback was also common in blue oaks that showed symptoms of water stress, had canker rot symptoms, or were heavily colonized by mistletoe. Fungi and insects that specifically attack twigs or branches did not appear to be the primary cause of branch dieback in most cases, although boring insects and decay fungi were common on dead and declining branches.

Excluding data from the biased plot 2001001, 8.9 percent of the oaks receiving complete ratings showed characteristic canker rot symptoms, and an additional 2 percent had other cankers that may have been caused by canker rot fungi. The incidence of canker rot symptoms varied significantly between plots, ranging from 0 to 44.6 percent. Symptoms and fruiting bodies of canker rot fungi were also found in the vicinity of several plots where no canker rot was tallied within the plots. Excluding plot 2001001, canker impact was rated as moderate to high in 12.9 percent of tree canopies and 13.4 percent of tree trunks. Among live trees, average dieback rating was significantly higher ($P<.001$) in oaks with canker rot symptoms (2.8 ± 1.0) than in those without canker rot symptoms ($2.3 \pm .9$).

Excluding data from plot 2001001, approximately 26 percent of the oaks rated had trunk decay ratings of at least 2, and

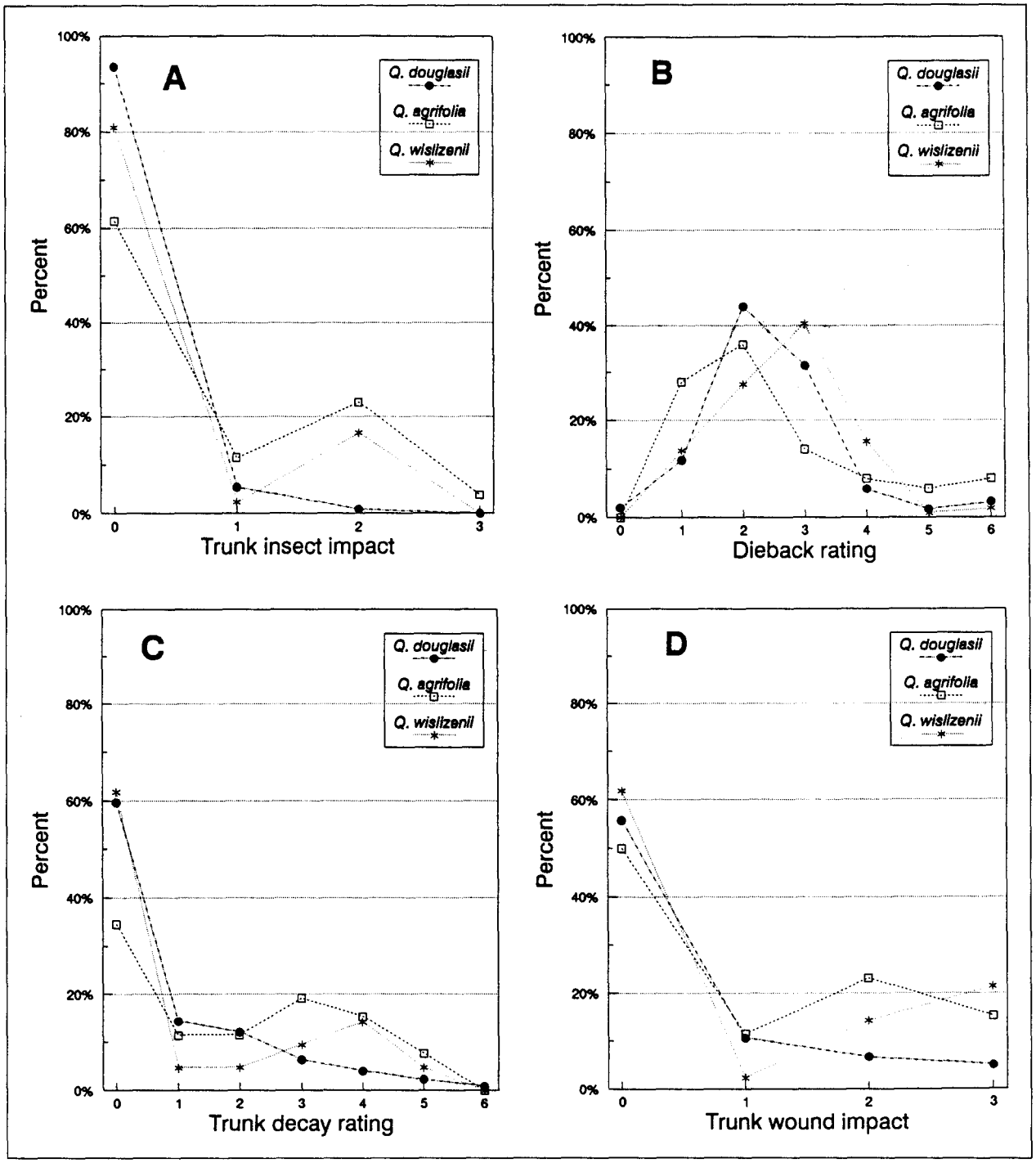


Figure 2—Frequency distributions of damage variables by oak species. A, Trunk insect impact rating. B, Dieback rating. C, Trunk decay rating. D, Trunk wound impact rating.

16 percent had trunk decay ratings of at least 3. Average trunk decay ratings were significantly greater in *Q. agrifolia* than in *Q. wislizenii* and *Q. douglasii,* but the live oaks *Q. agrifolia* and *Q. wislizenii* showed similar bimodal distributions of decay levels (fig. 2C). Trunk decay was associated with wounds in 40.7 percent of all trees rated, and the incidence of severe trunk wounds was also greater in *Q. agrifolia* and *Q. wislizenii* (fig. 2D). In *Q. douglasii,* trunk decay ratings differed significantly between plots and by canopy class, with the greatest levels of trunk decay occurring in dominant trees. The incidence of *Q. douglasii* trees with at least 20 percent of the trunk decayed ranged from 0 to almost 43 percent in the plots we surveyed. More than 1 out of 5 blue oaks had at least 20 percent trunk decay in 5 of the plots we rated.

Even though plot 2001001 was selected for rating because it showed severe disease impacts, most disease levels in this plot were within the range of the 17 randomly selected plots. Average ratings for mistletoe density, dieback, and condition, as

well as the incidences of canker rot and trunk decay ratings greater than 2, were all near the maximum levels observed among the other plots.

Ten-year mortality rates were estimated for each plot based on the number of trees that were judged to have died within the previous 10 years. Estimated mortality rates per decade ranged from 0 in seven of the 18 plots, to a high of 12.5 percent at plot 2001001. These estimated rates are likely to underestimate actual mortality in areas where dead trees are removed for firewood or are consumed in ground fires and cannot be tallied. Estimated 10-year plot mortality rates showed low correlations with canker rot incidence in live trees (r^2=.039) or average trunk decay ratings (r^2=.044).

DISCUSSION

Survey Methods and Ratings

Since no general disease and insect surveys have previously been conducted for rangeland oaks in California, we developed our rating system without prior knowledge of the agents that would be the most significant. Therefore, most of our ratings focused on damage symptoms rather than individual causal agents. We took this approach because tree condition is often affected by a complex of biotic and abiotic factors acting simultaneously or in sequence. The precise effects of individual agents or factors often cannot be partitioned out without a detailed study, which is impractical in an extensive survey. Symptoms such as dieback and flagging are not specific to a single agent, and can be caused by arthropods, pathogens, or abiotic factors. Other symptoms, including thinning and epicormic branching, are indicators of tree vigor which also do not correspond to attack by specific agents. Symptoms such as cankers and wood decay are normally caused by fungal pathogens, but the specific causal agent is not usually known. However, our rating system does allow for coding the identity of specific agents when they can be associated with a particular type of damage. Thus, the rating system allows us to rate tree condition without exact knowledge of each agent involved, yet provides for the capture of additional information on specific agents where possible.

Our rating system emphasizes damage to woody tissues, especially the larger branches and trunk. The integrity of these structural members is critical to the survival of the tree, whereas fine twigs and leaves are more readily replaced. While high levels of foliar damage can have a substantial impact on tree health, the condition of foliage may vary widely from year to year and even month to month. Therefore, it may not be meaningful to compare or summarize foliar damage levels from plots sampled in different months or years. In contrast, the condition of the trunk and larger branches normally changes much more slowly, so that valid comparisons can be made between plots sampled at different times. Moreover, the effects of previous pest, disease, and environmental impacts are integrated to some degree in the condition of the larger woody tissues, so their condition is a reasonable gauge of cumulative impacts.

The methods we developed and tested form the basis for future assessments of disease and arthropod impacts in California oak woodlands. These methods provide a standardized framework for characterizing disease and arthropod levels within oak stands. When used with permanent plots, these evaluation methods also provide a means for monitoring the change in the condition of individual trees over time. This information could be applied to estimate the rate of tree decline.

By coupling these tree condition assessments with site information, it is possible to examine the relationship between damage caused by diseases and arthropods and environmental factors or cultural practices. We were able to detect significant correlations between tree condition ratings and various site factors even though our sample size is somewhat limited (Swiecki and others 1990). Information on these relationships could have important applications in the development of management models and guidelines for California's oak woodlands.

Disease and Arthropod Impacts

The level of damage caused by arthropods to mature trees was relatively low in the plots we surveyed. Damage caused by foliar-feeding insects was generally low, and oak pit scale (*Asterolecanium* spp.), which is regarded as a significant pest of oaks in urban areas (Koehler and others 1977), was rarely encountered in our plots. Wood boring insects, though common, usually appeared to be acting as secondary pests, attacking weakened or wounded tissues. However, insect population levels can vary greatly between years, locations, and host species. Thus, although insect damage was generally below levels that significantly affected oak health and survival in the areas we sampled, these results should not be extrapolated to imply that insect damage is unimportant in *Q. douglasii* or other native oaks.

Leafy mistletoe was the only agent that was the specific focus of particular rating criteria. It is a conspicuous and readily quantifiable pathogen which has the potential to significantly affect oak health. Our survey methodology was modified specifically to increase the sample size for trees rated for mistletoe. However, mistletoe was detected somewhat inefficiently even with this increased sampling intensity, due to its clumped spatial distribution (Thompson and Mahall 1983) and its relatively low overall frequency.

Significant dieback was only associated with moderately high levels of mistletoe infestation. Therefore, only trees with multiple infections are likely to be adversely affected by mistletoe. As reported by Thompson and Mahall (1983), we observed that among mistletoe infected trees, the incidence of multiple infection was high. We observed the highest levels of mistletoe infection in open grown and dominant trees, which also have the largest trunk diameters. Similarly, Thompson and Mahall

(1983) observed that oaks with larger basal areas were more likely to be infected by mistletoe, although they did not consider canopy class. These results suggest that open grown and dominant oaks are most likely to be impacted by leafy mistletoe. Furthermore, since trees in these crown classes are visually prominent, the incidence and overall importance of mistletoe is likely to be overestimated by casual observations.

The levels of decay we found in blue oak were somewhat higher than those we calculated from the FIA database records (Swiecki and others 1990), but correspond with levels reported in the early literature. Both Jepson (1910) and Sudworth (1908) comment on the high levels of heartwood decay in blue oak in their descriptions of the species. Jepson (1910) notes that in some areas, 33 to 66 percent of the blue oaks were "badly rotted". Based on these historical accounts and our own observations (Swiecki and others 1990), we believe that moderate to high levels of decay are characteristic of mature and overmature blue oak stands. Most of the canker rot and other decay fungi affecting oaks in California are not limited to a single oak species, and wood decay was common in most of the oak species we observed.

As decay progresses, there is an increase in the severity of nonspecific decline symptoms such as canopy dieback and thinning. In addition, failure of large branches in blue oak and other oak species is often due to extensive wood decay, a relationship that was also noted by Jepson (1910). These breaks commonly extend into sound wood, opening new wounds that are subject to infection, furthering disease progress and tree decline.

Due to their high pathogenic potential (Sinclair and others 1987) and relatively high rates of incidence, the canker rot fungi and other wood decay fungi rank as the most important agents affecting oak health and survival in the plots we surveyed. Canker rot and other decay fungi have long been recognized as important pathogens of oaks in the southeastern U.S. (Hepting 1971). However, their role as primary oak pathogens in California has been largely overlooked in spite of or perhaps because of their ubiquity.

Wood-decay fungi are mostly slow-acting pathogens whose progress can be intermittently slowed or halted by host defense reactions including compartmentalization (Sinclair and others 1987). The rate of decay may be accelerated in trees under stress due to environmental or cultural conditions such as drought, severe overgrazing, fire, and changes in the soil water table. Since site conditions can significantly affect the rate of disease progress and tree decline, we were not surprised to find low correlations between estimated mortality rates and decay and canker rot incidence. We believe that although environmental and cultural factors may increase or synchronize oak decline and mortality in an area, canker rots and other wood decay fungi normally play a primary causal role in the decline of mature oaks in California (Swiecki and others 1990). Further information on the factors affecting infection and disease progress will improve our understanding of oak woodland ecology, and may have important implications for the future management of oak stands.

ACKNOWLEDGMENTS

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Inventory of Commercial Hardwoods in the High Sierra[1]

Norman H. Pillsbury George L. McCaskill[2]

Abstract: A hardwood resources assessment was completed for the Sierra Economic Development District in the north central Sierra Nevada. The assessment included the development of a tree grading system for the major hardwood species in the area, an inventory of the hardwood resources, and recommendations for hardwood management. Hardwood volumes of total wood available for utilization per acre were found to be low for stands classified in the Blue oak-Interior live oak association, moderate in the Black oak - Canyon live oak association, and high in the Madrone association. The volumes by species and grade reveals that madrone stands produce a relatively high amount of merchantable timber, while black oak stands produce moderate levels.

The purpose of this study was to determine the potential for a hardwood industry in the north central Sierra. The study area is defined as the counties of Amador, El Dorado, Nevada, Placer, and Sierra. In the study area, it is estimated that 548,000 acres are covered in hardwood woodlands or commercial timberland (Bolsinger, 1986). The study involved assessing the hardwood resource base to determine the quantity and quality by species of the product in the region.

The study's further objective was to develop management techniques to enhance and perpetuate the species that were found to be commercially abundant in order to establish a viable hardwood industry.

The species sampled in this study include: bigleaf maple (*Acer macrophyllum* Pursh), Pacific madrone (*Arbutus menziesii* Pursh), tanoak *(Lithocarpus densiflorus* (Hook. &Am.) Rehd.), canyon live oak (*Quercus chrysolepis* Liebm.), blue oak (*Quercus douglasii* Hook. & Am.), Oregon white oak (*Quercus garryana* Dougl.), California black oak (*Quercus kelloggii* Newb.), interior live oak (*Quercus wislizenii* A. DC.). White alder (*Alnus rhombifolia* Bong.) occurs in the area but represents less than one percent of the volume. It was included in the inventory, but not in the tree grading estimates, since there are already well established log grading rules for the genus.

BACKGROUND

California hardwood stumpage prices are low compared to their eastern counterparts. The low prices are a result of a perception that the hardwoods consist of limited supplies, small log sizes, and inferior quality. A recently completed assessment of this resource, however, has produced data which indicates that those perceptions may be false. Hardwood forests cover 9.6 million acres in California. The total volume of these trees are estimated to exceed 18 billion cubic feet. Of the hardwood trees over 29 inches in diameter, California has 19 percent of the nation's growing stock (Bolsinger 1986).

New information about hardwood distribution, the volume of standing timber, and the potential for producing different kinds of wood products, has recently encouraged resource specialists to consider greater use of California's hardwood resources (Passof 1986). Methods for determining the wood quality of local hardwood tree species is greatly needed.

A local tree grading system allows the landowner to determine the value of his hardwood resources, while providing a means to compare those values with other sources of lumber; and it improves the precision of a timber appraisal by allowing a value to be placed on hardwood trees based upon timber quality. This process will also aid future land managers, loggers and lumber processors to identify new sources of timber (Rast, Sonderman and Hilt 1986).

PROBLEM STATEMENT

The annual harvest of California's softwood resources amount to over 95 percent of its annual growing stock (Bolsinger, 1986). As a result, any additional demand for more wood products will severely strain that resource. It is possible that future needs for more wood products will be met by harvesting hardwoods rather than softwoods. Total volume of the commercial hardwood in California is estimated to be 25 billion board feet. The annual harvest amounts to less than 5 percent of the state's annual growth.

Information about the quality of California's hardwoods is meager. Data on quality as well as the quantity of high quality hardwoods should be obtained prior to the development of the hardwood resource. A constraint in evaluating California's

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

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hardwood resources was the lack of a tree grading system or rules to define a high quality hardwood tree (Rast and others 1986).

Objectives

The primary goal was to determine the commercial potential of hardwood resources on private land. A second goal was to determine the quality of the hardwood resource by developing a tree grading system.

In order to assess the hardwood resource base and develop management prescriptions, the following objectives were formulated:

1) To complete a broadly based inventory of the hardwood woodland areas in the counties of the High Sierra Resource Conservation and Development Area. Information on stand type and volume by log grade, crown density, and acreage was obtained in stands having a canopy cover of 33 pct or more;

2) To develop management recommendations for the major hardwood associations found in the study area;

3) To develop a tree grading system that will account for the high degree of variability in hardwood stands in the study area.

HARDWOOD RESOURCES OF THE STUDY AREA

In the study area, most stands of pure hardwoods are found below the 5000 foot level. As a result, the study area included only the western half of Amador, El Dorado, Placer and Nevada. An extensive field reconnaissance confirmed that very few hardwoods were found above 5000' and therefore, no inventory was attempted in Sierra county.

The remaining four counties are characterized by long, hot summers and cool winters with light snow below 5000' elevation. The topography is often steep, rugged and dissected by deep river drainages. Hardwood species are abundant on the warmer, drier south and western aspects. Hardwood stands with high crown densities are found in the transition zone between the mountains and the foothills. Most of the hardwoods can be found within the 580 foot to 4,700 foot elevation range (McDonald, Minore and Atzet 1983).

Three broad hardwood types, based on the Wildlife Habitat Rating Program are found in this area (Mayer and Laudenslayer 1988). They are the Valley-Foothill Hardwood type, the Montane Hardwood type and the Montane Hardwood-Conifer type.

HARDWOOD TIMBERLAND INVENTORY

Development of California Hardwood Tree Grading System

The local grading system used to evaluate the quality of standing hardwood timber was modified from eastern hardwood tree grading rules (USDA-Forest Service) to accommodate California's hardwoods. This modified system was simpler to follow, with final specifications based upon tree measurements collected during the study's reconnaissance cruise.

The grading section minimum length was reduced to an eight foot section compared to 12 feet used in the east, because local wood processors indicated that shorter lengths could be used if the log diameter was large enough.

In order to simplify the grading rules, single minimum diameters and minimum lengths of clear cuttings for the specifications in each of the tree grade categories were used.

Because of the greater variability found within the Sierra hardwood populations, the specifications for dbh and the number of defect indicators found on the grading section were given wider ranges (table 1).

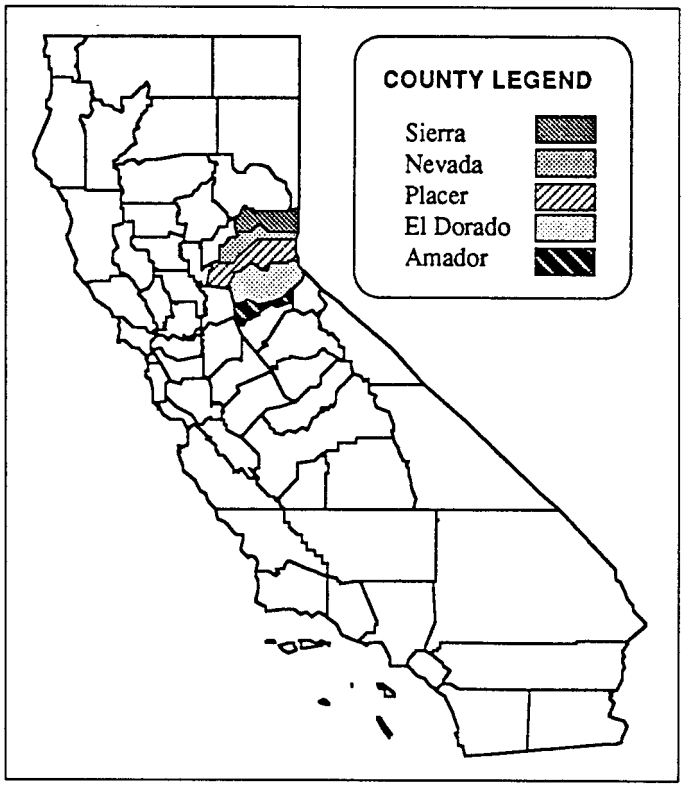


Figure 1—Five county study area of the Sierra Economic Development District in California.

Table 1—Hardwood tree grading rules developed and used in this study.

Grade Factor	Tree Grade 1	Tree Grade 2	Tree Grade 3
Length of grading section (ft.)	16	Best 12	Best 8
Minimum dib top of grading zone (in.)	14	12	10
Dbh, minimum (in.)	16	14	12
Total number of defect indicators (best of three faces)	6	9	12
Maximum number of defect indicators per face (best of three faces)	2	3	4
Minimum length of clear face (best of three faces)	8	6	4

The length of the grading zone for all grades is 16 feet. Defect indicators include: Sweep (>8 inches in 16-foot length); Crook; Rot and Seams; Knots>0.5-inch diameter; Overgrowth; Overgrowths with epicormic branches; Fire scars.

Field procedure for tree grading is as follows (figure 2):

1) Measure the diameter-breast-height (dbh) to the nearest inch;

2) Establish the location of all defect indicators on the surface of the 16 foot butt log, and then locate the best 8 foot section;

3) Estimate the diameter-inside-bark (dib) at the top of the 16 foot grading zone to the nearest inch; and

4) Estimate the amount of defect by percentage in the 8 foot section.

The grade of the 8 foot section becomes the grade for the tree, unless the grade can be improved by using a 12 or 16 foot section (figures 3-4) (McCaskill and Pillsbury 1990).

The Hardwood Resource Assessment Methodology

Because of the extensive size of the study area (five counties), a cluster-plot inventory was designed to insure that enough sampling units of the population were included. A total of 56 cluster plots were selected and plotted on county maps. Plots were located in stands greater than 5 acres so that a four plot cluster could be installed with a 50 foot buffer zone.

For inventory purposes, the sample stands were stratified by crown closure density classes so that stands with the greatest commercial potential (crown density classes > 33 pct) would be included in the study. Maps developed by the Forest & Rangeland Resources Assessment Program (FRRAP; Calif. Dept. Forestry & Fire Protection) were used to stratify hardwood stands.

Cluster plots were established to collect detailed information about individual trees, plot area descriptors, tree associated vegetation, and the quality of standing timber. Each cluster consisted of four plots, arranged in a "+" shape, with each of the legs being oriented in a cardinal direction.

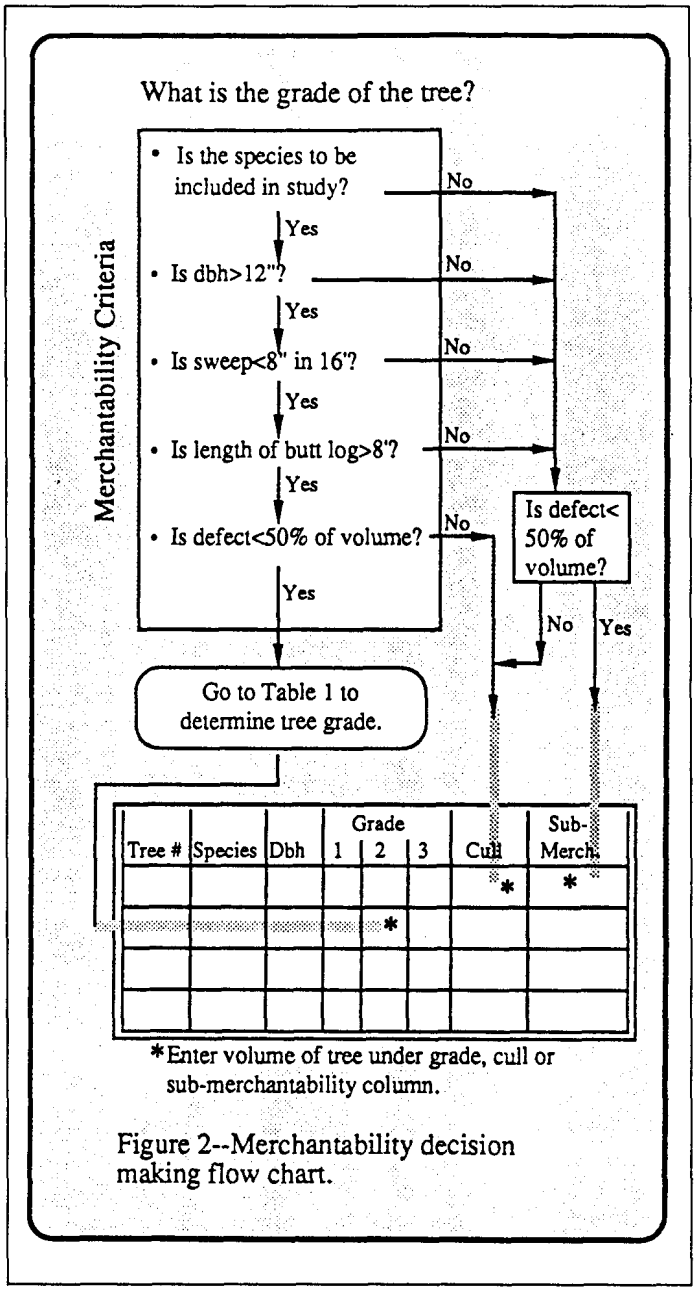


Figure 2--Merchantability decision making flow chart.

Figure 2—Merchantability decision making flow chart.

To begin, a reconnaissance cruise of the different strata (density classes) was conducted so that a sampling system could be designed that met statistically acceptable standards and was representative of the population.

Variable plot sampling was used to select the sample trees. A prism with a ten square foot basal area factor was used for the inventory based on the results of the reconnaissance cruise. Volume data was collected at one of the four plots in the cluster. The volume measurement plot was selected randomly by the use of a die. Information on diameter at breast height, height, vigor, and crown closure was recorded. Tree volume was calculated from this data.

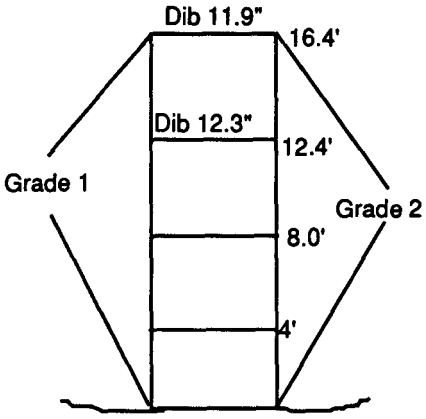


Figure 3—Relationship between dib (diameter inside bark) and tree grade. The dib at 16 feet 4 inches above the stump is not large enough for grade 1. However, at 12 feet, the dib meets grade 2 requirements.

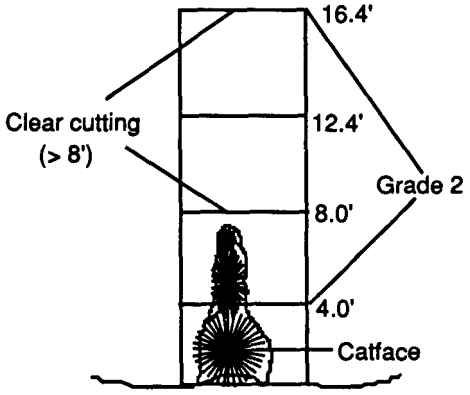


Figure 4—Effect of catface on tree grade. Because of catface, the surface is grade 2 and not grade 1. If total cull is less than 50 percent, retain the tree grade at 2.

Volume per Acre Determination

The following steps were used to process and summarize the field data:

1) The plot sheets were arranged in numerical sequence and the information was tallied by species, diameter class, and grade.

2) The gross volume by species and log grade was calculated using the volume equations for California hardwoods (McDonald 1983) and (Pillsbury and Kirkley 1984);

3) The cruise data was summarized showing gross volumes by species and log grade;

4) The cruise data was grouped into hardwood associations for analysis;

5) The diameter class information was tallied and used to determine the average diameters per species;

6) The determination of cubic foot and Scribner board foot volumes per acre from variable plot sampling methodology was calculated.

RESULTS

Based on field observations and data analysis, three hardwood associations were developed; that is, certain hardwood species were found to have similar habitats, ranges, and common grading qualities. The three hardwood species associations are the Blue Oak - Interior Live Oak Association, the Black Oak - Canyon Live Oak Association, and the Madrone Association. The Association names were based on those hardwood species that were found most often growing in the same stands (table 2).

Table 2—Species composition in percent by species association.

Species	Blue oak-Interior live oak	Black oak-Canyon live oak	Madrone
Canyon live oak	7.0	24.0	7.0
Interior live oak	42.0	6.0	
Black oak	1.0	66.0	1.0
Blue oak	47.0	1.5	
Madrone		2.0	75.0
Tanoak	3.0		8.0
Oregon white oak			7.0
White alder		0.5	0.5
Big leaf maple			1.5
	100.0	100.0	100.0

The Hardwood Resource Assessment

The hardwood sample included 2,117 trees measured on 56 cluster-plots. This was an average of 9.5 trees per plot. Black oak had the highest tree count with 694 trees tallied. Interior live oak, canyon live oak, and blue oak had similar sample sizes; with 399, 339, 377 trees measured, respectively. Madrone, which was found to occupy only a small proportion of the study area had 268 trees measured.

Approximately 539 trees were graded for form and defect. The merchantability of each tree was determined by diameter size and log length.

Table 3—The percentage of each species by grade.

Species	Grade 1	Grade 2	Grade 3	Cull	Sub-Merch.
Canyon live oak	3.2	12.9	16.1	19.4	48.4
Interior live oak	0.0	2.9	1.0	11.5	84.6
Black oak	7.5	19.9	18.4	13.9	40.3
Blue oak	0.0	3.2	13.8	7.4	75.6
Madrone	12.3	18.4	24.6	10.8	33.9

Hardwood Volumes

The cubic foot and board foot volumes/acre were calculated for the three hardwood associations (table 4a). All cubic foot volumes/acre estimates fell within the ranges tabulated in the statewide assessment (Bolsinger 1986) for the five major hardwood species of this study. The Madrone Association volumes were twice as high as Black Oak - Canyon Live Oak Association and over four times higher than Blue Oak - Interior Live Oak Association. The inventory also produced results showing the existence of large diameter trees that compared favorable with the statewide data.

Madrone produced the greatest amount of merchantable volume (grades 1-3), over 8000 board feet per acre (table 5). Black oak had about 2500 board feet per acre. Common characteristics that might account for the relatively high merchantable volumes per acre pure stands and average diameters larger than the minimum required for merchantable grading. Blue oak, interior live oak, and canyon live oak had very low volumes in merchantable timber, reflecting their smaller diameters and poorer forms.

This method can be used to assist the landowner in appraising hardwood resources.

Summary of Results

The hardwood timber inventory concentrated on the higher density stands. The tree grading focused on those hardwood species with the greatest potential for wood utilization. From the work on the hardwood inventory and evaluating applying the local tree grading rules, the research yielded these results:

1) Three unique hardwood species associations were identified based on common range, habitat and grading characteristics;

2) A local hardwood tree grading system for evaluating California woodlands in the Sierras was developed;

3) An assessment was completed of the hardwood volume per acre in the Sierra Economic Development District area by species, associations, and tree grade.

CONCLUSION AND RECOMMENDATIONS

The purpose of conducting a feasibility study of the hardwood resource base of the area was to determine if there was sufficient quantity and quality to develop a value-added hardwood industry. It was found that a viable hardwood industry is possible in the study area. However, the methods discussed here must be used on a site-by-site basis to assess each property.

The assessment design provided sample data from both medium (34 pct-75 pct crown cover) and high density stands. This allowed us to determine the potential for commercial management and product development.

Species composition and diameter at breast height (dbh) were found to be the best indicators for evaluating the commercial potential of a hardwood stand. The results of the study showed that the major hardwood species in the study area were black oak, blue oak, canyon live oak, interior live and madrone. All other hardwood species investigated in the study were found to be a minor component of the total population.

The study grouped specific hardwood species into associations based on common habitats, ranges, and similar grading qualities. The study identified three associations: The Blue Oak - Interior Live Oak; the Black Oak - Canyon Live Oak; and the Madrone Associations. These hardwood associations are found in larger vegetative groups such as the Valley-Foothill Hardwood, Montane Hardwood, and Montane- Hardwood-Conifer types of the Wildlife Habitat Relationship (WHR) program (Mayer and Laudenslayer 1988).

Table 4—A comparison of hardwood volumes with the statewide assessment.

	Hardwood Volumes by Association		Statewide Data (Bolsinger 1986)		
Hardwood Association	Mean Volume (c.f.)	Mean Volume (b.f./ac.)	Species	Mean Volume (c.f.)	Maximum Volume (c.f.)
Blue Oak/Interior Live Oak	964	2896	Blue oak	381	1767
Black Oak/Canyon Live Oak	2229	6879	Interior live	612	3779
Madrone	4330	11133	Canyon live	1503	4128
			Black oak	1213	4000
			Madrone	1705	4519

Table 5—Hardwood volumes by species and grade.

Species	Grade 1 (b.f./ac.)	Grade 2 (b.f./ac.)	Grade 3 (b.f./ac.)	Cull (b.f./ac.)	Submerch. (b.f./ac.)	Tot.* (b.f./ac.)
Blue oak	0	32	238	95	1104	1469
Black oak	444	1176	1054	817	910	4401
Canyon live oak	9	30	51	50	119	259
Interior live oak	0	38	18	234	955	1245
Madrone	1532	3465	3320	538	473	9328

* The species volumes in this table are a component of the volume of their hardwood association.

The primary difference between those vegetative classifications and the system used in this study, was that in addition to considering similar habitats and ranges, comparable tree grading qualities were also used as criteria for finding hardwood associations that could be identified. This additional guideline enhances a resource manager's ability to develop specific timber management recommendations for the various hardwood woodland types found in the study area.

Hardwood Quality

The tree grading process produced data showing that blue oak and interior live oak trees contained little merchantable timber. This is especially noteworthy because only the medium and high density stands were sampled. Canyon live oak results were highly variable, but about 35 percent of the trees were of merchantable quality. The majority of the black oak and madrone trees were classified as merchantable. It was also observed that black oak and madrone stands frequently contained trees with merchantable sized diameters. Canyon live oak was near the 12 in requirement, and blue oak - interior live oak mixtures were dominated with diameters of sub-merchantable sizes.

When considering both diameter and grading for each species, it was concluded that madrone, black oak and possibly canyon live oak trees had commercial potential for producing a variety of wood products. However, the major wood product possible for blue oak and interior live oak remains fuelwood until a more efficient technology becomes available.

If a land manager compared the medium and high density stands for each hardwood association, he will see that the Blue Oak - Interior Live Oak Association contained a majority of hardwoods with inadequate tree size or form, while the Black Oak - Canyon Live Oak and Madrone Associations have a majority of hardwoods with sufficient tree quality to be managed for commercial lumber production.

Hardwood Volumes

Hardwood volumes per acre by association for medium and high density stands indicated the Blue Oak - Interior Live Oak Association had a low level volume, Black Oak - Canyon Live Oak had a moderate level, and the Madrone Association had high volume of total wood available for utilization.

The volumes per acre by species and grade revealed that madrone stands produced a relatively high amount of merchantable timber, while black oak stands produced moderate levels. Merchantable sized timber was almost non-existent in blue oak - interior live oak, and pure canyon live oak stands.

Recommendations for Management of Hardwood Associations

The Blue Oak - Interior Live Oak Association should be managed to insure adequate regeneration, particularly the erratic and highly predator-susceptible acorn production of the blue oak. Acorns must be protected from rodent, deer and livestock predation; the best protection is to insure that large numbers of acorns are produced (Oyler 1987). Managing for adequate stand basal areas will help to insure enough trees are present to produce the acorns.

The Black Oak - Canyon Live Oak Association have an extensive range within the study area. Black Oaks have very good grading qualities and their stands produce moderate levels of merchantable timber. Canyon live oaks have highly variable grading qualities.

The Madrone Association is found on some of the highest quality sites within the study area. All the species found within this Association have very good grading qualities, but their quantity is very limited. Madrones are usually found in pure stands and their stands produce high volumes of commercial timber.

Black oak, Canyon Live Oak, and Madrone have good reproduction from both seeds or sprouts (Bartolome, Muick and McClaran 1986). Seeds are usually used for genetic improvement and sprouts for vegetative reproduction.

Given these features, the Black Oak - Canyon Live Oak and Madrone Associations should be managed for the production of timber as well as aesthetics and wildlife values. Landowners are encouraged to consult a registered professional forester to conduct an on-site evaluation.

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Hydrologic Impacts of Oak Harvesting and Evaluation of the Modified Universal Soil Loss Equation[1]

Charlette R. Epifanio Michael J. Singer Xiaohong Huang[2]

Abstract: Two Sierra foothill watersheds were monitored to learn what effects selective oak removal would have on watershed hydrology and water quality. We also used the data to generate sediment rating curves and evaluate the modified universal soil loss equation (MUSLE). Annual sediment rating curves better accounted for the variability in precipitation events from year to year, which may be at least as important as total rainfall, on the amount of runoff and sediment yield. Measurements before and after oak removal indicated small but not statistically significant increases in the runoff/rainfall ratio and fewer tons of sediment leaving the watershed after cutting. The MUSLE predicted quite accurately when calibrated for these watersheds.

Resource agencies, professionals and the public, concerned with soil erosion, water quality and maintenance of wildlife habitat, have been alarmed about the potential loss of valuable oak stands due to commercial firewood harvesting or to land clearing practices (Passof and others 1985).

Accelerated erosion in the wake of efforts at improving water yields through vegetative type conversion has been a major problem (Pitt and others 1978; Rice 1974). Rowe and Reimann (1961) concluded that the amount of increase in water yield obtained depends on depth and storage capacity of the soil, amount and distribution of annual rainfall, as well as the vegetation occupying the site before and after conversion. Furthermore, any disturbance that increases runoff and subsequently flow rate should also effect the rate of sediment movement within the watershed (Flaxman 1974).

Analytical tools for measuring erosion and sediment yield can be valuable aids to assess the changes brought about by vegetation manipulation. The importance of water quality planning as a result of section 208 of the Federal Water Pollution Control Act of 1972 and additional pressures for more intensive management of western rangelands has created the need for soil erosion and sediment yield models. An important need can be met by coupling a hydrologic model to water quality data for validation and improvement. The Modified Universal Soil Loss Equation (MUSLE) is a logical place to start for rangeland use. Williams (1975) modified the USLE to predict sediment yield for watersheds by replacing the rainfall energy factor with a runoff energy factor. The runoff factor represents energy used in transporting as well as in detaching sediment.

This investigation addresses three oak management issues: 1) Does selective oak harvesting result in increased water yield? 2) Is water quality lowered by the addition of sediment after selective harvesting? 3) Can the processes be modeled and predictions be generated which accurately answer these questions?

STUDY SITE

The study area is part of the University of California Sierra Foothill Range Field Station (SFRFS) located 60 miles (96 km) northeast of Sacramento. The 64 acre (26 ha) Schubert 1 (S1) and 254 acre (103 ha) Schubert 2 (S2) Watersheds are representative of the oak-woodland rangeland on the lower western slopes of the Sierra Nevada. Precipitation is dominated by low intensity, short duration rainfall from about October 1 to March 30. Average annual rainfall for the last 20 years has been 29 inches (732 mm).

Elevation ranges from 500 ft to almost 1400 ft (152 m to 427 m) above sea level with 2 to 50 percent slopes. The watersheds have ravines containing both ephemeral (S 1) and perennial (S2) streams that are tributary to the Yuba River below Englebright Reservoir. Soils are red, medium textured, gravelly and rocky, shallow to moderately deep, in the Auburn-Sobrante-Las Posas Association.

PROCEDURE

Oaks were clearcut from small selective stands on 44 percent of the 64 acre Schubert 1 beginning January 1984 and ending May 1985. Oaks were similarly cleared from about 14 percent of the 254 acre Schubert 2 beginning July 1984 and ending May 1986. Approximately 831 trees on S 1 and 1350 trees on S2 were harvested. Cutting and removal of the trees was done primarily during the dry summer months to minimize watershed disturbance. Average blue oak density, at sites representative of the areas harvested was 68 trees per acre.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland, October 31 - November 2, 1990, Davis, California.

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Water measurements began in 1980 before the selective removal of oak trees. Two rain gauges measure precipitation. Each stream is equipped with a Parshall flume for measuring the quantity and flow rate of runoff from high flows and a 90° "V" notch weir for measuring low flows. Automatic water samplers installed upstream from the waterflow gages periodically collect water samples for suspended sediment concentration determination.

Sediment-rating curves for computing annual sediment yield as a function of runoff volume were estimated by linear regression analysis.

The Modified Universal Soil Loss Equation (MUSLE) was evaluated by calibrating the MUSLE coefficients for the Schubert Watersheds. Measured sediment yield values were compared to estimated values using calibrated and published coefficients. Published MUSLE coefficient α=95 and β=0.56 were used as specified in the USDA-SCS (1980) Geology Note No. 2 for predicting the concentration of fine sediment in short tons from channels for single-storm events.

Data for every other storm throughout the year was fit to the model and put through a calibration procedure. The procedure rests heavily on linear regression analysis after logarithmic transformation of the original MUSLE to determine a best fit series of model coefficients for the storms. The remaining half of the measured sediment data was used for validation of the calibrated equation. A paired t-test determined the strength of the null hypothesis that the mean differences between the measured and the predicted storm sediment using both the calibrated and published parameters was equal to 0.

The equation's USLE factors were obtained using appropriate guides (USDA-SCS, 1977; and Wilson, 1986). Curve generation and MUSLE evaluation were conducted using Statistical Analysis Systems (SAS) programs (Ray 1982) and the standard linear regression procedures outlined in Affifi and Clark (1984) and Neter and Wasserman (1974).

RESULTS AND DISCUSSION

Runoff and Sediment Yield

A comparison of post-cut measured runoff values with those estimated by simple linear regression of pre-cut runoff on rainfall indicated no significant difference (95 percent confidence level) in the annual runoff response after harvesting. Comparisons between similar years show an apparent increase in runoff for the same rainfall on Schubert 2 after oak harvest. In the 1980-81 precut year, 21 inches of precipitation generated 3 inches of runoff, while in the 1987-88 postcut year, 19 inches produced 11 inches of runoff (table 1).

A possible reason for the higher runoff in the postcut year may not be cutting, but rather the distribution of rainfall, particularly the "priming" effect of the November and December storms which were followed by heavy rainfall in January. The early winter storms refilled the depleted soil moisture storage so the January precipitation quickly saturated the soil and produced runoff.

Fewer tons of sediment left Schubert 2 after cutting and tons per inch of runoff decreased about 60 percent (table 1) but the difference was not statistically significant. Year-to-year comparisons between similar rainfall years are less clear for sediment production than for runoff. The distribution and intensity of precipitation events may be at least as important as total rainfall in determining sediment yield. In the postcut year 1987-88, tripling the runoff tripled the total sediment load compared with the sediment load for the precut year 1980-81 (Table 1). But the 35 percent greater runoff in 1988-89 produced nearly 2 tons less sediment than the precut 1983-84 year.

Sediment Rating Curves

Equations 1 and 2 are the rating curves for the combined 1981-1986 water years on Schubert 1 and 2, respectively. The value 0.2 was added to all Schubert 2 suspended sediment concentration (Cs = milligrams per liter) values so that real values equal to 0, which have no logarithmic equivalent, would not be lost from the data base. The value 0.02 was added to the runoff volume (cfs = cubic feet/second) data to compensate for the adjustment to the Cs data. Both values are the smallest measured Cs and cfs values.

SCHUBERT 1 RATING CURVE (Eq. 1)

$$\log_{10}(Cs) = 1.6 + 0.5 \log_{10}(cfs)$$

SCHUBERT 2 RATING CURVE (Eq. 2)

$$\log_{10}(Cs+0.2) = 1.2 + 0.8 \log_{10}(cfs+0.02)$$

On Schubert 1 and 2, respectively, 43 percent and 48 percent of the variation in the sediment concentration was explained by the runoff volume for water years 1981-1986 as indicated by the coefficient of determination (r^2) from regression analyses (table 2). Often, separate curves for individual years performed better than one curve for all six years on each watershed. For example, r^2 was 0.80 for 1980-81 and 0.73 for 1984-85 (table 2). As a result, separate rating curves for individual years were chosen for estimating the suspended sediment concentration from runoff.

MUSLE Evaluation

The residual plot of sediment yield predicted by the calibrated MUSLE indicated multiplicative error terms or an increase in the error variance as the predicted values increased. As a result, the model was logarithmically transformed and a linear regression method for a least squares estimate of single-storm sediment yield was employed (Eq. 3). The USLE C, P and K factors were held constant at 0.003, 1.0 and 0.4, respectively, for calibrating the MUSLE. LS values used were 8.44 for S1 and 8.96 for S2.

Table 1—*Annual rainfall (RF), runoff (RO), runoff/rainfall ratio (ROIRF), total suspended sediment load (SED), and total suspended sediment load/runoff (SED/RO) for Schubert 2 Watershed, Sierra Foothill Range Field Station, 1980-1989.*

Year	RF	RO	RO/RF	SED	SED/RO
	in/yr			short tons	
PRE-CUT					
80-81	21	3	0.14	1	.33
81-82	47	26	0.55	32	1.23
82-83	40	31	0.78	25	.81
83-84	29	14	0.48	12	.86
MEAN	**34**	**18**	**0.49**	**18**	**.81**
POST-CUT					
84-85	18	7	0.39	2	.29
85-86	33	21	0.64	8	.38
86-87	13	10	0.77	10	1.00
87-88	19	11	0.58	3	.27
88-89	28	19	0.68	10	.53
MEAN	**22**	**14**	**0.61**	**6**	**.49**
9-Yr MEAN	28				
20-Yr MEAN	29				

NOTE: Rainfall and runoff values are rounded to the nearest whole numbers.

$$\log_{10}(Y/k)=1\log_{10}(\alpha)+\beta\log_{10}(Q*q_p) \quad \text{(Eq. 3)}$$

Y=sediment yield from the basin (tons);
Q=storm-event surface runoff volume (ft^3);
q_P storm-event peak flow rate (ft^3/s);
k=USLE K, C, P, and LS factors;
α,β=coefficients.

For all years, comparing MUSLE estimates with measured values, equations 4, 5, and 6 gave the highest correlation (r^2 values were 0.90 and higher) on Schubert 1, 2 and the combined watersheds, respectively. The percentage error of the average estimate is 50 percent, 36 percent and 74 percent of the dependent variable's mean, respectively, for Schubert 1, 2 and the combined watersheds. The significant difference (99 percent confidence level) between the calibrated coefficients and the published coefficients, α = 95 and β = 0.56 is related to the difference in watershed characteristics and the erosion rates of the sites presently investigated and those previously studied.

Table 2—*Number of observations (n), and Coefficients of determination (r^2) and variation (CV) for a simple linear regression of suspended sediment on runoff for Schubert 1 and 2, Sierra Foothill Range Field Station.*

Year	n	r^2	CV (percent)
SCHUBERT			
1981-86	259	.43	48
1980-81	9	.80	24
1981-82	59	.44	51
1982-83	87	.39	46
1983-84	14	.73	62
1985-86	32	.38	40
SCHUBERT 2			
1981-86	585	.48	60
1980-81	49	.74	40
1981-82	85	.81	43
1982-83	94	.44	44
1983-84	201	.26	65
1984-85	74	.28	69
1985-86	82	.40	51

Table 3—*Comparison of Schubert 2 annual storm sediment yield measured with the amount estimated using the published and calibrated MUSLE $\log_{10}(Y/k+1)=\log_{10}(1.1)+0.78\log_{10}(Q*q_p+1)$. Sierra Foothill Range Field Station, 1980-86.*

	Measured	MUSLE Published	MUSLE Calibrated
		Short Tons	
MEAN	.49	9.4	.45
Standard Deviation	1.4	21.9	1.4
Standard Error of Estimate		2.3	.04
Paired T-test probability[1]		.0002	.35*
r^2(for Y & O(Y,^))[2]		.96	.92

[1](*) indicates no significant difference (99.5 percent confidence level) between means of measured and estimated yields

[2]Coefficient of Determination for means of measured (Y) and estimated (O(Y,^)) yields

$$S1\ Y=2.1\ (Q * q_P)^{0.76} k \quad \text{(Eq 4)}$$

$$S2\ Y=(1.1\ (Q * q_p + 1)^{0.78}-1)k \quad \text{(Eq. 5)}$$

$$S1\&2 \quad Y=1.7\ (Q * q_p)^{0.70} k \quad \text{(Eq 6)}$$

The mean differences between the measured and estimated storm sediment yield using the calibrated equation for Schubert 2 was not statistically significant as indicated by paired T-test results shown in table 3. Whereas, the mean difference between the measured and estimated storm sediment yield using the published MUSLE was significantly different (99.5 percent). On S2, the published MUSLE overestimated the storm sediment by about 1900 percent.

Table 4—*Measured sediment yield for several single-storm events and the yields estimated using the published and calibrated MUSLE for Schubert 2 Watersheds, Sierra Foothill Range Field Station, 1980-86. Runoff volume and flow rate are given for each event.*

DATE	VOLUME RUNOFF	RUNOFF RATE	STORM SEDIMENT YIELD Measured	Calibrated Estimate	Published Estimate
	(inches)	*(ft^3/sec)*		*(short tons)*	
11-30-80	.02	.05	.000	.001	.15
01-26-81	7.86	2.97	.34	.15	6.65
03-15-81	.28	.42	.004	.002	.35
03-25-81	5.24	4.12	.23	.14	6.37
11-22-81	.09	.82	.002	.002	.27
11-27-81	1.24	1.42	.01	.02	1.56
12-31-81	1.44	2.75	.02	.03	2.46
02-13-82	37.94	33.10	3.97	3.44	61.99
01-22-83	31.45	21.50	1.95	2.12	43.82
11-23-83	13.08	16.80	1.31	.88	23.38
02-06-85	27.76	27.30	3.05	2.32	46.71
02-12-86	159.88	48.20	8.98	14.19	171.21
03-15-86	13.67	11.60	.44	.68	19.46

Table 4 shows that the calibrated MUSLE performed quite satisfactorily in predicting the sediment yield for single-storm events compared to the estimations made with the published coefficients. There may be a tendency for the calibrated equation to underpredict small storms and overpredict large ones which is the reverse of the findings reported by Johnson and others (1985).

CONCLUSION

No evidence was found supporting the hypothesis that carefully controlled oak removal increased runoff or sediment yield.

Annual sediment-rating curves performed better than a single curve generated to predict sediment over several years. This is to be expected since there is less variability in one year compared to a six-year average. Annual curves better account for the variability in the distribution and intensity of precipitation events from year to year, which may be at least as important as total rainfall, on the amount of runoff and sediment yield.

We have shown that the MUSLE is useful for predicting single-storm sediment yield and can be used by watershed planners and managers for predicting the effects of management options on water quality, within a reasonable degree of accuracy. However, the accuracy of the model is improved when calibrated for our particular watershed sites.

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Microhabitat and Environmental Relationships of Bryophytes in Blue Oak (*Quercus douglasii* H. & A.) Woodlands and Forests of Central Coastal California[1]

Mark Borchert Daniel Norris[2]

Abstract: Microhabitat preferences and species-environment patterns were quantified for bryophytes in blue oak woodlands and forests of central coastal California. Presence data for mosses collected from 149 400 m^2 plots were analyzed using canonical correspondence analysis (CCA), a multivariate direct gradient analysis technique. Separate ordinations were performed for terricolous, saxicolous and epixylic mosses using 14 environmental variables. Fifty-six species of bryophytes were collected from the study area. Only the terricolous moss CCA was shown to be significantly related to environmental variables. Thirty-nine soil bryophyte species were arranged along 4 environmental gradients: potential annual solar insolation, moderate soil trampling, tree density and overstory crown cover. The significance of each environmental factor is discussed in relationship to the ecology of the species.

Bryophytes and lichens are an important component of the flora in blue oak woodland and forests. Despite a high abundance and diversity in this type, bryophytes have received very little study. An extensive list of lichens is available for blue oak in the San Joaquin Experimental Range (Herbert and Meyer 1984) but there are no comparable lists of bryophytes in blue oak. In the extensive range literature for blue oak and related annual grasslands, Heady (1956) briefly describes fluctuations in the cover of soil mosses that paralleled changes in vascular plant cover, but he did not identify bryophyte species.

We collected presence data for bryophytes in conjunction with a study to classify blue oak vegetation in southern San Luis Obispo and northern Santa Barbara counties, California. The objectives of this paper are: (1) to give a descriptive account of bryophytes and their microhabitat preferences in blue oak woodlands and forests on the Central Coast and (2) to identify bryophyte species-environment relationships.

STUDY AREA

The study area includes 6 7.5'topographic quadrangles and is a patchwork of blue oak woodland and forest in southern San Luis Obispo and northern Santa Barbara Counties at the juncture of three mountain ranges: the La Panza Range, Garcia Mountain, and the Sierra Madre Mountains. The center of the study area (35° 10'N, 122° 10'W) is located approximately 52 km ESE of San Luis Obispo. The climate is mediterranean. Average annual precipitation at Pozo (9.5 km west of San Luis Obispo, CA) is 526 mm. In 1986 precipitation was 713 mm, higher than the average, and 269 mm in 1987, well below the average.

Eight allotments within the study area have been grazed almost continuously by cattle since 1900. Allotment grazing regimes have been highly variable historically. Currently three allotments are grazed year around and the others are grazed from one to five months. None of the plots had burned within a period of 5 years before the study.

METHODS

Plot data were collected from the study area over a period of two years from late March to late May. In 1986 and 1987, 69 plots were sampled in the area from Pozo to the Cuyama River west of Branch Mountain. In 1987, 80 plots were sampled in the area from the Cuyama River to Miranda Pine Mountain.

Plots of 400 m^2 were subjectively located in stands where blue oak overstory crown cover was at least 20 percent and understory herbaceous cover exceeded 60 percent. A stand was sampled only if oaks were relatively evenly distributed over the plot on the same slope and aspect.

Slope angle, aspect, elevation, landform, slope position, and within-plot vertical and horizontal micro-relief were recorded for each plot. Slope and aspect were used to obtain an estimate of potential annual solar insolation using the tables of Frank and Lee (1966).

Bryophytes were collected from soil, rocks, downed logs and tree boles within each plot. Bole mosses were collected to 3 m. Percentage foliar cover of all vascular plant species was estimated visually and recorded into a modified Braun-Blanquet

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cover scale: 0-1 percent, 2-5 percent, 6-25 percent, 26-50 percent, 51-75 percent, and 76-100 percent. Midpoints of each of these cover classes were used to calculate total understory cover used in the data analysis. The cover of overstory trees was measured with a spherical densiometer (Lemmon 1956) by averaging five values taken in the plot: one at plot center and the others 7.5 m parallel and perpendicular to the slope contour from plot center. Trees larger than 5 cm dbh were counted, and their diameters measured at 1.4 m.

A soil pit was excavated in each plot to a depth of 100 cm or bedrock, whichever was encountered first. Soil characteristics taken for the A horizon and subsoil included: color, texture, pH, percentage coarse fragment and horizon thickness. Soil structural characteristics were used to create classes of soil trampling: light, moderate, heavy and severe. Lightly trampled soils had well developed A horizons with granular structure. At the other end of the gradient severely trampled soils had platy structure or no structure (massive) in the A horizons, and, in some cases, were heavily eroded. Seven soil textural classes were used in the analysis: loam, sandy loam, gravelly loam, gravelly sandy loam, fine sandy loam, sandy clay loam, and clay loam.

DATA ANALYSIS

We analyzed bryophyte presence data using canonical correspondence analysis (CCA)(Ter Baak 1986). CCA is designed to detect unimodal relationships between species and external variables by performing a correspondence analysis ordination but with the added feature of canonical ordination. Ordination axes extracted by this method are required to be a linear combination of environmental variables. Axes appear in order of the variance explained.

Continuous variables used in the CCA analysis included elevation, aspect, slope, solar insolation, basal area, tree density, overstory crown cover, total understory cover and soil pH. If necessary, continuous variables first were normalized and then standardized to a mean of 0 and standard deviation of 1. Categorical variables used in the analysis included slope position, within-plot horizontal and vertical microrelief, trampling class and soil texture.

Because bryophytes usually have very specific microhabitat preferences, we separately performed ordinations of the terricolous, saxicolous and epixylic species. Too few plots had logs for analysis. Total understory cover, soil texture, and trampling class were used only for the analysis of terricolous mosses.

Species with less than 20 percent of the most frequent species were down-weighted by reducing abundance values in proportion to their frequencies of occurrence. A Monte Carlo test (Ter Baak 1986) was used to determine if the first canonical axis of each ordination was significantly related to environmental variables.

RESULTS

Terricolous Mosses

Fifty-six bryophyte species were collected from the 149 plots. Thirty-four were primarily found on soil and, of these, 21 were uncommon or rare (<4 occurrences)(table 1).

Thirty-nine species in 101 plots entered the CCA analysis of terricolous mosses. Species on the first canonical axis were significantly related (p=0.01) to the environmental variables. Moderate trampling is positively correlated and solar insolation negatively correlated with the first canonical axis (table 2). Density and overstory cover are positively correlated with the second and third axes, respectively (table 2). Density and overstory cover were moderately correlated (r=0.52) but moderate trampling and solar insolation were uncorrelated (r=-0.07).

The relationship of ground bryophytes to environmental variables is presented in the CCA ordination (biplot) diagram (fig. 1). Arrow length in the CCA ordination diagram is propor-

Table 1—*Terricolous moss specks. Species are listed by the number of occurrences in all microhabitats (N) and percent frequency by microhabitat.*

		Microhabitat			
Species	N	Logs	Boles	Rocks	Soil
Brachythecium velutinum (Hedw.) B.S.G.	8	—	—	13	87
Brachythecium albicans (Hedw.) B.S.G.	15	—	20	—	80
Bryum lisae DeNot.	4	—	—	—	100
Bryum spp.	7	—	14	14	72
Ceratodon purpureus (Hedw.) Brid.	6	—	—	—	100
Fissidens bryoides Hedw.	30	—	3	—	97
Fossombronia pusilla (L.) Dum.	20	—	—	15	85
Funaria hygrometrica Hedw.	6	—	—	—	100
Homalothecium arenarium (Lesq.) Lawt.	30	3	20	3	74
Phascum cuspidatum Hedw.	6	—	—	—	100
Targionia hypophylla L.	6	—	—	23	67
Timmiella anomala (B.S.G.) Limpr.	27	—	—	7	93
Weissia controversa Hedw.	6	—	—	—	100

Species with N <4 that were collected exclusively from soil: *Acaulon muticum* (Hedw.) C. Muell., *Anatolia menziesii* (Turn.) Par., *Anthoceros fusiformis* Aust., *Asterella bolanderi* (Aust.) Underw., *Claopodium bolanderi* Best, *Didymodon vinealis* (Brid.) Zander, *Ephemerum serratum* (Hedw.) Hampe, *Fissidens sublimbatus* Gront, *Funaria muehlenbergii* Hedw. f. ex Lam. and DC., *Phaeoceros bulbiculosus* (Brut.) Prosk., *Pleuridium subulatum* (Hedw.) Rabenh., *Pottia bryoides* (Dicks.) Mitt., *Pottia davalliana* (Sm.) Jens., *Pottia lanceolata* (Hedw.) C. Muell., *Pottia starckeana* (Hedw.) C. Muell. *Pterygoneuron subsessile* (Brid.) Jur., *Riccia nigrella* DC., *Scleropodium touretii* (Brid.) L. Koch, *Tortula bolanderi* (Lesq.) Howe, *Tortula inermis* (Brid.) Mont and *Tortula princeps* DeNot.

Table 2—***Canonical coefficients and intraset correlations of the CCA for terricolous bryophytes. Only correlation coefficients equal to or greater than 0.40 on one of the first 3 axes are shown. The first 3 axes accounted for 82 percent of the variance in the weighted average of the species with respect to environmental variables.***

Axis variable	Canonical coefficients			Correlation coefficients		
	1	2	3	1	2	3
Solar insolation	-.59	.26	-.06	-.62	.08	.08
Moderate trampling	.33	-.03	.13	.40	-.08	.13
Density	.20	.38	.29	.30	.46	.00
Overstory tree cover	.04	-.14	-.55	.28	.16	-.48

tional to the strength of the correlation between environmental variables and ordination axes. Arrow direction indicates whether a variable is positively or negatively related to the axis. A species point projected perpendicularly onto each environmental axis corresponds approximately to the ranking of the weighted average of the species with respect to that environmental variable. The weighted averages are approximated in the diagram as deviations from the grand mean of each variable. The origin of the plot represents the grand mean.

As an example, we show frequency histograms of *Homalothecium arenarium* for solar insolation, moderate trampling and tree density (figs. 2a-c) to illustrate the position of this species in the biplot diagram. *Homalothecium arenarium* shows a preference for low-solar insolation (mesic) sites (fig. 2a) that are moderately trampled (fig. 2b). It is also more frequent in stands with high tree densities but this preference is less pronounced (fig 2c). The position of this species in the biplot diagram clearly reflects its distribution on these gradients.

The overall pattern of species in figure 1 shows that they are equally distributed on the solar insolation gradient but that more species are associated with higher than average tree densities especially in high-solar insolation (xeric) sites (fig. 1; upper left quadrant). Species that inhabit low-solar insolation stands are most prevalent on moderately trampled soils independent of tree density.

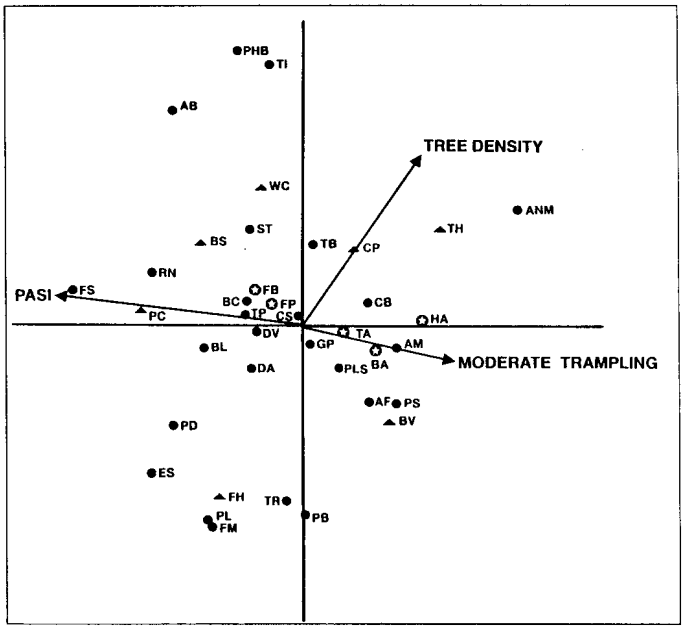


Figure 1—CCA ordination diagram with species and environmental variables (arrows) for the 101 plots. First axis is horizontal, second axis is vertical. Species with N> 15 are starred; those with 5< N < 15 are indicated with triangles and species with N< 5 are indicated with dots. Species are as follows: *Asterella bolanderi* (AB), *Anthoceros fusiformis* (AF), *Acaulon muticum* (AM), *Anatolia menziesii* (ANM), *Brachythecium albicans* (BA), *Bryum capillare* (BC), *Bryum lisae* (BL), *Bryum* spp. (BS), *Brachythecium velutinum* (BV), *Claopodium bolanderi* (CB), *Ceratodon purpureus* (CP), *Crossidium squamiferum* (CS), *Didymodon australasiae* (DA), *Didymodon vinealis* (DV), *Ephemerum serratum* (ES), *Fissidens bryoides* (FB), *Funaria hygrometrica* (FH), *Funaria muehlenbergii* (FM), *Fossombronia pusilla* (FP), *Fissidens sublimbatus* (FS), *Grimmia pulvinata* (GP), *Homalothecium arenarium* (HA), *Pottia bryoides* (PB), *Phascum cuspidatum* (PC), *Pottia davalliana* (P D), *Phaeoceros bulbiculosus* (P H B), *Pottia lanceolata* (PL), *Pleuridium stramineum* (PLS), *Pterygoneron subsessile* (PS), *Riccia nigrella* (RN), *Scleropodium touretii* (ST), *Timmiella anornala* (TA), *Tortula bolanderi* (TB), *Targonia hypophylla* (TH), *Tortula inermis* (TI), *Tortula princeps* (TP), *Tortula ruralis* (TR), and *Weissia controversa* (WC). *Pottia starckeana* is not shown but is positioned in the upper left quadrant

Epixylic Mosses

Twenty species in 143 plots entered the CCA for this group. The 1st canonical axis was significantly related (p=0.05) to environmental variables but none of the correlation coefficients equaled or exceeded 0.40. Species of the genus *Orthotrichum* clearly dominate this group and *Tortula laevipila* and *Orthotrichum lyellii* are nearly ubiquitous (table 3). Both species consistently grow at the bases of trees and in low solar insolation environments. Where there is ample fog, *O. lyellii* extends into the canopy on larger branches.

Saxicolous Mosses

Twenty-eight species in 30 plots entered the CCA analysis of rock mosses (table 4). The 1st canonical axis was not related to the environmental variables (p=0.21). In general, rocks are infrequent in the study area and where present, their cover seldom exceeds 4 in^2 (1 percent). Not unexpectedly, the genus *Grimmia is* best represented in this microhabitat.

Mosses Distributed Among Several Microhabitats

Species without a clear microhabitat preference are listed in Table 5. *Antirichia californica* is one of a large number of western North American species that can be found as readily on trees as on rocks. The microhabitat amplitude of the other species is largely due to their preference for rocks or trees that have a thin layer of sediment deposition.

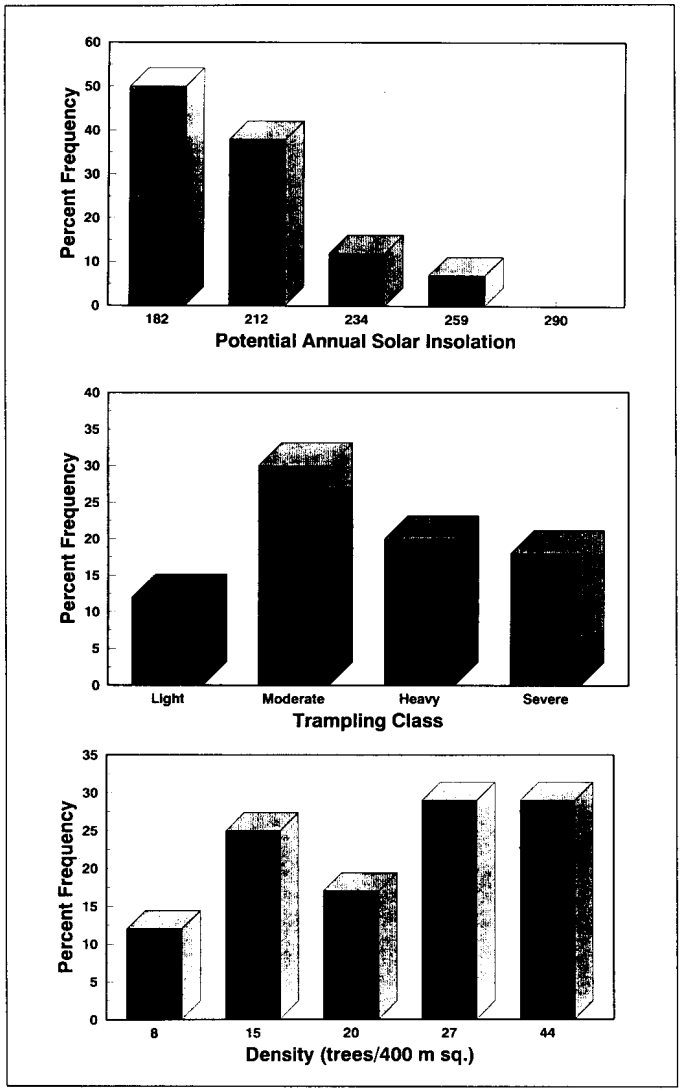


Figure 2—Frequency histograms for Homalothecium arenarium for (a) solar insolation, kcal/cm^2/yr (b) trampling class, and (c) tree density. Frequencies are for 5 classes of solar insolation and four classes of tree density. The values on the x axes of (a) and (c) are the means for each class.

Table 3—*Epixylic bryophyte species. Species are listed by occurrence in all microhabitats (N) and percent frequency by microhabitat.*

Species	N	Microhabitat			
		Logs	Boles	Rocks	Soil
Homalothecium nuttallii (Wils.) Jaeg.	12	—	100	—	—
Orthotrichum lyellii Hook. and Tayl.	128	2	98	—	—
Orthotrichum pumilum Sw.	6	—	100	—	—
Orthotrichum tenellum Bruch ex Brid.	8	—	100	—	—
Tortula laevipila (Brid.) Schwaegr.	130	6	92	2	—

Species with N <4 that were collected exclusively from tree boles: *Amblystegium varium* (Hedw.) Limpr., *Fabronia pusilla* Raddi, *Orthotrichum diaphanum* Schrad. ex Brid., and *Scleropodium cespitans (C.* Muell.) L. Koch. *Dicranoweisia cirrata* (Hedw.) Lindb. in Milde was collected only from logs.

Table 4—*Saxicolous brypohyte species. Species are listed by occurrence in all microhabitats (N) and percent frequency by microhabitat.*

Species	N	Microhabitat			
		Logs	Boles	Rocks	Soil
Grimmia laevigata (Brid.) Brid.	5	—	—	100	—
Grimmia pulvinata (Hedw.) Sm.	11	—	—	91	9

Species with N <4 that were collected exclusively from rocks: *Bryum pseudotriquetrum* (Hedw.) Gaertn., *Grimmia alpestris* (Web. and Mohr) Schleich ex Nees, *Grimmia ovalis* (Hedw.) Lindb., Meyer and Scherb., *Homalothecium pinnatifidum (Sull.* and Lesq.) Lawt.

Table 5—*Bryophyte species without strong microhabitat preferences. Species are listed by occurrence in all microhabitats (N) and percent frequency by microhabitat.*

Species	N	Microhabitat			
		Logs	Boles	Rocks	Soil
Antitrichia californica Sull. in Lesq.	15	27	60	13	—
Crossidium squamiferum (Jur.) Giac.	4	—	—	50	50
Didymodon australasiae (Hook. and Grev.) Zander	11	—	18	36	45
Didymodon vinealis (Brid.) Zander	55	—	38	16	46
Tortula ruralis (Hedw.) Gaertn., Meyer and Scherb.	38	3	53	32	13

Species with N <4 on trees and rocks: *Bryum capillare* Hedw., *Didymodon rigidulus* Hedw., and *Grimmia trichophylla* Grev. occurred on soil, trees and rocks.

DISCUSSION

Terricolous mosses are the dominant (70 percent) species group in blue oak on the Central Coast and show definite species patterns in relation to macroenvironmental gradients. Other ordination studies of terricolous moss assemblages have centered almost entirely on plant communities well to the north of blue oak: artic (LaFarge-England 1989), subartic forest-tundra (Robinson and others 1989), and boreal forest (Lechowicz and Adams 1974; Johnson 1981; Brumelis and Carleton 1989). Species patterns in these studies were correlated with soil chemistry (Johnson 1981; LaFarge-England 1989; Robinson and others 1989), soil texture (Robinson and ethers 1989), slope (LaFarge-England 1989), light and temperature regimes (Lechowicz and Adams 1974; Johnson 1981; Brumelis and Carleton 1989) and disturbance (Johnson 1981; Brumelis and Carleton 1989).

Terricolous mosses in blue oak woodlands are organized along at least four environmental gradients, the strongest of which is solar insolation. Solar insolation is a complex gradient

and may be a surrogate for soil moisture. Although soil moisture was not measured, field observations on the rate of drying of annual plants indicated that low-solar insolation sites remained moist much longer than high-solar insolation sites. Species distributions of vascular plant vegetation also are correlated with solar insolation (r=-0.69) (Borchert and others 1990). Nevertheless, slope angle, a significant environmental variable (r=0.44) for vascular plants (Borchert and others 1990), is not important to soil mosses.

Tree density and overstory cover may reflect gradients in light and/or soil nutrients. Overstory cover in blue oaks is predominately composed of branch, twig and bole cover with a relatively smaller percentage furnished by foliage. Moreover, because woody cover is present year around, it constitutes a more constant source of shade than deciduous foliage. In addition to light, bryophytes may be responding to a density-related gradient in soil nutrients or soil structure. Blue oak litter increases soil nutrients, organic material, friability, water holding capacity and creates a more equitable soil temperature regime (Holland 1973; Callaway 1990). Thus, regardless of solar insolation, dense stands may provide a better microclimate and soil environment for terricolous mosses than low-density stands. Vascular plant species were also significantly related (r=0.40) to overstory cover.

The emergence of moderate trampling as a significant variable suggests that disturbance plays a role in the distribution of ground mosses in low-solar insolation sites. The impact of livestock trampling on soils is complex. Hoof action can cause vegetation injury and loss, compaction of the soil surface and reduced infiltration (Abdel-Magid and others 1987). Observations indicate that trampling produces extremely variable microtopography. Hooves create small cutfaces that, if left undisturbed, are colonized by bryophytes, as are the small mounds of soil pushed up at bases of the cutfaces. Where trampling is very heavy, however, mosses are completely eliminated but it is not clear why mosses are not also associated with lightly grazed sites.

Semiarid blue oak woodlands are comparatively rich in bryophyte species. For example, a similar number of plots in coast redwood (*Sequoia sempervirens*) forests in southern Monterey County, California produced only 16 bryophyte species (in prep.). Future studies of bryophytes in blue oak should concentrate on terricolous species with a particular emphasis on low-solar insolation environments where this group has the highest cover. Successional studies on species in mesic sites would be of particular interest because mosses may be more sensitive indicators of livestock grazing effects than vascular plants.

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The Effect of Land Use Changes on Blue Oak Regeneration and Recruitment[1]

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Abstract: Lack of blue oak (*Quercus douglasii*) saplings and seedlings throughout much of its range has prompted research into the regeneration status of the species. Our ability to assess whether the current lack of regeneration is a natural pattern or a response to human induced environmental change is limited by lack of data on the history of blue oak establishment. This study presents data on blue oak age stand structure collected from three sites on the Tejon Ranch, in the Tehachapi Mountains. Over half of the trees aged became established during the 1850s, whereas almost no new trees have come in during the last 120 years. The evidence suggests that blue oak regeneration and recruitment has been strongly influenced by changes in fire frequency and human land use.

Blue oak (*Quercus douglasii*) appears insufficient at the present time to replace many existing stands (Muick and Bartolome 1987, Bolsinger 1988). It is unclear whether the present pattern represents a natural cycle, or is a response to environmental change associated with European settlement. Evidence based on age structure studies has identified a period of successful regeneration during the latter half of the 19th century (White 1966, Vankat and Major 1978, McClaran 1986). This paper reports age structure data from three sites on the Tejon ranch, in the Tehachapi Mountains.

Tejon Ranch has been held as a single property since the 1860s, and includes some of the largest undisturbed oak woodlands in the state. Cross-sections were cut from stumps, following a wood-cutting operation. Stumps were cut at or below ground level in order to obtain the oldest possible age (McClaran 1986, Frank Davis pers. comm. 1988). Tree ring analysis of 279 cross-sections showed that 56 percent of all trees sampled became established in 1856 (fig. 1). Prior to 1856, recruitment was relatively continuous, with several new trees becoming established every decade. A noticeable lack of regeneration was found after 1864, with only 3 percent of all trees becoming established since this date. Analysis of fire scars found an increase in numbers of scars in the 1850s and 1860s (fig. 2). Following 1864, there is a distinct decrease in fire scars for a 70 year period.

DISCUSSION

The results seem to indicate three distinct patterns of regeneration and recruitment which coincide with different periods of local land use. The earliest period (pre-1842) predates European settlement and reflects regeneration under aboriginal land use. Regeneration was low, but relatively continuous. Given the inevitable gaps in the record from mortality and heart rot, there appears to have been no regeneration and recruitment problem during the Indian period.

The period between 1843-1865 was one of active European settlement. During this time, new tree establishment was unusually successful. Fires were particularly frequent, and the evidence suggests that the regeneration peak in 1856 is primarily the result of regeneration by sprouting of previously established seedlings and saplings, which had been top-killed by frequent fires. McClaran and Bartolome (1989) have hypothesized that fire temporally concentrates post-fire sprouts. Figure 2 illustrates an increase in fire activity during the 1850s. Almost half of the trees from the 1856 cohort have more than one stem, an indication that they probably originated from sprouts. The strong regeneration peak associated with high fire frequency appears to support McClaran and Bartolome's hypothesis.

Following successful regeneration, browsing may suppress sapling growth and limit recruitment. During the occupation period of Fort Tejon (1854-64), soldiers regularly held hunting parties (Giffen 1942, Crowe 1957). Hunting likely reduced the local deer population thereby reducing browsing pressure. Trees established within one year of a fire have been shown to grow almost twice as fast as other trees (McClaran 1986). Rapid vertical growth of sprouts during a period of reduced browsing may have contributed to tree survival by quickly raising the apical meristem above the browse-line (135 cm).

In 1866, the ranch was consolidated into a single property and commercial livestock grazing was introduced. Fire frequency declined markedly. Relative absence of fire for a 70 year period contributed to survival of the 1856 cohort, and resulted in a dense, even aged stand. Since 1866, there has been a virtual absence of regeneration and recruitment. Lack of new tree establishment may result from intraspecific competition due to an increase in woodland density and canopy cover, an increase in livestock and deer browsing, changes in fire frequency, or competition for soil moisture between seedlings and introduced annual grasses (Gordon and others 1990).

[1] Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, Davis, Calif.

[2] Graduate Student, Department of Geography, University of California, Berkeley.

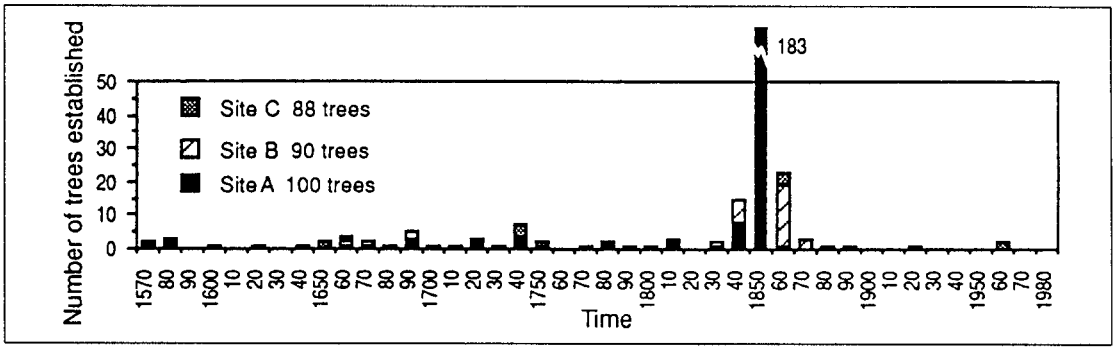


Figure 1—Number of blue oaks established per decade by site on Tejon Ranch, Kern County, California. Of the 183 trees established in the 1850's, 156 date to 1856, including 61 from site "A", 44 from site "B", and 51 from site "C".

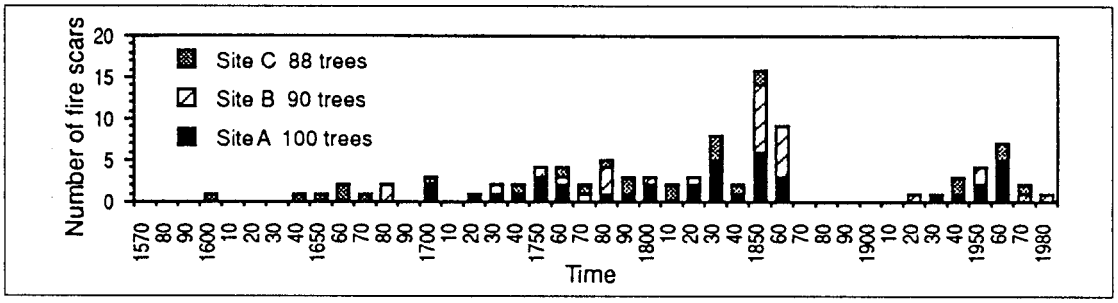


Figure 2—Number of fire scars on blue oaks, per decade, by site on the Tejon Ranch, Kern County, California.

CONCLUSION

During Indian occupation of the area, the woodland appears to have been less dense, with a slow but steady process of replacement, adequate to maintain the woodland. Changes in fire frequency and browsing patterns, associated with European settlement in the mid 19th century, resulted in unusually high rates of regeneration and recruitment. Since the 1860s, the combination of an increase in density, reduction of fire frequency, and the introduction of livestock grazing have resulted in virtually complete suppression of regeneration. Regeneration under the present conditions may require a significant change, such as a large crown fire, changes in grazing practices, or a combination of these and other events. Since these events are largely controlled or influenced by people, future regeneration of blue oaks in these woodlands will be increasingly dependent on land use management decisions.

ACKNOWLEDGMENTS

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Genetic Variation Sampled in Three California Oaks[1]

Lawrence A. Riggs Constance I. Millar Diane L. Delany[2]

Abstract: As a first step in acquiring genetic information about oak species indigenous to California's hardwood rangelands we drew on experience from both forest regeneration and species conservation and applied biochemical techniques for rapidly assaying patterns of genetic variation. In a study sponsored by the California Integrated Hardwood Range Management Program we sampled 860 trees from 29 populations of three species of oaks spanning their distribution in California. Using leaf tissue collected from each tree we performed starch gel electrophoresis to assay allozymic variation within and among populations and species. Our findings included some surprises and confirmed certain interpretations made by previous taxonomic work. We found large genetic differences between all pairs of species, including blue and valley oaks, with many unique genes distinguishing each species. Our allozyme results support assigning blue oak to the white oak group. At the population level we found little variation within populations of coast live oak and valley oak. Blue oak was about twice as variable within populations as the other two species. Differences between populations within species were small. We could detect no geographic pattern in allozyme variation in any of the species and no indication of racial or subspecific variation.

Experience in both production forestry and species conservation has demonstrated the importance of knowledge about genetic variation and its distribution within and among populations. Until recently, little has been known about natural genetic variation in any of California's oak species. With land conversion and more intensive land use diminishing the ranges of several species and unsuccessful regeneration becoming a matter of concern, genetic approaches may help us to understand possible causes and remedies for population declines. To begin acquiring the genetic information needed as background for answering management questions, we undertook a survey of allozyme variation in three species of California oaks. We chose allozyme techniques as a first step to describing patterns of genetic variation because they are well established, relatively quick and inexpensive, and have been shown to yield useful information in most cases.

We directed our study toward describing genetic variation in two endemic California oak species that appear to be particularly affected by land conversion and regeneration failure: valley oak (*Quercus lobata*) and blue oak (*Quercus douglasii*) of the subgenus *Quercus*. As an ecological and taxonomic "control" on our findings we included coast live oak (*Quercus agrifolia*) of the subgenus *Erythrobalanus* in our survey.

METHODS

We sampled 15 stands of coast live oak and seven stands each of blue oak and valley oak representing the full range of each species in California. Twenty trees were selected from each of 15 stands of coast live oak. After discovering that levels of genetic variation were lower than we initially expected, we elected to sample a larger number of trees (40) from fewer populations (seven) in order to improve our chances of detecting meaningful patterns of variation among stands. With all species, foliage (10-15 leaves) was collected from mature trees of varying sizes spaced 50-100 meters apart. Trees at most sites were marked or mapped to facilitate repeat collections and possible use by other investigators.

Leaf tissue extracts were prepared from foliage samples using techniques described by Mitton and others (1979). Extracts were electrophoresed on starch gels using established techniques (Conkle and others 1982; Millar, 1985), and gel systems (Strauss and Conkle 1986). Eighteen loci resolved in coast live oak and 21 loci in valley oak and blue oak.

FINDINGS

Our findings are reported in detail elsewhere (Millar and others, unpublished draft). A general overview is provided here. Those interested in more detail should contact the authors for information.

In contrast to our initial expectations based on life history traits, we found little variation within coast live oak and valley oak populations relative to what has been found for conifers and other oak species that have been studied in the eastern United States. Blue oak populations were markedly more variable than those of either of the other two species—about twice as variable

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as coast live oak with respect to the percent of loci polymorphic.

A major finding of our study was the striking allozymic differences among the three species, attributable to both the occurrence of unique alleles and distinguishing allele frequencies. Genetic distance measures show valley oak and blue oak to be very distinct but about equally separated from the even more distinct coast live oak. These results support the taxonomic assignment of blue oak to the subgenus *Quercus* and previous expectations about the magnitude of allozymic differences expected between subgenera (coast live oak is in the subgenus Erythrobalanus). The large genetic distance between the congeners valley oak and blue oak and the relatively small distances among populations within each species contrasts with some previous findings and suggests an explanation based on the paleobotanical record (Millar and others unpublished draft).

Genetic differences among populations were small as expected on the basis of life history traits (Hamrick and Godt 1990) but especially so for valley oak and blue oak. We expected to find differences among populations that might reveal patterns of local adaptation or historical isolation and origin. We found no detectable geographic pattern in allozyme variation in any of the species and no indication of racial or subspecific variation.

MANAGEMENT IMPLICATIONS

The study reported here has generated a basic description of how one component of genetic diversity (allozymic variation) is distributed within and among populations. With this fundamental knowledge we can proceed to compare our interpretations with those generated by other kinds of population data. We can also begin to recognize which of various applied problems can be addressed using allozyme assays and which may be better served by other approaches. It now seems apparent that allozyme markers will not be very useful for rapid assessment of population identity or provenance. Analysis of DNA restriction fragment variation or of variation in specific DNA sequences may prove more useful in this regard. However, allozyme markers may provide a relatively simple and inexpensive way to identify and characterize hybrid populations or individuals and to help determine whether interspecific gene flow should be actively encouraged or discouraged in particular management situations.

Another management implication of this study is that we should not jump to the common conclusion that low levels of allozymic variation are indicative of 'genetic trouble' for a population. Successfully regenerating coast live oak populations typically exhibited lower levels of variation than even the most isolated valley oak or blue oak populations that we examined in this study. Observed levels, and patterns of variation will have to be interpreted in the context of the evolutionary background and life history of each species. Within species, however, there are indications that a comparative use of variability indices may help focus attention on populations that should be evaluated more closely using a suite of demographic, ecological, and genetic approaches. Continuing work by one of us (Riggs) is addressing these possibilities.

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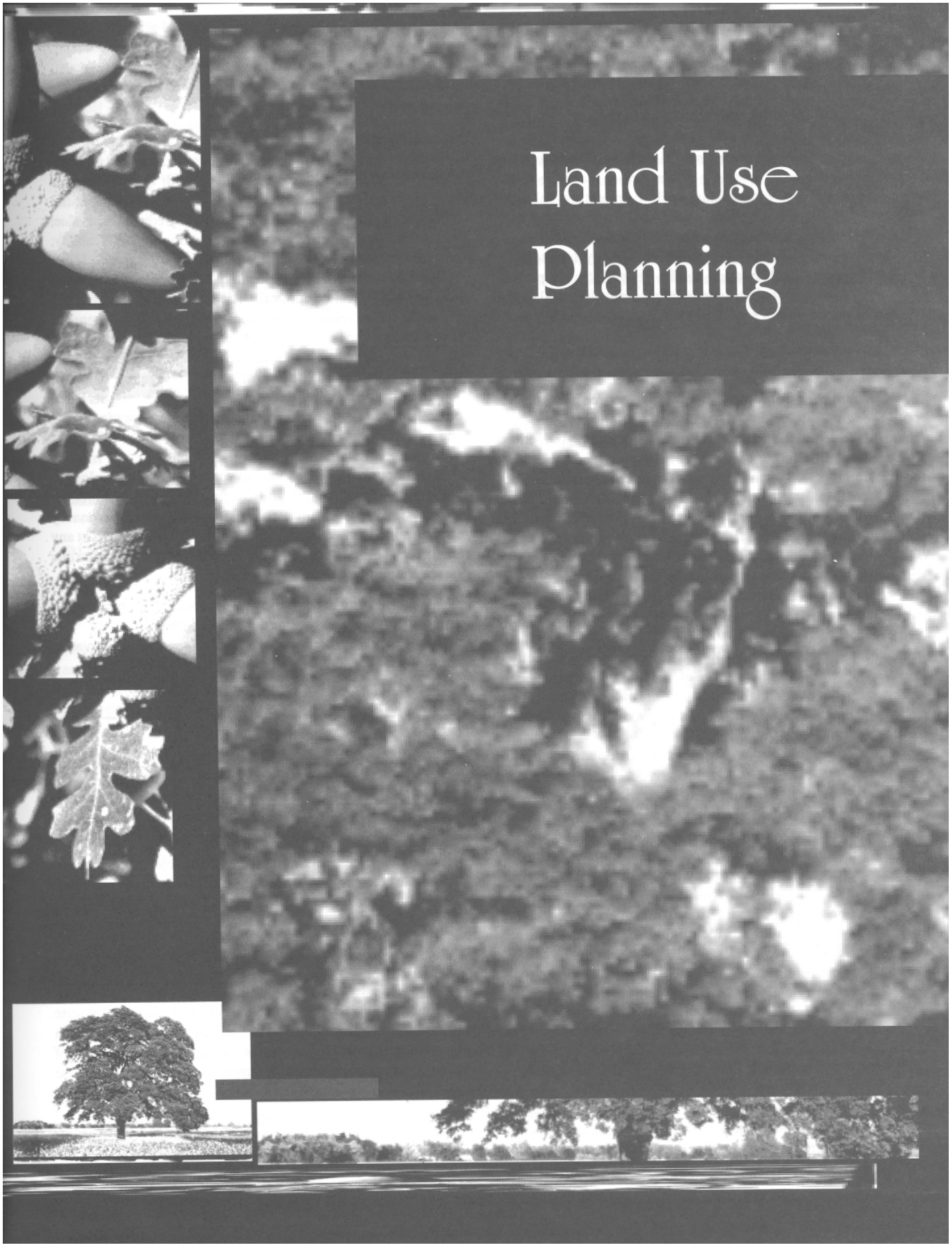
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Land Use Planning

Identifying and Prioritizing Critical Hardwood Resources[1]

Sam C. Doak Sharon Johnson Marlyce Myers[2]

Abstract: A logical framework is required to provide a focus for the implementation of a variety of landowner incentive techniques in accordance with existing goals to protect and enhance hardwood resources. A system is presented for identifying and prioritizing critical hardwood resources for site specific conservation purposes. Flexibility is built into this system so that various sources of information can be utilized, the scope can vary from state-wide to local perspectives, and additional criteria can be added within specified system parameters.

Concern over California's hardwood resource has focused on: (1) decreased stocking of hardwood stands due to increased removals and limited successful regeneration; and (2) reduction in the extent, or number of acres, of hardwood land caused by conversion to more intensive uses. These changes, combined with a general shift in ownership and management of hardwood land, are resulting in a general decline in the diversity and quality of benefits available from the hardwood resource.

To address this concern, the California State Board of Forestry (BOF) has adopted a policy of protection, enhancement and restoration of hardwood habitat to assure that (1) all hardwood species are regenerating; (2) soil and water quality are preserved; and (3) sufficient habitat diversity is maintained statewide to protect the viability of wildlife species. Currently, the Board relies on a program of research, education and monitoring to implement this policy. Most of the responsibility for management of hardwood resources remains with private landowners and local governments.

This non-regulatory approach provides opportunities to utilize an array of conservation incentive techniques such as easements, land purchases, and landowner registry programs to protect important hardwood habitat that otherwise may be lost under overwhelming economic and social pressures. Given careful guidelines, these types of conservation efforts can supplement the BOF's program by addressing the short-term need to protect 'critical' hardwood areas. In order to provide a focus for these types of conservation efforts, it is first necessary to devise a system for defining, identifying and prioritizing these 'critical' hardwood areas.

Numerous criteria have been utilized in the development of systems to identify and rank areas for conservation purposes. Efforts to evaluate the significance of natural areas and potential wildlife conservation areas have used both quantitative and qualitative criteria such as: rarity or uniqueness; diversity; size; naturalness; productivity; representativeness; educational value; amenity value; scientific value; ecological fragility; replicability; and threat (Smith and Theberge 1986; Margules and Usher 1981). All but one of these criteria speak to some type of value, whether ecological or cultural. The last criteria, threat, introduces the risk of resource value loss due to a potential change in land use or an undesirable management goal. The juxtaposition of value criteria and risk criteria provide opportunities to narrow the field of interest based on a sense of urgency of effort.

Identifying hardwood resource conservation targets based on both value and risk criteria requires a system for identifying and prioritizing critical areas that can be readily utilized at statewide, regional and local levels. Such a system must be flexible enough both to respond to variations in both ecological and cultural characteristics and to utilize information sources of varying scope and intensity. It should be reasonably unconstrained, however, by lack of suitable information at any one level. This paper reports on the development of a flexible system responding to this need to:

1) define and identify critical hardwood resources using various ecological and cultural attributes; and

2) prioritize critical areas by relative need for conservation action.

CRITICAL DEFINITION CRITERIA

In the system proposed here, the definition of critical hardwood resources is the initial decision variable in the allocation of possible conservation strategies. Only those areas identified as critical will be considered for conservation action under this system. Critical resources are defined here in terms of:

1) resource attributes of concern; and

2) activities that threaten to diminish the value of those resource attributes.

Since this system is intended to dovetail with current state efforts and programs, the goals of the BOF will act as a guide in identifying resource attributes of concern. For purposes of defining critical hardwood resources these attributes will be limited to:

1) the extent and distribution of hardwood species;

2) water and soil quality risks; and

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3) wildlife habitat diversity.

These attributes are quite broad, and additional criteria are necessary to narrow the scope of interest. Hardwood resources that encompass the attributes stated above will be deemed *critical* only when their status is *threatened* by one of the following types of activities:

1) removal or harvesting of hardwoods;

2) conversion to intensive agricultural use or residential or commercial development; and

3) management activities (such as grazing, hydrologic manipulation, clearing, etc.).

Critical hardwood resources then, are defined here as a function of (1) resource attributes of concern, and (2) activities which threaten their stability. That is:

Critical Hardwood Resource f(Rc,Ta)

where: R = hardwood related resources
c = species extent & distribution, water & soil, and wildlife habitat diversity
T = threats
a = harvesting, conversion or management activities

PRIORITIZATION CRITERIA

The scope of potential critical areas, as defined above, is too broad to efficiently target sites for conservation. Further criteria are needed to prioritize areas by relative need for action. For example, endangered species habitat that is currently in the development permit process should logically receive a higher priority than similar areas under less immediate or damaging threats.

Site prioritization will be achieved by:

1) ranking the resource value of each threatened hardwood area under consideration;

2) ranking the importance of the perceived threat(s); and

3) combining threat and resource value rankings to derive final site priority rankings.

While initial identification of broad critical areas may occur at statewide and regional levels, proritization of these sites will likely occur at more local levels. To aid in the prioritization process, two other resource categories will be considered in addition to the three primary resource attribute criteria used to identify critical hardwood resources. These additional categories are: (1) range industry value; and (2) resources of particular local interest.

Traditionally, livestock production has been the dominant renewable resource use on California's hardwood lands, and the range industry has been a vital force in sustaining vast areas of hardwood lands in open space. Retention of a viable range industry provides greater opportunities for maintaining the level of open space required by many wildlife populations. The viability of the livestock industry depends, among other things, upon maintaining a flexible range of management options for operators while ensuring sound conservation practices.

Local interest in hardwoods reaches from individual character trees in urban settings to extensive areas of rural open space. Concern over change in the hardwood landscape often originates from local individuals or groups. This concern may be driven by a variety of factors including aesthetics, symbolism, and recreation. Moreover, most attempts to initiate conservation measures must involve both landowners and local government since these groups generally have the most discretion over hardwood land use (Doak and others 1989). Hardwood-related resources of particular local interest should be incorporated into the broader state-wide goals to ensure overall program support and success.

ISSUES AND ASSUMPTIONS

Several issues arise when considering criteria for defining and prioritizing 'critical' resources:

- What level of information should be used to identify and rank critical areas? What is the relative availability of information? Should criteria vary from local to regional and statewide perspectives based on information type and availability?
- Should protection efforts be focused on only the most viable areas, or should restoration potential be considered as well? In other words, should only the best be preserved, or should areas in poor condition be restored to their full biological potential?
- How do size and biogeographic factors affect identification and ranking? When does a parcel become too small to be a viable conservation target? How does adjacency of different ownerships and land uses affect viability?
- Should off-site mitigation be considered in the ranking process? That is, should preservation of areas under relatively low threat of destruction be considered as mitigation for the inevitable loss of ecologically similar sites?
- How does 'do-ability' factor into the identification and ranking of critical sites? That is, given the socio-economic environment affecting a given parcel, is it realistic to assume that desirable resource attributes can actually be preserved?

The system developed here is designed to be flexible in terms of the type of information used to describe resource characteristics. Broad statewide information can be used in initial assessments, but more refined data can be utilized at focused site-specific levels. Moreover, the nature of the scoring system ensures that lack of information at any level will not

impede the evaluation process. The system is also designed so that additional criteria can be added, under the appropriate resource heading, without upsetting the overall process.

In general, the focus of conservation efforts under this system is on sites that are ecologically viable. Opportunities do exist, however, for the inclusion of hardwood sites in need of restoration. While restoration of degraded sites is not a major focus of this system, it is considered when evaluating regeneration potential and the reversibility of the effects of various land use activities.

Biogeographic factors and individual parcel size are important factors in ranking critical sites. It is extremely difficult, however, to provide meaningful quantitative guidelines for size and spatial relationships as these are likely to vary considerably with the nature of the resource in question. For example, the preservation of a one acre lot may be critical to an endangered species, but the fate of a 40 acre parcel may have relatively little effect on soil and water quality. For these reasons, size and biogeographic factors are included only in general qualitative considerations.

The concept of off-site mitigation is not incorporated into this particular system. More likely, the process itself will be used in off-site mitigation efforts to identify certain types of resources. While the relative probability of conservation success, or 'do-ability,' is a critical question in directing resource conservation efforts, it is not incorporated in the system, but should be considered later when defining criteria for implementation .

THE CHRIP SYSTEM

The Critical Hardwood Resource Identification and Prioritization (CHRIP) System outlined here and presented in table 1, combines the criteria described above for defining, identifying and prioritizing critical hardwood areas. While each of the five resource attributes (hardwood stand characteristics, water and soil, wildlife habitat, range industry, and local resources) receive equal weight in the prioritization process, only the first three are considered in the initial identification of critical sites. Each attribute is represented by one or more categories (e.g., species of special concern and habitat diversity) which are rated individually within each attribute. If information is not available for one category, it can be by-passed without impeding the evaluation process. Likewise, additional categories can be added under the primary attributes as more information becomes available.

The extent and distribution of California's hardwood species varies considerably. Blue oak has the most extensive range and also occupies the greatest area. The blue oak type covers about 2.9 million acres, or almost 40 percent of the 7.4 million acres of hardwood woodland in the state. Engelmann oak, on the other hand, has a very limited range, occurring only in southern California and Baja California on about 39,000 acres (Bolsinger 1988). Valley oak has a fairly extensive range, but its actual distribution is quite limited. Adequate regeneration and recruitment has been a concern in several hardwood species, particularly valley oak, blue oak and Engelmann oak. Hardwood stand characteristics are rated here according to the status of existing or potential regeneration and recruitment, presence of scarce species or types, and relative significance of sites to the overall extent of certain species.

The maintenance of water quality and soil productivity are constant concerns in land management. Land use activities that typically occur on hardwood lands—such as residential and commercial development, agricultural conversion, wood harvesting, and livestock grazing—all have the potential to adversely affect both water quality and soil productivity. Soil and water characteristics are rated here according to regional watershed values, erosion hazard ratings, and proximity to various stream classes.

Wildlife habitat characteristics are rated according to the status of species of critical concern, importance as habitat for migratory deer, and overall habitat diversity. Hardwoods support more wildlife species than any other habitat type in California. The broad array of wildlife species found in hardwood habitats depend upon the extensive diversity of vegetative composition and structural characteristic of hardwood types. Broad habitat management goals, then, focus on the maintenance of an array of habitat components related to compositional and structural diversity. The Interim Wildlife/Hardwood Management Guidelines of the California Department of Fish and Game (1989) emphasize the importance of minimizing drastic changes in hardwood canopy cover and in maintaining overall structural diversity.

Rating range industry values can be problematic, and is best accomplished at the local level by those familiar with local industry practices. Groups of resource professionals should be formed at the local level to rate critical hardwood areas according to their value to the range industry. Criteria is likely to vary from area to area but may include location, size, topography, accessibility, proximity to other forage, irrigation, and distance from sources of conflict.

Local resource characteristics can only be evaluated by local interest groups, established in more focused phases of the prioritization process and using self-defined criteria. These criteria may include contribution to open space, historical significance, scenic beauty and other local amenity values.

The immediacy, intensity, and potential effect of perceived threats to hardwood-related resource values may vary considerably. Areas that are currently involved in the development permit process, for example, are more immediately threatened than similar areas that, given their demographic and legal environment, are likely to be developed within five years. The potential effect of certain activities, such as over-grazing, may be reversible upon cessation whereas the impact of other activities, such as commercial development, are essentially permanent. Potential and existing threats affecting a site are rated based on the relative immediacy of threatening activities, the expected permanence of potential effects, and perceived extent of the

effects on hardwood-related resources within and beyond the immediate area of concern.

SUMMARY

The CHRIP system for identifying and prioritizing critical hardwood areas provides basic guidelines for focusing conservation incentive programs on significant hardwood resources that may be lost under overwhelming socio-economic pressure. The flexibility designed into this method allows the incorporation of multiple levels of information from various sources and provides opportunities for adding criteria as more information becomes available. Given this flexibility, the basic structure can be used to identify broad areas at statewide and regional levels, and specific sites at local levels. This flexibility, however, also presents an inherent level of ambiguity in terms of the exact nature of criteria to be utilized. For this reason, the guidelines presented here should be viewed as a framework to be filled in as circumstances allow rather than a rigid, airtight system.

ACKNOWLEDGMENTS

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Table 1: ***Critical Hardwood Identification and Prioritization System***

Use the following five step key to identify critical areas (I) and prioritize them by relative need for conservation action (II, III, IV).

-I-

Is: (1) the extent and distribution of hardwood species; (2) water and soil quality stability; or (3) wildlife habitat diversity threatened by: (1) commercial harvesting of hardwoods; (2) conversion to intensive agricultural use or residential or commercial development; or (3) other land management activities?

NO Not a critical hardwood resource

YES Critical hardwood resource. Continue to II.

-II-

Evaluate each of the following five resource categories. Ratings are normalized within each category and may range from 0 to 100. If the status of a particular category is unknown it will be represented by a "U" and will not be considered in the ranking process. [3]

A. Hardwood Resource Value Point Allocation

Condition	Points
—hardwood regeneration and recruitment—	
status unknown	U
no hardwoods present	0
poor or inadequate regeneration	1
fair or potentially good regeneration	3
good regeneration and recruitment	5
—presence of particular oak species or types—	
status unknown	U
no hardwoods present	0
hardwoods present	1
blue oak present	3
valley oak present	4
Engelmann oak present	5
—extent of species range—	
status unknown	U
no hardwoods present	0
hardwoods present	1
hardwood species on the extreme of range	3
Engelmann oak or valley oak on the extreme of range	5
Total points	___

Hardwood Resource rating (total points / maximum possible points * 100 for those categories not answered with a "U") ___

B. Soil and Water Resource Value Point Allocation

Condition	Points
—regional watershed value—	
status unknown	U
below average regional watershed value	0
moderate regional watershed value	1
high regional watershed value	3
very high regional watershed value	5
—erosion hazard rating—	
status unknown	U
75% of site dominated by low erosion hazard	0
75% of site dominated by medium erosion hazard	1
75% of site dominated by high erosion hazard	3
75% of site dominated by extreme erosion hazard	5
—proximity to stream classes—	
status unknown	U
not within 500 feet of Class I or II stream	0
within 500 feet of Class I or II stream	1
bisected by or adjacent to Class II stream	3
bisected by or adjacent to Class I stream	5
Total points	___

Soil and Water-Resource rating (total points / maximum possible points * 100 for those categories not answered with a "U") ___

C. Wildlife Resource Value Point Allocation

Condition	Points
—species of special concern—	
status unknown	U
unlikely habitat for species of special concern	0
potential habitat for species of special concern	1
species of special concern present	3
threatened or endangered species present	5
—migratory deer—	
status unknown	U
not migratory deer habitat	0
migratory deer corridor	3
fawning beds	5
—habitat diversity—	
status unknown	U
low habitat diversity	1
medium habitat diversity	3
high habitat diversity	5
—riparian habitat status—	
status unknown	U
not supporting or adjacent to hardwood riparian area	0
adjacent to hardwood riparian area	1
contains or is potential hardwood riparian area	3
over 50% of site hardwood riparian area	5
Total points	___

Wildlife Resource rating (total points / maximum possible points * 100 for those categories not answered with a "U") ___

[3]Just as some categories may be bypassed in this process, others may be added under the appropriate resource heading.

D. Range Industry Resource Value Rating

—AUM value—	
status unknown	U
no value to range industry	0
low value to range industry	1
medium value to range industry	3
high value to range industry	5

Total points ___

Range Resource rating (total points / maximum possible points * 100 for those categories not answered with a "U") ___

E. Local Resource Value Rating

—local values—	
status unknown	U
no local value	0
low local value	1
medium local value	3
high local value	5

Total points

Local Resource rating (total points / maximum possible points * 100 for those categories not answered with a "U")

- III -

Evaluate the status of threats affecting or perceived to threaten hardwood resources. Ratings are normalized within each category and may range from 0 to 100. If the status of the threat is unknown it will be represented by a "U" and the site will be considered NOT critical.

Threatening Activity Point Allocation

Condition	Points
—immediacy—	
status unknown	U
no foreseen threats	0
likely within 5 years given socio-political environment	1
likely within 1 year given socio-political environment	3
activity proposed or application filed	4
activity in process	5
—permanence—	
status unknown	U
no foreseen negative effects	0
effects of activity reversible following cessation	1
effects reversible only with restoration effort	3
effects essentially permanent	5
—potential extent—	
status unknown	U
no foreseen negative effects	0
effects limited to immediate area	1
effects likely to extend to adjacent areas	3
effects likely to extend more than one mile beyond site	5

Total points ___

Threatening Activity rating (total points / maximum possible points * 100 for those categories not answered with a "U") ___

- IV -

Compute individual scores by multiplying the threatening activity rating by resource ratings only where indicated.

A. Is the extent and/or distribution of hardwood species threatened?
Yes — hardwood stand rating * threat rating = **Score-A** ____
No ..... **Score-A** = 0
Rating = 'U' ..... **Score-A** = 'U'

B. Are water and soil quality threatened?
Yes water & soil rating * threat rating = **Score-B**___
No ..... **Score-B** = 0
Rating = 'U' ..... **Score-B** = 'U'

C. Is wildlife habitat diversity threatened?
Yes wildlife habitat rating * threat rating = **Score-C** ___
No ..... **Score-C** = 0
Rating = 'U' ..... **Score-C** = 'U'

D. Are range industry values threatened?
Yes range industry value rating * threat rating = **Score-D** ___
No ..... **Score-D** = 0
Rating = 'U' ..... **Score-D** = 'U'

E. Are resources of local importance threatened?
Yes local resource value rating * threat rating = **Score-E**
No ..... **Score-E** = 0
Rating = 'U' ..... **Score-E** = 'U'

-V-

Compute the normalized site ranking by totaling values for all five scores (Score A - E) that do not equal 'U' and divide by the total number summed (0 - 5). That is:

Site Rank = [(Σ Score (A-E)) / N]

Where N = number of scores not = 'U'

The Legal Environment for Hardwood Lands in California[1]

Sam Doak Kass Green Sally K. Fairfax Sharon G. Johnson[2]

Abstract: Intensified use of California's hardwood lands is evolving rapidly. With these changes come clashes over the appropriateness of various land uses and, in some cases, regulatory efforts to control some of these activities. The legal environment facing hardwood landowners is a confusing mix of state, Federal, and local measures. This paper first describes and compares the legal environments facing hardwood land owners as defined by Federal, state and local policies, and secondly identifies some of the causal factors that have contributed to the current legal environment, particularly at the local level.

Attention has recently focused on the use and management of California's hardwood resources and hardwood lands. While once characterized by low use and low value, California's increasing population and suburban expansion have served to focus new demands on hardwood lands. Concerns today focus upon (1) the decline of hardwood stocking caused by increased tree removals and limited regeneration success, and (2) the decline in the number of acres of hardwood land as caused by conversion of these acres to industrial, residential, and agricultural uses.

The use of California's hardwood lands is evolving rapidly. With these changes come clashes over the appropriateness of various land uses and the policies and regulations intended to guide them. Yet the legal environment facing hardwood landowners is a confusing mix of state, Federal, and local measures that has until now, remained undescribed.

The purpose of this paper is two fold: first, to describe the legal environment facing hardwood land owners as defined by Federal, state, and local policies and regulations, and secondly, to describe some of the causal factors that have contributed to that legal environment, particularly at the local level. The information presented here is a summary of a larger report prepared for the California Division of Forestry and Fire Protection as part of the Integrated Hardwood Range Management Program (Doak and others, 1988). Case studies and background information that could not be presented here are contained in that report.

METHODS

Because of the complex nature of the legal environment for hardwood lands, this study required the review and analysis of a broad range of data. Federal and state statutes, policies and programs providing the framework of the current legal environment were inventoried and examined. Policies were characterized as to (1) whether they were regulatory, educational, or incentive in nature, (2) how they were implemented, (3) the level of transference of property rights from the private to the public sector, (4) the level of transference of resources from the public to the private sector, and (5) the relative effect on hardwood stocking or hardwood land use. This inventory of state and Federal statutes was then combined with profiles of the primary organizations [e.g., Board of Forestry, Department of Fish and Game] that work within this legal framework.

Next, local ordinances and other restrictive polices regarding hardwood tree removal were inventoried and analyzed. Phone interviews were conducted with county and city personnel throughout the state and relevant documents were collected and examined. This inventory aided in the selection of case study counties and in the eventual development of a typology of local ordinances and policies affecting hardwoods and hardwood lands.

Finally, six case study counties, Monterey, Nevada, San Diego, Tehama, Tulare, and Ventura, were selected for an in depth investigation of causal factors stimulating the regulation of hardwood cutting. The regulatory environments in these case study counties were investigated in three ways. First, diverse variables describing the economic, ecologic, and demographic conditions of the case study counties were examined, as was the relative presence of Federal and state government in local affairs (as suggested by e.g., number of Federal and state employees, grants, expenditures).

Each case study county was then visited and studied in depth through extensive interviews with planning directors, and other persons with interests or influence in local land use decisions. Ordinances, code books, and planning documents were also extensively reviewed. The information collected on these county visits lead to the clarification of county regulatory histories, the identification of conditions leading to regulation, and notable similarities and differences within and between counties.

Lastly, the local, state, and Federal legal environments were described and compared. Causes of variation were analyzed both statistically and heuristically for each case study county. Greater detail on these analyses is available in Doak and others, 1988.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31 - November 2, 1990, Davis California.

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A DESCRIPTION OF THE LEGAL ENVIRONMENT

The legal environment created by the state and Federal governments has developed for different reasons than that created by local governments and similarly is implemented through different mechanisms. Financial and manpower resources also greatly vary between Federal, state and local jurisdictions. These factors, combined with divergent policy objectives, history of policy development and varying implementation capacities, create a confusing array of regulation that any hardwood landowner must face.

Variation In Levels of Police Power

Local policies affecting hardwood lands tend to be strict applications of police power while state and Federal policies are more likely to involve some level of compensation in exchange for increased public control over private land use. This tendency is modeled in figure 1. Local regulations tend to fall along a line parallel to the vertical axis, while state and Federal policies more often fall along the diagonal line, representing an exchange of land use discretion for an equal value of benefits.

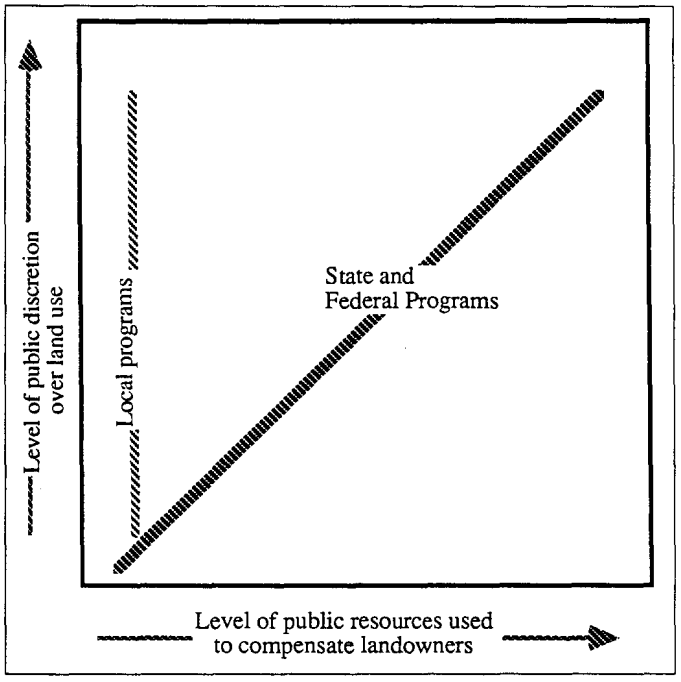


Figure 1—Local Policies v. State and Federal Policies.

Variation in Breadth of Focus

State and Federal law also tends to provide a framework within which various local laws emerge, but the actual promulgation of local statutes, generally reflects local issues and site-specific economic, demographic, physiographic, and ecologic factors. Often, local ordinances are somewhat narrowly focused on local land-use issues rather than addressing the larger resource issues involved. Resulting local land use controls may preserve trees and hardwood lands by restricting development and preserving open space, but they are generally not designed to protect related ecosystems.

Similarly, ecological factors such as soil stability, erosion, and sedimentation, as well as aesthetic factors like visual quality, and historic significance may emerge as the issues that precipitate local regulation. But when voiced by resource professionals or planning staff alone, these issues are not likely to result in regulation. Instead, regulation occurs only when concern for these issues is shared by a coalition of community interest groups that can apply their combined political muscle to the issue at hand. Development and agricultural groups usually share anti-regulatory values, and together they can often squelch, or at least modify, proposed regulations. Unless negatively affected by the incident, agricultural operators and developers will generally join to oppose most forms of county-wide hardwood land regulation. Thus, the necessary coalitions are often difficult to assemble on a county-wide level, but may be successful at more local levels, as evident in the measures adopted in area plans (Monterey County), and special zones (Scenic Resources Protection zones in Ventura County).

Many state and Federal programs affect hardwoods indirectly by influencing the overall viability of agricultural operations on hardwood lands. But these programs may have widely differing effects on hardwood retention as they are rarely designed with hardwoods in mind. For example, programs that reduce the cost of land ownership, such as the California Land Conservation Act [also known as the Williamson Act] which provides mechanisms for tax relief to encourage the continuance of agricultural land uses—or programs that increase the revenue opportunities available to landowners—such as the Ranching for Wildlife Program, which encourages improved wildlife habitat management on private land while creating opportunities for increased income from hunting—may provide incentives to retain hardwood land in large ownerships. Similarly, other programs may encourage the maintenance of hardwoods by providing a disincentive for converting land to agricultural uses by increasing the costs of such operations. For example, the sodbuster provision of the 1985 Federal Farm Bill [Title 12 of The Food and Security Act of 1985, Public Law 99198], was designed to discourage agriculture on highly erodible land but may also encourage the retention of hardwoods. Conversely, water supply projects that encourage new agricultural development on hillsides may diminish the extent of hardwood lands.

Although, most state-level hardwood protection on private lands to date, has occurred as an indirect consequence of other policy—such as the Williamson Act which was implemented in

response to concern over the loss of prime farm land—current concern for the hardwood resource as voiced by citizens, counties and resource professionals has initiated consideration at the state level. Currently the State of California, through the Board of Forestry, has adopted a hardwood policy focusing on research, education and monitoring. The research for this paper (Doak and others, 1988) was funded by the State and is part of that effort.

Urban Versus Rural Focus

A major contrast between state/Federal and county policies and regulation is that county policies are generally limited to urban or urbanizing areas while state and Federal programs are focused on rural areas beyond the urban fringe. Because they tend to be urban-oriented, local tree-specific ordinances—or even open space policies—tend not to affect large expanses of undisturbed woodland and may result in resource islands rather than any great amount of contiguous open space. In turn, however, the site-specific, urban nature of local policies limits interference in the economic livelihood of most rural agricultural operations.

Inter and Infra-county Regulatory Differences

The propensity of counties to regulate hardwood land use varies measurably both between and within counties. Monterey County, for example, has a wide array of instruments that affect tree cutting such as local tree-cutting ordinances, land clearing ordinances, open space programs, and hillside development restrictions that affect hardwood land use. In contrast, Tehama County's regulatory structure addresses little more than basic agricultural zoning.

Within an individual county, tree removal ordinances tend to be site-specific, and rarely extend county-wide. Only three counties have ordinances with county-wide restrictions: Los Angeles, San Bernardino, and San Mateo. Other county ordinances apply restrictions only in particular zones. Monterey County's several area specific tree ordinances, for example, still leave the majority of hardwood land free of tree removal restrictions. The application of other county ordinances and policies similarly varies from site to site depending on the type of land use activity to be regulated. Agricultural exemptions, which are common in many types of local ordinances, further complicate the picture.

In summary, the state and Federal legal environment for hardwood lands generally differs from the local legal environment in the following ways:

- Local controls tend to be site-specific while state and Federal programs are resource specific;
- State and Federal programs generally focus on rural land use while local policies affecting hardwoods are usually limited to urban, suburban or developing areas;
- Many state and Federal programs offer landowners some compensation for increased public discretion over land use while local statutes are usually strictly regulatory;
- The state and Federal programs that affect hardwood lands often do so by influencing the economic viability of certain land use activities.

CAUSES OF VARIATION WITHIN THE LEGAL ENVIRONMENT

Changes in the local legal environment are generally precipitated by incidents of tree cutting or development that negatively affect people other than the land owner. In contrast, changes in the Federal or state regulatory environments are more likely to be initiated by shifts in national interests, such as economic factors, than by the degradation of the hardwood resource itself.

Although large scale tree removal often results in public outcry, extensive but discrete degradation of hardwood-related ecosystems may not. This is particularly evident in situations where dispersed residential development is hidden by retention of extensive tree cover, as is common in the foothills of the central Sierra.

While a major cutting/development incident may be necessary to precipitate change in the local legal environment for hardwood land, it is not a sufficient force in of itself. Instead, the eventual implementation of restrictive policy depends upon a political bargaining process involving community agricultural, development, and residential interests as well as planning staff and resource professionals. The creation and adoption of policy thus often reflects the relative influence of these interest groups and their perceptions of both the proposed statute and the incident that precipitated the proposal.

Incidents of tree cutting or development are most likely to occur along land use margins and are usually precipitated by changes in economic conditions. When the economic environment affecting a land ownership changes, than the likelihood of change in land use increases. The relatively low value of hardwood land, traditionally used as range, makes it susceptible to land use changes and potential conflict, especially when located near urban centers.

Whether or not a tree cutting or development incident leads to a change in the local regulatory environment depends on:

1) The spatial distribution of land uses and hardwood lands within each county [spatial factors]; and

2) The resultant bargaining between organizations affected by the incident [organizational factors].

In general, cutting or development incidents are more likely to evolve into increased regulation when:

1) Trees are perceived as scarce. Ventura County, for example, has limited tree cover and local ordinances focus on preserving the few remaining native species.

2) The greater the erosion potential, as a function of slope and soil type, of hardwood lands. Monterey County's oak ordinance, for example, originated from concern over soil erosion resulting from the clearing of oaks from a steep sandy hillside.

3) The area contains unique trees. The massive valley oaks of the City of Visalia are a focus of civic pride and are protected by ordinance.

4) The pattern of development is more fragmented. Many ordinances emerge from incidents in areas where agricultural activities are juxtaposed with residential use.

5) Residential interest groups are relatively affluent, well educated, and politically powerful. Restrictions are more common in the affluent coastal areas of Monterey and Ventura Counties than in the interior rural, agricultural regions of these counties.

6) The traditional coalition between development and agricultural interests deteriorates.

7) Resource professionals find a coalition with politically powerful residential interest groups. Local resource professionals often have considerable expertise in proposing and designing environmental controls, but they have little direct power and cannot effect policy implementation without gaining support from other local interest groups.

The process of change in the various legal environments affecting hardwood land follow a similar basic pattern. First, an incident—whether a visible tree removal, shifts in the economy, or a professional report—is perceived to be a significant issue by individuals or groups with access to political power, and the issue is brought before a legislative authority (e.g., Congress, local board of supervisors, or state legislature). This authority, may decide either to actor not to act. Action may result in change in regulation or policy, or a decision to study the matter. Study, in turn, may lead to change or to no action. This simple pattern is demonstrated in figure 2.

In summary, Federal, state and local policies create a complicated legal environment for California's hardwood landowners. The complexity of this environment is compounded by the tremendous variation between and among counties. Changes in this legal environment are generally precipitated by an incident of tree cutting or development, but while an incident may be necessary for change, it is not sufficient in of itself. The interaction of the spatial and organizational variables inherent to local situations will define when a cutting or development incident will lead to public uproar, whether or not an ordinance or policy will result, and where and to what intensity the ordinance will be applied.

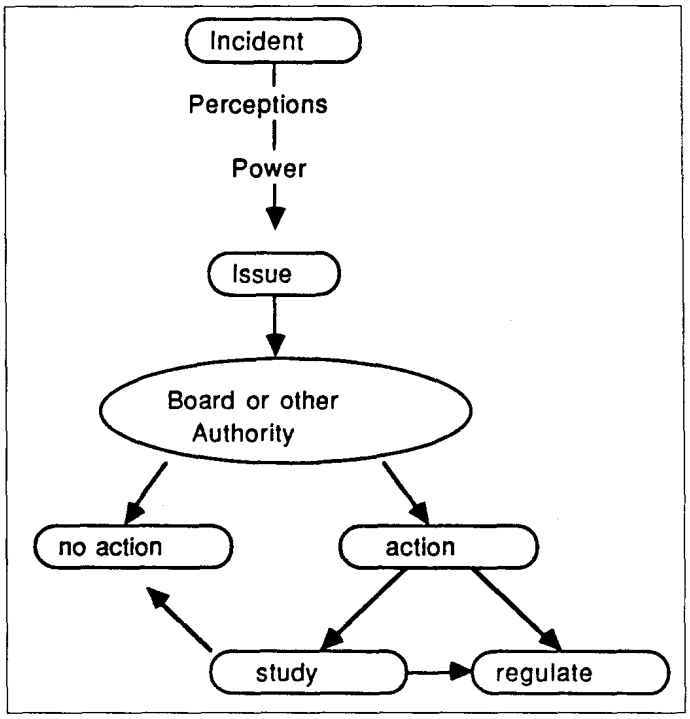


Figure 2—Pattern of Change in Legal Environments for Hardwood Lands.

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Oak Sustainability: A Challenge Through Public Education and Outreach Programs[1]

Gregory A. Giusti Robert H. Schmidt Kenneth R. Churches [2]

Abstract: Throughout California, public awareness on the role humans play in the decline of oak acreage is increasing. Public and private organizations, agencies, and individuals are instituting planting days, releasing articles on oaks to the media, and sponsoring lectures. Many of these activities are limited in scope and lack a strong educational component that promotes sustainability. Educational programs certainly need to address such issues as site selection and preparation, acorn selection and storage, nursery propagation, species identification, and audience identification. This paper discusses sustainability as it relates to stand restoration and landscape-wide ecosystems. Educational delivery methods are examined and potential audiences are defined.

Sustainability is a concept that has become very popular in recent years. Today we see this term attached to agriculture, forestry, fisheries, rangelands and nearly every other area of resource management. In this paper, we propose that sustainability concepts be applied to oak restoration, preservation, and management schemes.

A homeowner may perceive sustainability as the preservation of a single tree for 10 years, while a rancher, county planner, or landscape architect may define sustainability as the continuance of a stand of oaks over 100 years. Resource management professionals might apply the term to the perseverance of plant and animal species diversity and ecological community continuity within oak woodlands for perpetuity.

In all cases, individuals may be interested in preserving oaks but may view the trees in completely different terms. A common pitfall of homeowners and planners is the focus on preserving individual trees, concerning themselves with the retention of a "museum piece" that, in terms of sustainability, has little to do with maintaining genetic diversity, providing wildlife habitat, or even producing progeny that will ensure replacement over time.

The literature has many examples stressing the need for a systems approach to hardwoods management (Bolsinger 1988, Passof and others 1985, Plumb and Pillsbury 1987, Schmidt 1991). However, the vast majority of people who have direct impacts on oaks in California have little knowledge or access to these documents. As our awareness of oak-related issues expands and grows, educators must analyze and present information in such a way that the concepts are understandable, attainable and, in terms of education, sustainable. This paper reviews our perceptions about successful approaches and potential pitfalls to oak-related educational projects.

AUDIENCE IDENTIFICATION

If the concept of sustainability is to be incorporated into educational programs, then audience needs must be analyzed. The audience for oak-related information must be identified, and the needs of the audience must be addressed.

Professional horticulturalists, gardeners, arborists, and landscape designers often are interested in oak-related issues. However, individuals representative of these groups often focus on the "sick tree" approach. Though what they do is important for landscape and aesthetic purposes, as a group they are often dealing with clientele whose focus is on single trees. In recent years, urban and wildland forest consultants, city and county planners, and resource management professionals have become more involved in oak-related issues as the interested public has demanded a broader expertise. These are the groups that are focused, through regulatory obligation or professional responsibility, on the concept of sustainability and how it may apply to a localized situation. Even within this group, however, there is a broad range of competence regarding sustainability. Oftentimes resource management professionals are limited in their perception of audience needs.

Another group often mentioned as an important audience component in relation to oaks is the "developers," since development-related pressures have been responsible for three-quarters of the oak woodland acreage lost over the past 15 years (Bolsinger 1988). However, when trying to define this group, it often becomes apparent that any person who purchases a parcel of land is a potential developer. It is extremely difficult to target educational programs toward any one person or group who may or may not some day be considered a developer. This lack of clear definition causes difficulties when trying to define the major players in oak sustainability programs. The misconception that developers are a well-defined group who can be reached through conventional approaches can impede an education program if the audience definition process is not comprehensive.

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Although this "developer" contingent is an important clientele group whose actions are obviously significant, they can be reached or affected through alternative channels. For example, commercial developers are often aware of trends and conditions via the appropriate planning department. Therefore, it is not always necessary to target the developer as a separate audience since it is local policy that will dictate what can and cannot be done with oaks. A key group when trying to promote sustainability to developers are the private, city, county, and state planners who are in the process of developing and enforcing relevant policies having a direct impact (general plans, codes, ordinances, and other types of regulations). We do not suggest that the developers as a whole be ignored when developing educational programs. We are stating that developers can receive information and educational material via alternate channels.

Planners, often well represented at conferences and symposia on oak-related topics, have shown a great deal of interest in the issue of sustainability. As a whole, this group represents the "troops on the front line." They must have access to information that allows them to outline and protect the direction that the city or county will take in the present and the future. Though many planners would like to incorporate the concept of sustainability into their decision-making process, they are often working with divergent groups with variable knowledge levels, a variety of political concerns, and widely opposing goals. They need to be given applicable information that is useful in day-to-day decisions.

An important group often absent from oak-related workshops is the ranchers. Ranchers, as livestock producers, are both the primary owners and managers of hardwood range (Bolsinger 1988). However, on an individual basis, many ranchers see the current interest in oaks as a "non-issue" to their daily operations. This is not true at the state level, where representatives of the various livestock associations are keenly aware of the issues and how future trends may impact their groups. As a group, livestock operators have difficulty understanding the range and depth of political and social pressures on them in regards to the conservation of hardwood resources, including oaks. This is especially true of individuals who have had their land in the family for multiple generations. They perceive an increasingly urban society trying to regulate a resource that they consider to be abundant. We have not found this group to be ignorant of oak values. We have found differences of opinion as to the importance of oak-related issues as compared to other issues which affect their livelihood.

Finally, school-age children of all ages and backgrounds must be considered an important clientele group. Regardless of the cliche, today's children *are* tomorrow's leaders (and resource users). Minority groups in particular need to be targeted with educational programs which impress upon the children that they can impact their environment.

EDUCATING THE PUBLIC

We have all heard individuals stand before a group of people and expound on the need to "educate the public" on a wide spectrum of subjects. With the current political climate in California and the turmoil surrounding natural resource policies and management, ranging from water allocations to mountain lion (*Felis concolor*) hunting to forest harvest practices, coupled with the fact that every special interest group is trying to "educate the public" to their particular viewpoint, it is easy to imagine that the public is being overrun with "education". Giusti and Schmidt (1988) discussed the need to bring all groups together in order to facilitate communication between people with strongly divergent views. In the case of oaks, most people are in agreement that oaks are worthy of *some* attention, and the problem is one of a lack of understanding and agreement rather than completely polarized views. In this regard, with our efforts to try and "educate the public," at least the current climate is not one of pro versus con but rather one of focus and educational delivery. We need to tailor educational and extension strategies which exploit this consensus. It is important not only for all impacted clientele groups to learn more about oak sustainability, but it is equally important that all groups understand the concerns carried by all *other* groups. Consensus building and negotiation never work unless all affected groups recognize that they each have something to lose (and hopefully something to gain). Education is a critical part of that process.

EDUCATIONAL APPROACHES

In 1985, the California Department of Forestry and Fire Protection, the California Department of Fish and Game, and the University of California established the Integrated Hardwood Range Management Program (IHRMP) in order to address concerns regarding the lack of natural regeneration of some species of native oaks combined with a statewide decline in acreage of these trees. This educational approach was taken in lieu of strict regulations threatened by the Board of Forestry. Passof (1987) and Tietje and Schmidt (1988) gave a descriptive overview of the process and outlined the goals and objectives of IHRMP. They further described the needs and methods for developing an educational program and the need to convey information to landowners, special interest groups, and the general public. Since 1985, a great deal of effort has gone into research and education. Evaluation programs aimed at determining the effectiveness of these programs are now underway. The general public is more aware of oak issues. In addition, predictions of under-utilized hardwoods such as tan oak

(*Lithocarpus densiflorus*) and exotics (*Eucalyptus* spp.) fording a greater share of the market are now being realized (Passof 1987). However, the issue of sustainability is still with us.

We have been responsible for a variety of educational programs related to oaks and directed to a wide range of clientele groups. These activities have included oak planting schools, 4-H projects, publications and newsletters, meetings with planners, classroom teaching at community colleges, newspaper and radio interviews, lectures to service clubs, tree ordinance committees, research symposia, testimony to local government bodies, field tours of research and demonstration plots, and organized educational forums. Two full day educational forums in Sonoma County alone, entitled "Construction Among the Oaks" and "A Day for Oaks," had 200 and 270 registrants, respectively. We literally have reached tens of thousands of people. Have we really promoted and emphasized the issue of sustainability?

We now find ourselves at a crossroads needing to choose between information, education delivery systems, and audience needs and values. Many people have now accepted the fact that oaks are a resource needing special attention. With this realization often comes the zealous approach inspired by this new found cause. We must insure that all clientele groups be concerned about sustainability. We must make sure that the "museum piece" mentality is de-emphasized and that landscape processes are emphasized. The sustainability of thousands of acres, if not hundreds of thousands of acres, of oak woodlands lie in the balance.

SUSTAINING OAK WOODLANDS THROUGH EDUCATION

Incorporating the concept of sustainability into education as it relates to hardwoods will be most successful when the message can reach a defined audience in such a method and manner that the long term retention of the information that is being conveyed will be insured. In order for this approach to be feasible, audience identification is crucial to the process and an educator must know the audience's needs and perceptions prior to delivery of information. The educator must also understand sustainability.

Brochures, pamphlets, and handouts are all tools that can be used as part of an educational program. One of the more attractive brochures, *Living Among the Oaks* (Johnson no date), is a useful and helpful source for people who have specific questions regarding their oaks on home grounds. Once again, this material focuses on single tree issues that can easily be addressed in a short pamphlet. However, sustainability issues should have been addressed. We must utilize every opportunity to get the message across. If a homeowner wants to find out about watering oak trees, he or she can learn about watering while at the same time learning about the regeneration concerns, biodiversity, and the impacts of habitat fragmentation.

Churches' (1989) publication on oak tree planting presents the 4-H student with basic identification of oaks, the collecting and storing of acorns, planting techniques, transplanting and care of seedlings, and control of oak pests. The project is designed to be taught over several weeks in order to ensure that the students will absorb the information. The booklet is also designed so that a teacher in the primary or secondary level could easily adjust it to meet their needs. This type of "step-by-step" approach begins by explaining to students that oaks are not merely a stately tree outside the local shopping mall, but rather they are a living organism that goes through several stages during its life span. This multi-staged approach to education can now be included within the natural resources curriculum that a teacher may have already established.

Students, being a captive audience, are sometimes the easiest group to reach. The difficult audience may be the teachers. Many local communities already have programs aimed at involving teachers and providing them with information that they can use in their classrooms.

Examples of existing and credible programs include the California Farm Bureau's program "Ag in the Classroom" and the California Department of Fish and Game's "Project Wild." Both of these programs are aimed at teachers, and are presented in such a way that they can be adapted to meet an individual's needs and have credible standing within the teaching community. These two programs could easily encompass materials and information on oak trees and are designed to present the material over an extended period of time. Issues of sustainability should be incorporated into these programs.

It is not always necessary to "re-invent the wheel" when trying to secure a mechanism to deliver the concept of sustainability. Already existing programs and a population of enthusiastic primary and secondary teachers, eager to present their students with materials about natural resources, are sound and credible starting points.

Other avenues include the formation of inter-agency forums that include public input. On a local level these have proven successful in delivering sound information over an extended period of time. The key to this approach is to allow people to hear various viewpoints and let them have input into the learning process, allowing them to absorb what is being presented. One consequence to this approach is the increased amount of time that is needed to deliver this information.

Public education and outreach programs are very popular today. Various individuals, groups and organizations are all trying to deliver information that they feel is important regarding oaks. If we are going to promote the idea of sustainability of California's oak resource we must also begin to include sustainability in our messages. The mechanisms are in place; we as educators now need to encourage people to stop looking at the trees as individuals but rather as part of a larger system.

Additional programs need to be developed to address the needs and concerns of all the affected clientele groups discussed above. Continuous evaluation programs are also necessary in order to track the effectiveness of educational programs and materials. This feedback loop would allow for modifications as needed to maximize program effectiveness.

THE FUTURE OF SUSTAINABILITY

The effectiveness of today's programs will be measured decades or centuries from now. This time lag differential demonstrates the importance of incorporating sustainability into educational programs immediately. Oak woodland environments throughout California have been impacted tremendously by humans over the past 200 years. We have modified plant and animal species diversity and population numbers. California leads the continental United States in numbers of threatened and endangered species. California will have over 30,000,000 inhabitants by the year 2000. Human impacts on oaks will expand at an increasing rate. The best that we can do is blunt the impact of the coming years on oak woodland ecosystems. By striving for sustainability of our remaining stands, whether they occur in urban, rural, or wildland settings, we hope to preserve functional, sustaining, and diverse oak woodlands.

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San Diego County Planning Efforts to Preserve Oak Woodlands[1]

Thomas A. Oberbauer[2]

Abstract: Development of San Diego County has traditionally taken place on the coastal plain and in coastal valleys. Within the past two decades, it has spread into the foothills resulting in conflicts with oak woodlands. The County of San Diego has proposed a number of measures to protect oak vegetation including a tree protection ordinance, land use designations and zones designed to protect outstanding sensitive vegetation, and a brushing and clearing ordinance. The predominant method for preservation of oaks is through open space easements within subdivisions. This usually results in the protection of small, habitat patches. However, a coordinated effort needs to be made to preserve large blocks of habitat.

San Diego County has one of the fastest growing human populations in the United States. The development in this County has taken place predominantly on the coastal plain where chaparral, coastal sage scrub, grassland and vernal pool vegetation occurs. However, in the past twenty years, agriculture and urban development have moved into the foothills where vegetation consists of oak woodlands and chaparral. Because oak trees are a valuable aesthetic and wildlife resource in this part of Southern California, the County government has grappled with attempts to protect them from the adverse effects of land development.

Distribution of Woodlands in San Diego County

The oak woodlands that grow in San Diego County occur in a variety of forms. Many coast live oak (*Quercus agrifolia*) occur along small arroyos in the coastal region. In the portion of the County inland from the coast, the terrain takes on a foothill/valley aspect where coast live oaks occur on the margins of large valleys, north facing slopes and filling smaller alluvial valleys. In some of the foothill areas, Engelmann oak (*Quercus engelmannii*) occurs on rolling hilltops as well as mixing in with coast live oak. Farther inland, above 3,500 to 4,000 feet, the California black oak (*Quercus kelloggii*) becomes a common species. In some locations, it forms nearly pure stands. In the higher mountains, the canyon live oak (*Quercus chrysolepis*) also grows. At the time of pre-settlement of San Diego by Europeans, it is estimated (Oberbauer 1990) that there were roughly 80,500 acres of oak woodland that form an open configuration on rolling hills and interior mesas, and about 28,900 acres of the dense, and linear form of woodland. However, oaks also constitute a major portion of the species composition within the coniferous forest which covers roughly 79,000 acres of San Diego County.

There have been two trends that have dominated the disposition of oak woodland vegetation in San Diego County in the past. The first evolved from a public view that trees are a valuable visual and aesthetic resource in an area that was generally covered by shrub vegetation. Traditionally, there has been a concern to protect oak trees in coastal areas for their ability to create shade and provide a beneficial environment for human inhabitants. The Native Americans were somewhat dependent upon oak woodlands for food sources and the European inhabitants, while no longer requiring such a food source, still greatly appreciated oak trees. The result has been that many of the oaks that originally occurred along the coast remained without much disturbance other than for limited fire wood gathering which had an unknown effect. The interior regions, however, support more oaks. With the greater numbers, the value of the individuals seems reduced. Consequently, this has resulted in the second trend: woodcutting greater amounts of firewood and heavy levels of cattle grazing. In recent decades, these trends have somewhat changed. With the introduction of imported water into the region, the ability to create artificial woodlands of faster growing trees was enhanced. It also became possible for urbanization to spread and for orchard agriculture to be produced over hillsides and slopes. In fact for some, orchard agriculture may have replaced oaks in fulfilling a psychological desire for trees.

Impacts to Woodlands and Alleviating Actions

Oak woodlands in the coastal regions have typically occurred in drainage areas along streams and arroyos mixed with chaparral while urban development took place on the mesas and in major valleys. Since the trends toward oaks have changed, the impacts to them have also increased. Furthermore, since urban development has invaded the foothills of this county where natural habitats had predominated, the result has been conflicts with woodland preservation.

The perceived loss of oak trees has raised concerns of many of the local citizenry. The San Diego County Board of Supervisors has responded to the concerns of the local citizenry by creating land use controls intended for protecting oak trees and

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woodlands. These have included policies in the Conservation Element of the General Plan and special zones. Additional state regulations such as the California Environmental Quality Act (CEQA) (1990) require the consideration of impacts on sensitive habitats which in the San Diego region include oak woodlands. However, the overall effect of these regulations has been a piecemeal approach to the preservation and protection of oak trees. Individual subdivisions are frequently approved with small open space or conservation easements that are dedicated to the County. These easements may preserve individual or even a clusters of trees, but they are not likely to preserve the oak woodland habitat as a viable wildlife area or corridor. In addition, a number of the woodland areas "protected" as open space are likely to eventually succumb to stress and damage from road and building construction close to their root systems. The urbanization of the foothills also results in increased levels of road construction. The majority of the roads in the foothills traverse drainages due to the topographic factors which facilitate construction. As the foothills develop, the expansion of the road system results in a significant loss of linear woodland habitat.

At this point in time, roughly 5-6 percent of the major areas of oak woodland are known to have been directly lost due to agricultural clearing and urbanization, but the figure of impacts may be greater due to the lack of complete data for historic periods. Furthermore, a significant percentage of the oak woodlands that occur in San Diego County have been grazed heavily by cattle for the last 200 years. Much of these areas now support little understory of vegetation; this has reduced the viability of the woodlands as habitat. Continued heavy grazing reduces oak reproduction since no young trees survive the grazing. The areas in which this problem is most prevalent are the rolling hills and mesas in the foothill and lower mountain slopes. The woodlands that occur in a linear fashion along narrow stream courses and drainage bottoms and those on steep lands may still support understory habitat and reproduction due to the lack of access by grazing animals.

The major effect of development in oak woodlands in this County is still increasing as it spreads through the foothills, engulfing all lands that are outside of the ownership of the Cleveland National Forest and California State Parks system. Major subdivisions in areas such as Valley Center, Ramona, and Alpine frequently result in the loss of oaks.

COUNTY PLANNING

The following are some case histories of measures attempted by the County of San Diego to regulate the destruction of oak woodlands.

Tree Protection Ordinance

In the mid-1970s, a proposal was created to adopt a tree ordinance into the Code of regulations of the County of San Diego. This ordinance would have designated trees as a protected status. Protected trees were to be defined as "Heritage trees"; this included trees specifically designated by the Board of Supervisors. The tree ordinance would have required the acquisition of a permit to cut more than a small percentage of protected trees per year. The ordinance also had provisions for replacement of the trees allowed to be removed. Trees that were not designated as Heritage Trees would not have had limitations on their removal, though CEQA would have still regulated protection of such trees when development was proposed. Due to concerns raised by backcountry residents and the agricultural community regarding the perceived restrictions of their property rights, the tree ordinance was not adopted in the County. The overall issue and pitfalls of utilizing ordinances to preserve trees have been well discussed by Rossi (1990).

Resource Conservation Areas

In the late 1970s, the Resource Conservation Area proposal was initiated by a task force working to create the Conservation Element to the state required San Diego County General Plan. The Conservation Element identified the need for special designation of particularly outstanding natural resources in the county. In 1979, the Resource Conservation Area was designed as an overlay designation, adopted as part of the Conservation Element.

Implementation of the Resource Conservation Area program was originally designed to be carried out in a phased manner beginning with mapping the outstanding natural areas and including adoption of those areas by the County Board of Supervisors in a formal hearing. Additional phases were to include the application of land use designations and special zoning regulations such as the Impact Sensitive designation and Sensitive Resource Regulator. Other phases involved careful consideration of the sensitive resources during the application of subdivisions and outright purchase. The criteria for creation of biological Resource Conservation Areas included locally important vegetation resources including oak and riparian woodlands in continuous drainage patterns or large patches. The Impact Sensitive land use designation is usually utilized for areas of woodland within floodplains but is also applied to upland areas. It requires parcel sizes based on slope ranging from minimums of four to twenty acres.

In the late 1970s, the County of San Diego also adopted the "Sensitive Resource Area Regulations" that could be applied through the zoning process to Resource Conservation Areas. This process also required a decision by the San Diego County Board of Supervisors during a noticed public hearing. The essence of the Sensitive Resource Area Regulations was that properties so zoned would require an administrative permit from the Director of the Department of Planning and Land Use,

including environmental review under CEQA, before undertaking vegetation disturbances. Therefore, the intent was that before sensitive habitat could be cleared, it would be necessary for the impacts of that clearing to be mitigated. The Sensitive Resource Area Regulations were applied to some vernal pool habitat in the Otay Mesa Area and to an oak woodland filled canyon northwest of Ramona. This canyon also contained a golden eagle nest site and a 50 foot waterfall. Again, concern for property rights made the application of these regulations controversial.

Shortly after the application of these regulations to the canyon area, the political composition of the Board of Supervisors shifted and the Board acted not only to remove the Sensitive Resource Area Regulations from this canyon, but also from the County zoning ordinance. The Director of Planning was later forced to resign and the Sensitive Resource Area Regulations were cited as one of the reasons.

At the present time, Resource Conservation Areas drawn up by planning staff have been applied to the majority of outstanding habitats in the western part of San Diego County through the community planning process (San Diego County General Plan, Part X Conservation Element 1990). They occur over substantial areas of oak woodland habitats in upland areas and on major oak woodlands along stream courses. In 1988, a large Resource Conservation Area was applied to the Palomar Mountain region as well as the Mesa Grande area where expanses of Engelmann, coast live and California black oaks exist. In 1991, Resource Conservation Areas are proposed for application to areas within and surrounding Cuyamaca Rancho State Park.

Though the Sensitive Resource Area Regulator has been removed from the San Diego County zoning ordinance (Zoning Ordinance, San Diego County 1990), Resource Conservation Areas still stand as an indication of areas that are considered outstanding natural resources by the County of San Diego. Discretionary permits which require County approval are evaluated carefully in these areas. In addition, the Parks and Wildlife Bond Act that was approved by the voters of California in 1988 contained specific provisions to provide funding for acquisition of San Diego County Resource Conservation Areas. In 1989, a portion of that funding was used to acquire more than 200 acres of Volcan Mountain near Julian. The property acquired supports pure stands of the California black oak (*Quercus kelloggii*) and open meadows.

Brushing and Clearing Ordinance

During the mid-1980s, several large areas of San Diego County were brushed and cleared under the guise of agriculture and to avoid environmental review when applying for development approval. Due to concerns by the public, the San Diego County Board of Supervisors adopted a brushing and clearing ordinance in 1989. This ordinance establishes a procedure to issue notices of violation if a property has been cleared of its native vegetation including chaparral, coastal sage scrub and oak woodlands. Exemptions are granted for lands that are smaller than ten acres in size, lands for which a brushing and clearing permit has been granted after environmental review and lands on which an agricultural exemption has been granted. Agricultural exemptions may be granted if the owner signs a statement certifying intent to develop the property to agriculture within one year and maintaining that use for five years. The penalties of the brushing and clearing ordinance may include fines of $1,000 per day and may be grounds for denial of all discretionary permits on the property for five years. The violation is also recorded on the property and can be removed only when the Planning Director and Board of Supervisors determine it is no longer in violation. Since the adoption of this ordinance, a number of violations have been issued including one where a major oak and riparian woodland was clearcut and one where oaks were heavily impacted by bulldozing beneath their canopies. However, the penalty phases are still in the process of being tested.

Offsite Mitigation

The County of San Diego is currently investigating a number of procedures for offsite mitigation of woodland or other habitat loss. While there has not yet been a coordinated procedure which San Diego County utilizes for offsite mitigation measures, there have been a few cases in which mitigation measures for development involved the preservation of offsite habitat. In particular, the County itself proposes to purchase offsite woodlands to mitigate the loss of oaks to several proposed landfills. Other options for offsite mitigation include "mitigation land banking" and the use of Land Trusts.

Mitigation land banking has a number of advantages and disadvantages. The advantages are that mitigation can take place in advance of project construction since the mitigation site would already be secured. Another advantage is that negotiating and establishment of mitigation in advance of project proposals provides the opportunity to implement mitigation in a timeframe not controlled by the deadlines of the development. In some cases, the initiation of a land bank planning effort may stimulate the development of local goals for habitat protection, enhancement and creation. They also must involve all of the appropriate local, state and federal agencies and private parties which can force conflict resolution. Another advantage is that a mitigation land bank formal agreement can be used to ensure commitment and establish responsibility for follow-up evaluation and adjustments in the bank management plan if the desired outcome is not achieved. Reduction in Federal permit processing time is another benefit because Federal and State agencies would have already concurred with the appropriateness of a mitigation banking procedure. It also has a benefit of public recognition of the importance of mitigation actions.

The first of the potential disadvantages may be the reduction in quality of project planning. A major risk associated with mitigation land banking is the possibility that bank credits would be used before all other means of avoiding impacts are exhausted. In reality, the only true mitigation is avoidance. A second major

disadvantage of mitigation banking is that it results in a net loss in habitat. Unless mitigation land banks involve habitat creation or restoration, which are still technically unproven concepts in San Diego County, mitigation banks represent a net loss in habitat if they result in the preservation of one habitat to "compensate" for the loss of another. Another potential problem is that there is no guarantee that all of the species lost at a project site will occur at a mitigation bank site. In highly developed areas, land available for offsite mitigation projects may be very limited and high in cost. This can result in mitigation banks that are located a considerable distance from development and a decreased availability of mitigation areas for other developers who are planning projects near land banks. Still, with all of its disadvantages, mitigation banking may assist in the creation of large blocks of sensitive woodland habitat rather than patchy mosaics of preserves.

Analysis of Regulatory Cases

In practice, the predominant method of protecting oaks in the County of San Diego is through the regulatory process of subdividing land or approval of use permits for development. Under CEQA, all discretionary projects, those that are not allowed by right but which require a decision for approval by an agency, must be evaluated for potential environmental impacts. This includes all permits such as subdivision approvals, special and major use permits, and grading permits and variances, but does not include ministerial permits such as building permits.

Under the California Environmental Quality Act, environmental impacts that are considered significant must be mitigated. In addition, in response to citizen ballot measures in 1989 the County of San Diego adopted and in 1990 amended the Resource Protection Ordinance (RPO) to deal with adverse development.

Under RPO and CEQA, oak woodland habitats are considered to be sensitive so that projects proposing to develop land containing them need to include mitigation measures. In most cases, these mitigation measures involve the dedication of the land to the County or a third party group as an open space easement. An attempt is made to connect these easements as linear corridors, in the case of woodlands along drainage bottoms, or in blocks, for woodlands on slopes and mesas. The disadvantages with this process are that open space easements may end up as "postage stamp preserves" rather than biologically viable habitats. Such preserves are inefficient and poorly able to protect woodland resources in perpetuity. They are likely to be affected by impacts from the surrounding developed uses and by an inability to control illegal activities such as clearing of the understories. Postage stamp preserves result from the fact that the creation of open space easements are often the result of political decisions rather than biological tenets. The area of an open space easement is frequently a compromise between the desires of an applicant, the staff recommendation, and the tolerance of the political decision makers. Such compromises may not take into account the need for "buffers" to insure the preservation of individual trees or adjacent, non-woodland habitat necessary to maintain woodlands as viable habitats. Oaks are often preserved as specimen trees because they are commonly considered valuable only for their aesthetic features rather than their habitat value.

An additional disadvantage of utilizing open space easements is that they are frequently dedicated to the agency that approves them, such as the County of San Diego. While their initial dedication may be the result of a need to mitigate the environmental impacts of a development proposal, it only takes a passing motion to vacate them. Once vacated, the mitigation measure that fulfilled the requirements of CEQA to mitigate the impacts of a development is removed. In reality, this should also mean that the project can no longer be approved, but it is not likely that an approved and built subdivision would ever be removed if a mitigative open space easement was vacated.

Another disadvantage of utilizing open space easements or any type of mitigation measure is the need to assure the maintenance of that measure in perpetuity. While CEQA (Sec. 21081.6) requires that mitigation monitoring be included in project approval by public agencies, it has been poorly implemented by most agencies. In addition, when an open space easement is approved, if it is later violated, the mitigation issue would have to be reopened.

Finally, the fire management issue can be a problem. Placement of open space easements within a subdivision or some other type of development creates a potentially hazardous fire condition. Fire protection requirements and areas to be cleared around structures are under the control of fire protection agencies. The use of open space easements may be an inappropriate approach to mitigate impacts to woodland vegetation in a development that should not be approved in the first place. Such developments may eventually degrade the woodland resource due to the need for fire controls at a later time.

STEWARDSHIP OF OWNING OAK WOODLANDS

To a number of landowners, oak woodlands are considered an attribute. Some capitalize on their value, particularly when developing residential development surrounding golf courses. The majority of landowners who propose to subdivide land are also willing to place the woodlands into open space. However, as the foothill regions become more developed and larger areas of woodland are encountered, the value of the oaks to property owners appears to diminish in some cases. There have been identified cases in San Diego County where owners purposely cleared the oaks from their property. While owners are willing to protect portions of oak woodlands on property, if the entire property is covered with trees, the situation becomes more problematic. Property owners may be willing to conform to

many regulations, but property rights are strongly held notions. Any proposal which can be viewed as a reduction in rights of property owners is usually controversial and may be weakened or reduced in effect during the political review process. In the interior regions of the County where oaks are dominants and development is not yet imminent, the ranchers are usually willing to leave their trees intact as an overstory of cattle grazing lands, but with little specific regard for oak protection.

CONCLUSIONS AND SUGGESTIONS

In conclusion, there are a number of different land use controls that can be used to attempt oak habitat protection. However, they all require the cooperation of the governing authority, the property owners and citizen conservation organizations. While the systems described above may be able to protect individual trees or groves of trees, there are few programs currently being well implemented that would protect oak woodlands as viable biological habitats in areas where development is taking place. Furthermore, the relative level of impact to oak woodlands has far from peaked. As the foothills are developed, there will continue to be significant losses of woodlands to land development.

The following are suggestions that would assist in better preserving oak woodlands in an urbanizing area such as San Diego County. While these suggestions are strictly directed toward oak preservation, application of several of them may be controversial.

1. Coordinate open space easements so that they all connect and create viable corridors.

2. Acquire mitigation land bank areas to preserve blocks of habitat while still attempting to save specimen shade trees and clusters within proposed developments. This is critical for shrub communities such as coastal sage scrub but will become more important for woodlands as foothill lands develop.

3. Investigate acquisition of large woodland tracts by public or other groups. In San Diego County, this would include the mountains and foothills of northern and central San Diego County.

4. Evaluate appropriate methods to enhance oak reproduction in foothill grazing lands.

5. Create standards for mitigation/replacement ratios of woodlands in foothill subdivisions and determine if revegetation and vegetation development is in fact feasible. Regeneration attempts should be performed only when all other means to avoid the impact are unavailable and should not be considered a full mitigation measure.

6. Consistently apply land use designations and zoning to foothill and mountain areas that are appropriate for areas with sensitive resources and lack of services and access.

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A Mitigation Process for Impacts of the All American Pipeline on Oak Woodlands in Santa Barbara County[1]

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Abstract: This paper outlines a mitigation program for pipeline construction impacts to oak tree habitat by describing the requirements for the Offsite Oak Mitigation Program for the All American Pipeline (AAPL) in Santa Barbara County, California. After describing the initial environmental analysis, the County regulatory structure is described under which the plan was required. The plan preparation and approval process is described, as well as how the plan was and is currently implemented in the field. The paper concludes with an assessment of plan objectives and recommendations for future mitigation efforts.

PROJECT DESCRIPTION

The All American Pipeline is a 1,250 mile long, 30-inch diameter buried crude oil pipeline constructed in 1985 and 1986 between Gaviota, California (20 miles west of Santa Barbara) and McCamey, Texas (fig. 1). The purpose of the pipeline is to transport Outer Continental Shelf (OCS) oil from the Santa Barbara and Santa Maria basins to refining centers in the Gulf Coast. Sixty miles of the pipeline are constructed in Santa Barbara County, along an alignment generally shown in figure 2.

Most of the pipeline was built using standard pipeline construction practice. This involved the clearing of an approximately 100-foot wide right-of-way (50 feet permanent and 50 feet temporary work space) to allow for ditch excavation, spoil placement, pipe stringing and welding, and passing room for equipment (fig. 3). Once the pipe ditch was backfilled, graded contours were restored and the right-of-way (ROW) was revegetated.

IMPACT ANALYSIS AND REGULATORY STRUCTURE

Approximately 60 percent of the pipeline length occurred on federal lands, therefore environmental impacts of the project were described and analyzed in a joint National Environmental Policy Act/California Environmental Quality Act (NEPA/CEQA) document (Environmental Research and Technology 1985). Impacts to oak woodlands occurred primarily in Santa Barbara County and were considered as Class I impacts requiring mitigation.

In Santa Barbara County, the primary discretionary review and approval for the AAPL project was a Development Plan. One of the 140 conditions of approval (Condition H-1) was the preparation of a Restoration, Erosion Control and Revegetation Plan (RECRP) for the pipeline ROW. Because of existing County concern regarding the protection of oak woodlands and the Class I impact to oak woodlands described in the Environmental Impact Report/Statement (EIR/S), Condition H-I specifically required procedures for oak preservation. Though never explicitly stated in permit condition wording, County representatives consistently stated that this meant 100 percent replacement of all removed oak trees. AAPL's Offsite Oak Mitigation Program is an appendix to the RECRP prepared pursuant to Condition H-1. The RECRP in turn is a component of the overall Environmental Quality Assurance Program (EQAP) for the project.

ALL AMERICAN PIPELINE OFF-SITE OAK PROGRAM

The plan finally approved by the County included provisions for minimizing impacts to oak trees during construction, replacing removed trees, using local seed sources, establishing habitat units, and maintaining and monitoring plantings until trees are 6 feet in size.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

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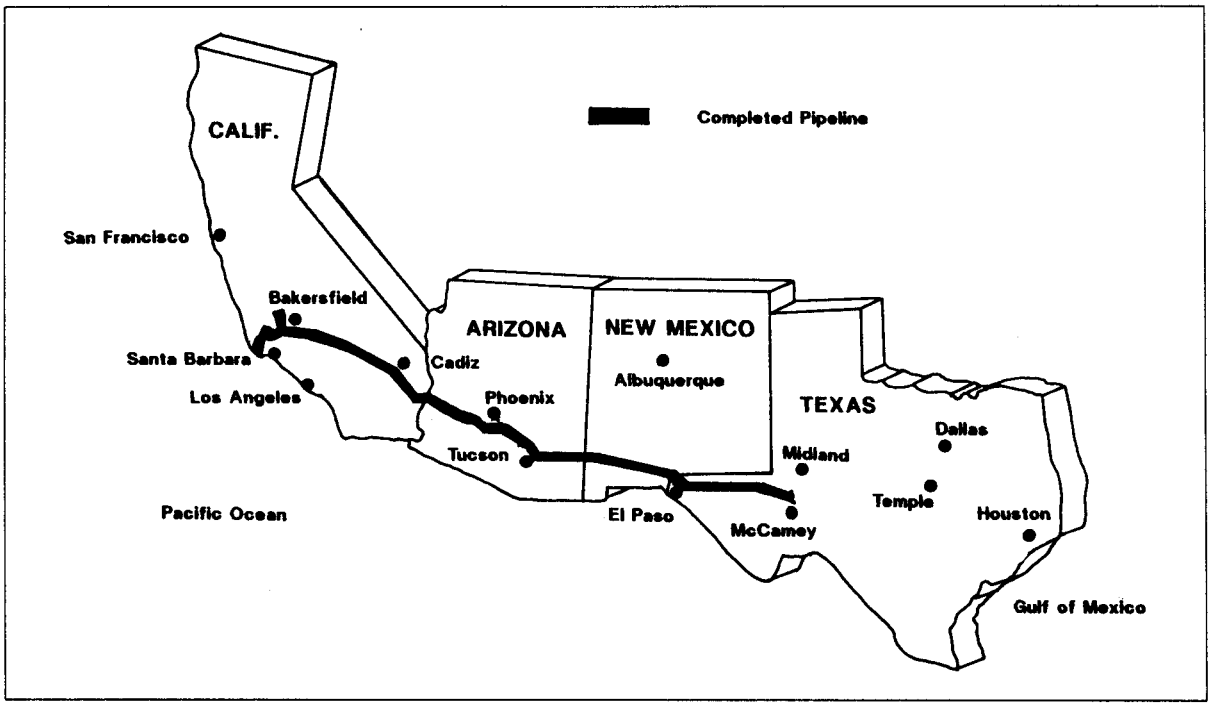


Figure 1—All American Pipeline route.

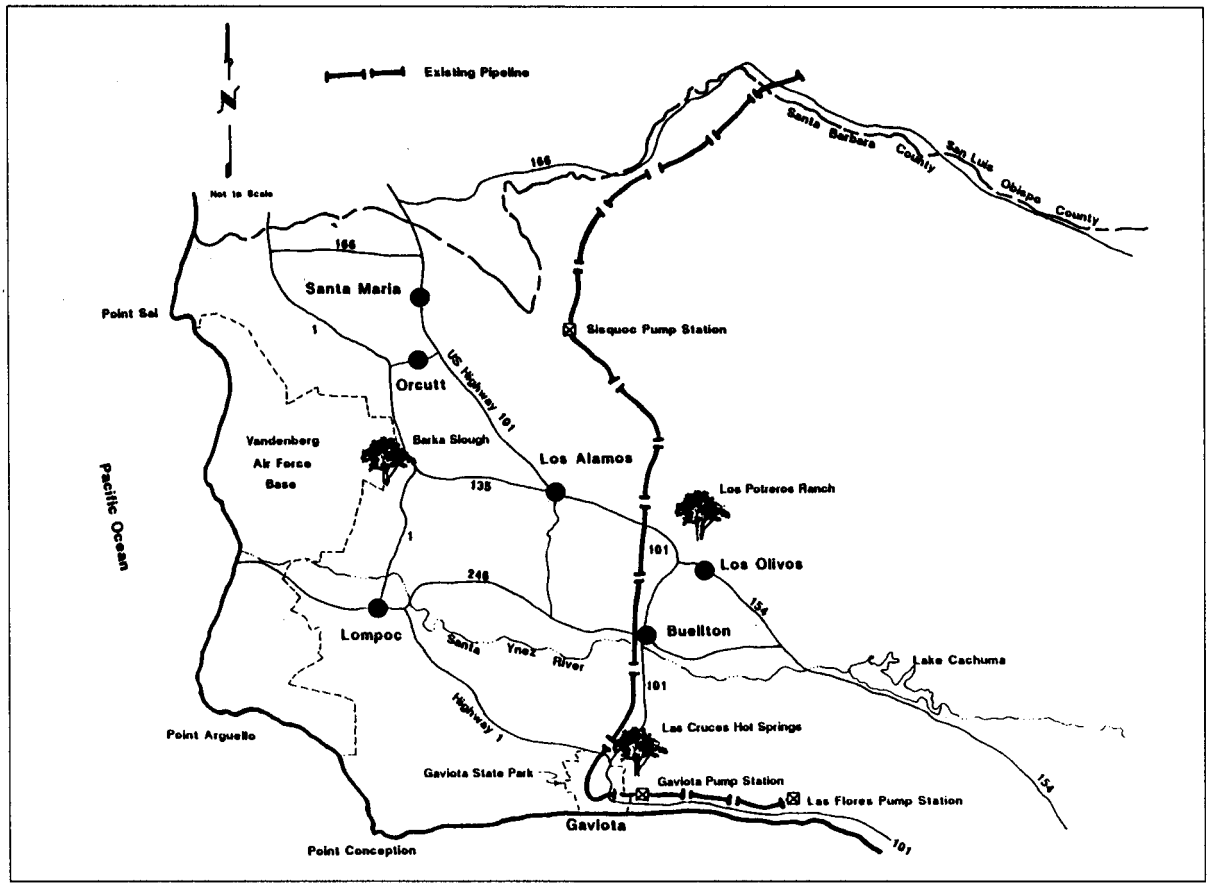


Figure 2—Pipeline alignment in Santa Barbara County.

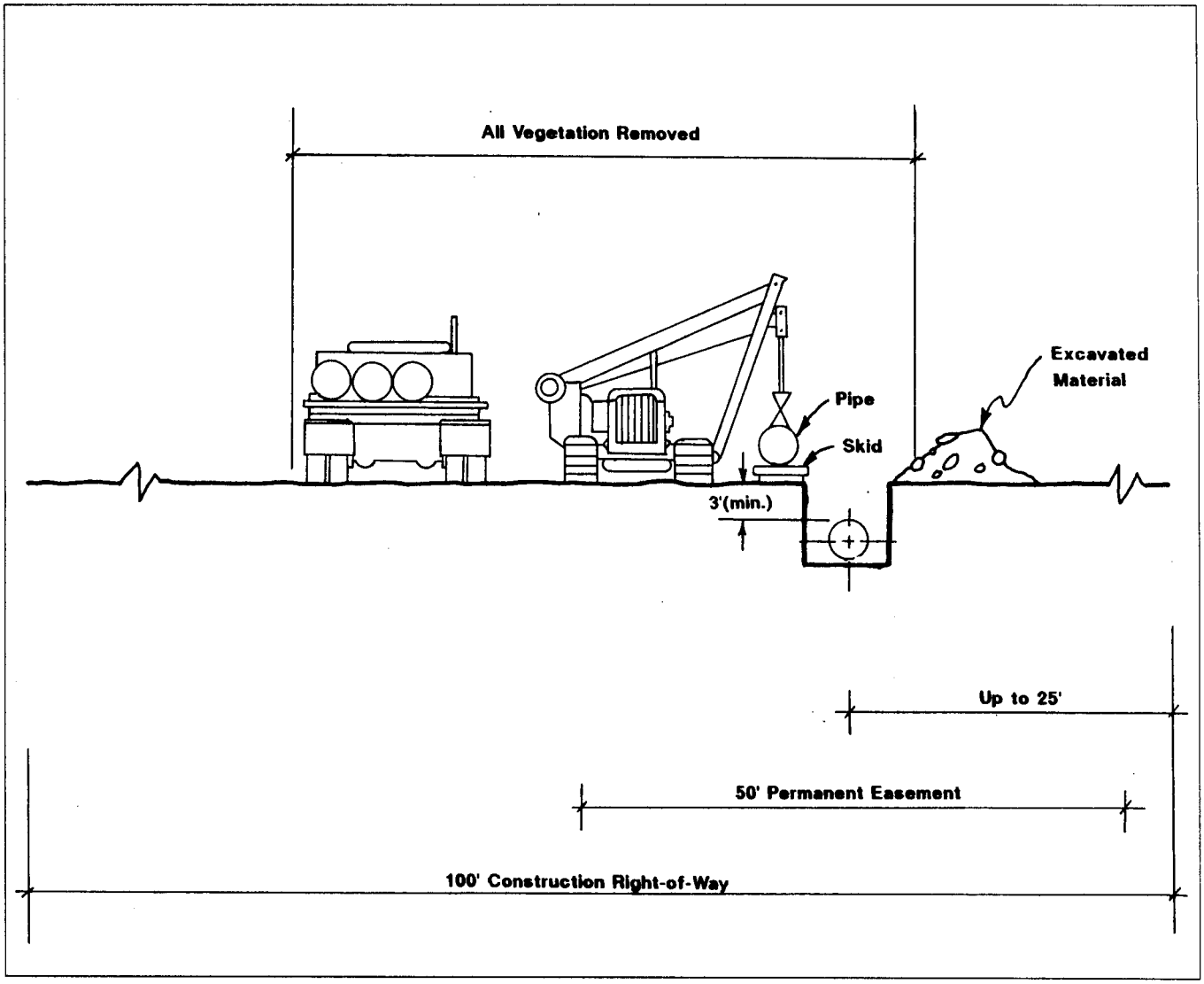


Figure 3—Typical construction right-of-way.

Minimizing Construction Impacts

During construction, trees that had to be removed were identified jointly between AAPL, the construction contractor, and Santa Barbara County's EQAP monitors. Where terrain allowed for a narrower construction corridor, the right-of-way width was reduced from 100 feet to 50 feet in oak woodlands. Where space allowed, individual trees were avoided within the construction ROW. Trees were trimmed instead of removed wherever possible. Slash was disposed of to reduce risk of disease associated with insect infestations. Trees were measured, marked and tallied in the field immediately ahead of construction. The tally was used to determine the number of trees to be replaced pursuant to the Off-site Oak Mitigation Program.

Plan Requirements

AAPL was required to replace all trees greater than 5 inches in diameter measured at breast height (about 40 inches above the ground). The plan estimated, based on aerial photographs, that approximately 500-1,000 oaks would be removed during construction. The final tally indicated that about 2,263 trees greater than 5 inches in diameter were removed. The majority of trees were coast live oak (1,303) and blue oak (878). Only 82 valley oaks were removed.

Habitat Units

The plan required that the trees be planted in natural habitat "units" as opposed to replacement in County Parks or in private landscaping. The plan specified that habitat units be a minimum of 1-5 acres in size. The plots were to be planted with seed source

material (acorns) collected from the site or from surrounding areas extending in concentric circles from the planting site. This was required in an effort to take advantage of genetic stock that should be adapted to each specific site's conditions.

Planting Methods

The program design allowed for flexibility in the methods used to establish new oak trees. Acceptable methods included enhancement of natural regeneration (protecting new seedlings), or planting acorns or propagated seedlings. The plan did not require watering, but allowed supplemental watering as an option. It specified protection of the trees from local predation and required weeding and pest control as necessary to maintain the trees.

MONITORING

The plan required that AAPL maintain, monitor and replant the plots until 6-foot trees are established. Six foot trees were set as the "performance criterion" because this size was expected to be well adapted to its site and large enough to cope with deer or cattle predation without fencing or other protection.

The plan requires that results of each year's efforts be documented in annual reports.

Plan Objectives

AAPL's objectives were to satisfy the condition in the most cost effective and efficient manner possible. In formulating the plan, AAPL depended on existing literature and scientific research to determine the appropriate techniques for planting. The plan was reviewed by recognized experts in order to solicit constructive criticism before the plan was finalized.

"Off site" Planting

The program was to be done "off-site" for several reasons. First, the County had recently approved, as part of a larger package of policies relating to oil and gas development, a set of policies requiring pipeline consolidation. These policies, still in effect today, require with certain exceptions that new pipelines be routed in approved corridors that have undergone previous environmental review. The All American Pipeline approval established a primary north-south pipeline corridor in the County. Therefore, future north-south pipeline approvals would be required to be constructed as closely as possible to the AAPL alignment. This in fact became the case for the County's recommendation for portions of the proposed Exxon Lompoc Pipeline. Therefore, any oak trees replanted along or adjacent to the AAPL corridor could be removed by future pipeline construction, establishing an endless cycle of unfulfilled mitigation.

Second, maintenance and inspection requirements for pipelines require that they be visible from the air and that vegetation on the ROW not hamper equipment in the event of an emergency. There also was a safety concern that roots of mature trees could affect the protective external coating and insulation on the pipeline. Therefore planting trees on the operational ROW was not acceptable.

Finally, it simply was not practical to efficiently manage the program across sixty miles. The pipeline as currently constructed in Santa Barbara County crosses over 40 individual land parcels as well as public lands (U.S. Forest Service and California Department of Parks and Recreation). Land use practices across the pipeline vary greatly. Replanting and maintaining trees in a line across so many different parcels with different management practices was not considered to be efficient. Planting oaks off-site also provided an opportunity to rehabilitate and/or establish new woodland habitats in large plots.

Establishing Valley Oak

Valley oaks are the most threatened species in Santa Barbara County. This is due to a combination of factors including conversion of habitat to other land uses such as crop lands, vineyard, pasture land and housing development, and a lack of natural regeneration and recruitment to the population. Increasing the number of valley oak, and oak savannah habitat in general, was a major focus of the plan.

Encouraging Natural Regeneration

Another overall approach in the plan was to encourage natural regeneration. The focus of the project was to establish young seedlings in habitats capable of supporting oak trees without long term supplemental watering. However, the last four years of drought have severely limited the success of this approach.

Finding Land Parcels

Interest in participating in the program was solicited through a series of formal and informal contacts with private organizations and public agencies. Presentations to service organizations (i.e., Lions Clubs and Rotary Clubs) on the pipeline as a whole always included a discussion of the off-site oak program. Interested parties were contacted and sites were evaluated based on site selection criteria developed jointed between AAPL and the County.

Site Selection Criteria

The primary selection criterion was the site's ability to support oak trees. Criteria for site selection included habitat characteristics such as soil type, slope, presence of oak trees and evidence of natural regeneration. Aerial photographs, soil surveys, interviews with local land managers, and several field trips were conducted to evaluate sites. Other important considerations were the site's size, its access, availability of water, grazing pressure, and future land use.

LANDOWNER OBJECTIVES AND AGREEMENTS

Three agreements were developed with Vandenberg Air Force Base, the California Department of Parks and Recreation (for a site in Gaviota State Park), and one with the Los Potreros Ranch, a family owned ranch in the Santa Ynez Valley. Each agreement allows AAPL to access and replant the site for the next 15 years, provides the land to AAPL without cost, and allows for the construction of structures to protect planted seedlings. The following section briefly outlines the specific objectives and requirements of each agreement.

Vandenberg Air Force Base (VAFB)

The site at VAFB is above Barka Slough and is dedicated wildlife habitat. The site is 900 acres in size and supports scattered coast live oak trees. Historically the site was grazed, and it is apparent trees were removed over time for crops and grazing. VAFB was interested in adding habitat structure to the site and speeding up natural recovery by adding new trees. VAFB agreed to eliminate grazing from the site while oaks were being grown. The site is fenced to exclude cattle, but predation from wild hogs and gophers, combined with continuing drought conditions, have resulted in total mortality of trees at this site. Future plans under consideration include a small planting experiment with supplemental watering.

Gaviota State Park

This regeneration site is within Gaviota State Park near the Las Cruces Hot Springs. The site currently supports coast live oak woodland with some natural regeneration. The site, about 50 acres in size, was burned in 1955. The park was interested in increasing regeneration of the burned site and in participating in a project that would help develop planting techniques for their continuing efforts to replace exotic species with native trees.

Los Potreros Ranch

The Los Potreros Ranch is located in the Santa Ynez Valley near Los Olivos. The ranch is 12,000 acres in size and contains some of the best remaining valley oak habitat in the County. The AAPL project removed 82 valley oaks during 1986 construction across the Santa Ynez Valley; most of the trees came from this ranch. The off-site oak regeneration sites consist of three separate subsites and two large valleys. The sites are less than 0.5 mi from the construction ROW.

Noting the decline of valley oaks on the ranch in the last 40-50 years, the owner was concerned with the lack of natural regeneration and in reversing the decline on their land as well as learning techniques that could be used on other ranches. Currently AAPL has three large fenced subsites on the ranch, each about 5 acres in size. In addition, AAPL is experimenting with small cattle exclosures and has been able to plant 400 trees in these exclosures in two separate valleys.

With the continuing drought in Santa Barbara County, and at the request of the ranch, AAPL has instituted a year round watering schedule for the valley oaks. The ranch has volunteered water for the trees; the plantings on the ranch are located in areas where watering is feasible.

One of the limitations of the landowner agreements is that the plots are not afforded permanent protection beyond the 15 years expected to be used to establish 6-foot trees. The plots are not protected by conservation easements. If permanent easements would have been required it is difficult to predict whether appropriate lands for the project could have been secured at all. The fact that two sites are located on public lands does provide some protection for the plots beyond the term of the AAPL program.

Since oaks are subject to protection in the County, the new oak trees resulting from the plantings should be afforded the same protection as provided naturally regenerated trees. Likewise, both Vandenberg Air Force Base and California Department of Parks and Recreation recognize the oaks as a resource worthy of protection. Oaks planted or present on agricultural lands could be impacted by ranch development if the activity is permitted by agricultural zoning; therefore to some extent the oak trees planted on Los Potreros Ranch are subject to protection as deemed appropriate by the ranch. In the future, the County's current tree protection plan and policies may be modified to address other species besides oaks and the policy may also apply to agricultural lands. If these changes in policy occur, the oaks planted by the AAPL program may benefit from further protection. Currently the greatest challenge to these trees is surviving the drought.

ATTAINMENT OF PLAN GOALS

The fundamental objective of the Offsite Oak Mitigation Program was to satisfy one of many permit requirements on the project in an innovative, resource-sensitive, and cost effective manner. Secondary objectives were to develop needed oak regeneration research data, and provide information for future regulatory policy decisions where oak resources were involved.

Success has been severely hampered by the continuing area-wide drought conditions. This external factor has indefinitely extended the time frame for plan implementation and success. While it was known and recognized during plan formulation that successive iterations of planting and maintenance would be necessary, the severity of drought-induced mortality has been much greater than expected.

Each season AAPL has followed through with best and reasonable efforts toward making the program work. The Offsite Oak Program is now in its fourth season. Based on summer 1990 results, there are approximately 336 valley oak seedlings, or 84 percent of the goal set for valley oaks. However, only 108 coast live oak or less than 1 percent of the coast live oak objective has been reached. This low success rate is directly related to drought-induced mortality at the VAFB and Gaviota State Park sites.

Some success has been achieved. With normal rainfall or supplemental watering, the' ultimate goals of the plan are not impossible but are surely farther away and at greater cost than either AAPL or the County anticipated.

The program continues to meet its objective of providing useful research information through the project's monitoring and reporting program. All information generated from this project is available to the public from AAPL or the County of Santa Barbara. AAPL has and will continue to provide access to the sites for qualified researchers and other interested parties to study and evaluate the ongoing program. Funding provided to the U.S. Forest Service by this project has provided for publishing existing research as well as supporting new scientific work. The program also continues to provide information for regulatory policy decisions, both for agencies as well as applicants.

Agencies can learn that while this program may serve as a precedent for requiring or at least considering this type of mitigation for similar projects in the future, it is obvious that natural conditions will govern the success of any tree replacement program.

RECOMMENDATIONS FOR FUTURE PROJECTS

While the program as envisioned is far from complete, several recommendations can be made for future oak woodland mitigation programs for pipelines and other corridor projects. These recommendations include avoidance, plan flexibility, appropriate program scale and location, and watering contingencies.

Avoidance

For linear or corridor development projects, the main strategy for minimizing impacts continues to be avoidance. Avoiding sensitive resources through careful routing is a special measure not available to all types of development. For corridor development, avoiding impacts altogether can be a realistic and effective method of minimizing environmental costs.

Even after discretionary approvals are obtained, applicants and permitting agencies should not be hesitant to consider minor realignments based on new field information, when the realignment is more beneficial to the resources involved. In order to do this effectively, the applicant must be able to concisely propose realignments and the permitting agency must be able to provide analysis and approval or denial in a timely manner.

Plan Flexibility

Despite the most favorable alignment, however, not all impacts can be avoided. Therefore, the costs of preparing and implementing mitigation programs of the nature described here should be carefully considered. In an effort to begin project construction, developers and agencies often assume that impacts can be easily mitigated. In order for an innovative project to be successful, involved parties must be willing to be flexible and accept a certain amount of "unknowns" in trying a new approach. Not every contingency can be accounted for during the formulation, negotiation, and approval of a mitigation plan, whether for oaks or any other resource.

Both the County and AAPL were willing to allow and encourage flexibility in developing and implementing this program. Both parties agreed to a plan that could not be fully specified until after construction had occurred, since the full scale of the plan (the number of trees ultimately removed) could not be known until that time.

Program Scale

It is necessary to have this flexibility in order to adapt the plan to fit each particular regeneration site's environmental conditions and constraints. What success has occurred to date has come from allowing for flexibility in the program. It will continue to be important in developing continuing strategies at each site as well as the possible selection of new sites.

To achieve an acceptable cost/benefit ratio, mitigation projects should be scaled to a size that is feasible to monitor and maintain effectively while achieving the desired results. Initially AAPL planted over 5,000 trees in an attempt to establish some trees on all of the plots. One site (VAFB) lost 1,600 trees within 3 months of planting due to severe drought at this location. Due to the terrain and size of the planting, it was impossible to institute watering in time to save the trees. AAPL is now considering a much smaller scale planting with supplemental watering to get oak trees started. It is recommended that a small scale but steady effort be done each year to establish trees.

Likewise, agency monitoring efforts borne by the project must be carried out consistently and cost effectively. In the case of AAPL, changes in agency personnel have resulted in additional costs to the project in terms of training and explaining programs that were already underway. In some cases, third party monitoring costs on particular project elements actually exceeded the cost outlay on the element itself.

Watering

The continual drought has been a serious limitation to the success of this natural regeneration project. AAPL is considering providing supplemental watering to those sites where water is available. Therefore, the availability of water and the practicality of establishing irrigation is an important consideration in site evaluation and selection.

In conclusion, it may not be reasonable to expect regeneration alone to provide and sustain oak trees in Southern California within a time frame normally expected and acceptable to most development projects. The results and recommendations in this paper are based on experience with severe drought. While years of normal rainfall could produce some different recommendations, early planning, avoiding trees, flexibility in program design, and proper location and scale of the ultimate mitigation project still remain as key planning factors for future projects.

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Oak Tree Preservation in Thousand Oaks, California[1]

William F. Elmendorf[2]

Abstract: The City of Thousand Oaks over the last 20 years has taken aggressive steps to preserve and protect the City's namesake, the oak tree. First adopted in 1972 as an Emergency City Council Proclamation, the City's Oak Tree Ordinance has been considered by some, to be one of the first and toughest municipal native tree preservation ordinances within the State of California. The current Oak Tree Ordinance has undergone twenty years of review and input and has shown to be successful in tree preservation as well as maintaining and increasing community character, quality of development, community image and the quality of life within the City of Thousand Oaks.

Many of the ideas and comments in this paper are a result of practical experience in the administration and development of a resource protection/preservation ordinance and program. They are meant to provide whatever practical information the reader may gain.

In the past, many municipalities and counties had no policy standards or mitigation measures to help offset detrimental impact and loss of oak trees, other hardwoods and associated environmental systems. At the present, the officials and staff of some California municipalities and counties are working with astute and dedicated interest in the protection and preservation of the hardwood resource. They recognize both the value and benefits of the tree resource, and various environmental concerns surrounding proper land and resource use. Enlightened administrative bodies and organizations have come to the realization that they are trustees of, and responsible for, a great and valuable resource to be held and used by both the public at large and future generations (Willeke 1986).

The public has become increasingly aware of the importance of the hardwood resource and the detrimental impact due to its decline. The resource provides many important benefits and values: historical, cultural, environmental, functional, aesthetic, recreational, wildlife habitat, economic, social, philosophical and psychological. This paper reports on how the City of Thousand Oaks deals with the problems caused by the decline of this resource and the steps we have taken to preserve, protect and reforest oak trees in our jurisdiction.

EVOLUTION OF AN OAK TREE ORDINANCE

The current City of Thousand Oaks Oak Tree Ordinance (Lavoie, Moore and others 1986) has undergone political and social evolution over the past 18 years. The Oak Tree Ordinance began as an Emergency City Council Proclamation in 1972, following public outcry after scores of large valley oaks were uprooted within an unapproved development near the center of the community.

Since this first attempt by the City to preserve and protect the community's namesake, the oak, it has become evident that many citizens greatly admire and identify with groves and individual oak trees. The citizenry imparted sometimes emotional, but always forceful political support for oak tree preservation and protection.

The success of the City's Oak Tree Ordinance is in large part due to this considerable and sometimes vocal support of the general community for oak tree preservation and protection, as well as legislative and City Staff support. During the review process of certain proposed oak tree removals to facilitate residential and commercial construction, infrastructure placement and other development, citizens have demanded that the oak trees be preserved and incorporated within development design. With the evolution of life in the City, the oak tree has come to symbolize the quality of life that has been found in Thousand Oaks and other areas of California. Probably the effort to preserve the oak/hardwood resource in Thousand Oaks is motivated by genuine concerns and emotional desires for resource preservation and protection, as well as apprehension for increasing growth, development, and loss of quality of life.

The City's Oak Tree Ordinance has undergone significant community and professional review and revision to reach the current state. It is basically an exercise of the City's police power to promote and preserve a valuable resource asset and the general welfare and health of the community (Mason 1990). In general, the objective of the City's Oak Tree Ordinance is to preserve healthy oak trees over 2 inches diameter breast height on both public and private property within the City's jurisdiction. The Oak Tree Ordinance is enforceable on both private and public property. It is justified by the fact that the City Council of Thousand Oaks has found the oak tree to be a valuable community asset that improves the general health and welfare of the community. The Oak Tree Ordinance protects oak trees from indiscriminate removal or damage. It outlines a procedure for administrative or Planning Commission/City Council review of

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1991, Davis, California.

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proposed oak tree removals, live tissue pruning and encroachment into a tree's protected zone (an area defined as the circumference of a circle 5 ft outside of a tree's dripline).

An applicant may apply for an Oak Tree Permit authorizing removal, or pruning of live tissue or encroachment into the protected zone, using application criteria set within the Oak Tree Ordinance. Certain application criteria may be waived by City Staff in the review process, but in general, application for an Oak Tree Permit must include:

a) A completed application form and a filing fee determined by the number of trees proposed to be impacted.
b) A site plan signed by a registered engineer that shows a tree's surveyed location, basal elevation of any protected trunk and the tree's protected zone measured in eight compass points. The footprint of any proposed development shall be shown on this plan in relation to any existing oak tree.
c) The numbering of all trees in the field and on the required site plan.
d) An Oak Tree Report that contains a thorough horticultural evaluation of any oak tree impacted by proposed development, including:
    1) An evaluation of tree health, aesthetics and structural stability.
    2) An impact summary sheet that summarizes proposed oak tree impact by tree number.
    3) Cross sectional diagrams of proposed oak tree protection zone encroachments and any associated pruning.
    4) Recommendations for cultural treatments such as structural pruning, pest/disease control, and fertilization.
    5) Specific mitigation measures for detrimental oak tree impact that incorporate engineered, architectural or arboricultural methods to lessen the severity of proposed oak tree impacts.
    6) An evaluation of any significant vegetation in addition to oak trees, located within the developmental boundaries.
e) A letter of justification to the City of Thousand Oaks Department of Planning and Community Development. It is an applicant's responsibility to justify in writing any proposed oak tree removals, encroachments, pruning or transplantations.

The City's Urban Forester, Landscape Architect and Planners review projects in relation to proposed oak tree impacts using criteria and standards set forth within the Oak Tree Ordinance as well as other City mandated development review standards. Oak tree removal, encroachment, or pruning of live tissue must be shown justifiable by poor tree health, threatening tree structure or reasonable and conforming land use.

Findings must be presented in writing by the Department of Planning and Community Development, showing that the proposed oak tree removal or impact are consistent with the intent and content of the Oak Tree Ordinance before an Oak Tree Permit can be issued to allow requested resource impact. In addition to defining a procedure for the review and approval of proposed resource impacts, the Oak Tree Ordinance sets strict standards and guidelines for replacement of oak trees approved for removal, approved pruning of live tissue and protection of preserved trees during development.

The Oak Tree Ordinance gives the City the authority to enforce breaches of the ordinance as misdemeanor violations of the Municipal Code and to use a variety of punitive and civil means to force community restitution for unauthorized oak tree removal or other damage. The City practices aggressive enforcement of the ordinance, using field monitoring, issuance of stop work orders, withholding of development permits, citation and legal suit to help assure that the ordinance is adhered to. In addition, the ordinance mandates that all owners of real property will provide oak trees on their property with proper care and maintain them in a healthy fashion.

In relation to the community, the Oak Tree Ordinance has had a number of unexpected indirect impacts. The ordinance has caused preservation of native landforms and habitat. It is impossible to properly preserve an oak tree, or grove of oak trees, without preserving the landform that trees grow upon. Engineers have been forced by the ordinance to develop grading plans that are more sensitive to natural landforms and that protect and enforce the natural character of the topography. The ordinance has caused site and developmental design to be created in a site specific fashion, in an attempt to meet individual site constraints caused by tree retention. The preservation and incorporation of oak trees within developments helps promote interesting and creative site designs. The City has discovered that imaginative and diverse architectural and engineering designs and devices must be used to preserve oak trees. Crib walls, retaining walls, grade beams, alternative slope manufacturing, alternative roof designs, custom floor plans, lot deletion, alternative road design and alternative utility placement are all used on a regular basis to preserve and protect worthy oak trees. Most important, the Oak Tree Ordinance has helped promote an environmental ethic within the community of Thousand Oaks.

TOOLS FOR OAK AND OTHER TREE PRESERVATION

The City is very concerned that a thorough environmental review that identifies all significant issues and required mitigation is accomplished under the guidelines of the California Environmental Quality Act. The City of Thousand Oaks, in addition to the Oak Tree Ordinance, uses a variety of zoning, police power, educative/participatory, incentive and policy standards in an effort to preserve and protect oaks, other native tree varieties, landmark trees and amenity trees threatened by development conversion or re-development activities. These efforts include:

a) The drafting of Environmental Impact Statements by the City for the great percent of projects.

b) The development of a proposed Community Forestry Preservation and Protection Ordinance that would protect all trees on commercial, industrial and common areas from indiscriminate removal or other damage.
c) The City's Landmark/Historic Tree Resolution.
d) Recognition of the importance of sound planning, management and maintenance of the community forest resource as a whole and the associated development of a City Forestry Master Plan and proposed Forestry Element to the City's General Plan.
e) The formation and empowerment of a Tree Advisory Board to act as an additional appeal board in tree related matters and as a champion for reforestation and tree preservation.
f) The offering by the City of incentives for tree preservation to developers and others. These incentives include timely permit processing, staff support of proposed projects and reduction or elimination of certain development conditions.
g) Aggressive tree planting, open space purchase and reforestation of the community forest resource.
h) City support of volunteer orientated, participatory community tree planting programs and tree-give-aways.
i) Environmentally directed community educational opportunities.
j) A homeowner's assistance program for tree questions and concerns.

PROGRAM COSTS

The City of Thousand Oaks has had good success in its attempt to preserve and protect oak trees. This success can be measured by improved quality of new development, legal judgements in favor of the ordinance and community acceptance of the ordinance. The Oak Tree Ordinance has some associated costs, such as increased political controversy within the community in terms of litigation, legislative appeal, campaign platforms, agitated public outcry and opposing issues. In addition, the City has discovered that further economic burdens are imposed through ordinance administration on developers and individual property owners in terms of resource evaluation, resource maintenance, document processing, alternative project design and loss of project density. These added costs occurred by developers and others to meet the intent and content of an Oak Tree Ordinance are often passed on to end users. As such, the City's Oak Tree Ordinance may have slight inflational impacts on structural and land prices. In addition to burdens placed on the private sector, additional organizational costs are placed on the City in terms of ordinance staffing, administration, and enforcement.

Year after year, community sentiment, as measured by a yearly Community Attitude Survey, ranks oak tree preservation in the top ten of community "desires" within Thousand Oaks. It is the City's belief, that private and public sector costs associated with the administration and enforcement of the Oak Tree Ordinance are insignificant when compared to its benefits: the preservation of an important natural resource while appreciating community image, character and quality of life.

Although the City of Thousand Oaks is working to protect and preserve oak trees and other community tree resources, the future of the hardwood resource in many areas of southern California is at this time questionable.

Some reasons for the reduction of the hardwood resource in southern California are:

a) Ever-increasing population and developmental growth;
b) Ever-increasing property values;
c) Lack of environmental awareness within some portions of the development community;
d) Economic factors that outweigh environmental concerns;
e) Lack of information on long term resource worth and management;
f) Court judgements that favor private property rights over environmental preservation;
g) Lack of environmental awareness and explicit goals and policies to identify and address environmental impacts within local governments that result in poor environmental decisions.

With educational, financial and legislative support from State and Federal authorities and sound local programs of resource/project review and evaluation (table 1), law enforcement, education, reforestation, open space acquisition, developer incentives and tough developmental standards, a portion of the hardwood resource now threatened by development conversion in southern California may be preserved.

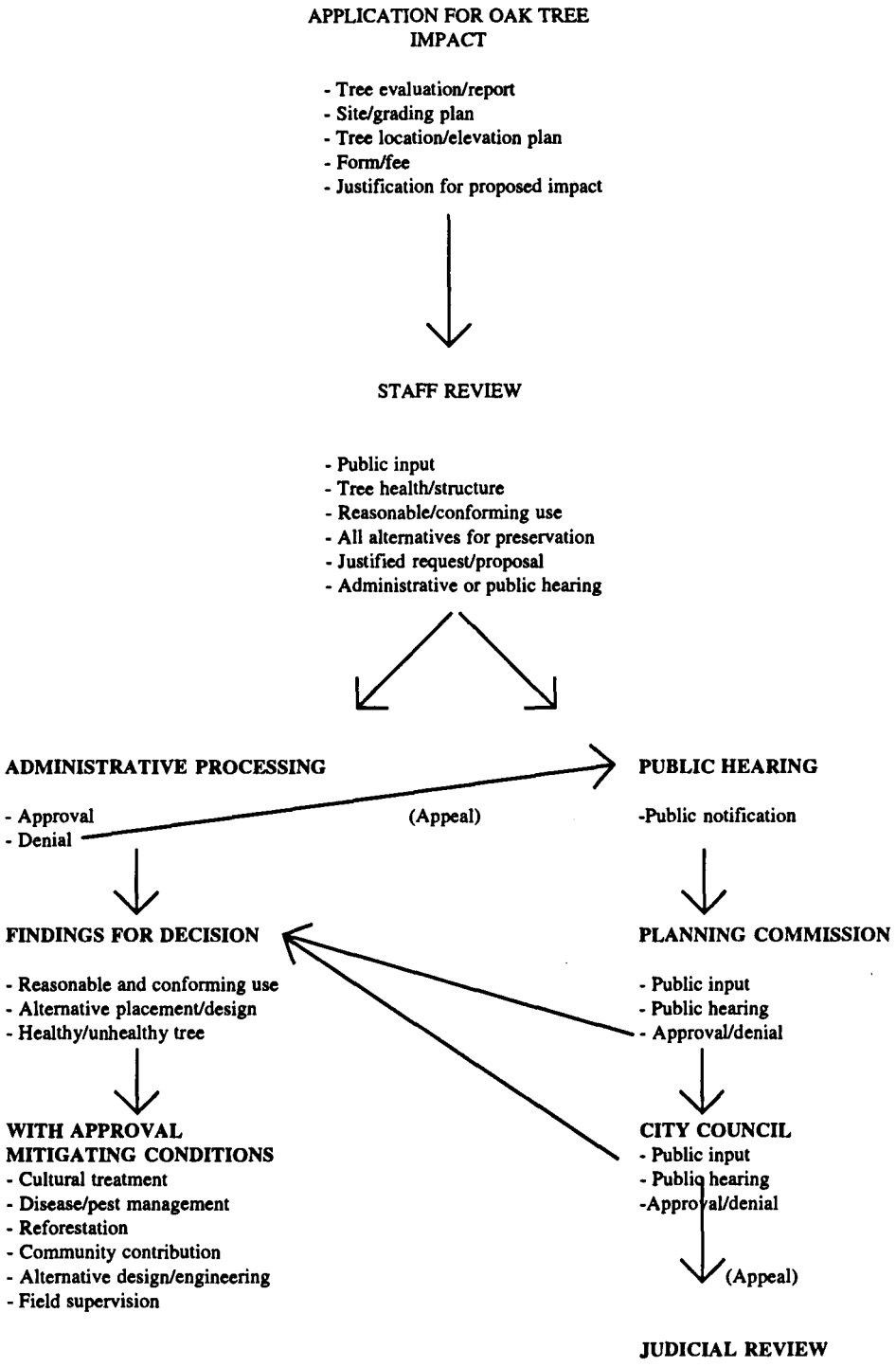
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Table 1— *Method for evaluation of proposed oak tree impact, City of Thousand Oaks*



Microcomputer Techniques for Developing Hardwood Conservation Strategies[1]

Steve McNiel[2]

Abstract: Hardwoods are disappearing from the California landscape at alarming rates. This is due to a variety of influences, both natural and man made. It is clear that conservation and rehabilitation of hardwood resources will require a large effort on the part of research institutes, universities, government agencies, special interest groups, private developers, maintenance workers and ordinary citizens. In order to study the problem and arrive at workable solutions, the author has developed computer assisted methods that help the researcher or land planner inventory, evaluate and manage the land, including hardwood stands. Microcomputer techniques can help us determine the cumulative effects of incremental loss of resources as well as help illustrate, through visual simulation, the potential consequences of future actions. Computers allow us to track changes as they occur and give us the means to develop effective conservation and mitigation strategies that will guarantee a landscape with hardwoods in the 21st century. This paper examines techniques that employ a systems approach and utilize geographic information systems, image processing techniques and photorealistic simulations as planning and decision making tools.

Managing the land is a human activity and reflects human values. Human values, in turn, reflect the needs of people to house and feed themselves. These human needs are often in conflict with those of wildlife and other natural systems and an understanding of the requirements of both is required to make intelligent decisions about land use.

Some of the most threatened landscapes occur at the edge of urbanizing areas. Geographic information systems provide a particularly effective tool for understanding the spatial conflicts and impacts inherent in the urbanizing edge because they facilitate the easy generation of composite maps. These composite maps, in the form of suitability or impact studies, provide guidelines for generating creative design solutions that balance the need to preserve the integrity of natural systems while providing for the needs of humans. Digital cartography and image processing of aerial photographs have also been employed by the author to provide thematic maps for insertion into geographic information systems. In addition to geographic overlays, the author has developed a capability for producing photorealistic simulations. Photorealistic simulations illustrate how a landscape will appear after a change in development or management, and can help us predict many types of impacts. Simulations are particularly effective for eliciting an emotional response from the public.

The Macintosh micro computer, used in these studies provides a powerful tool to assist in this process. It is relatively inexpensive and will run powerful software, while being easy to learn and use. A range of existing software applications have been used to develop the methods reported here. Several geographic information systems were developed, using Filevision IV™, which runs on all Macs, starting with a Mac Plus. The more sophisticated graphics applications, such as Photoshop™, use gray scale or true color (6.8 million colors) and require a Mac SE-30 or a color Mac II series computer. Similar graphic applications are available for DOS and OS/2 machines, however, Filevision IV™ is unique to the Macintosh.

HARDWOOD RESEARCH

While the loss of mature trees is an on-going and acceptable process in a natural ecosystem, one problem facing California is the lack of regeneration of oaks. In some areas, few, if any juvenile trees occur in areas of existing mature oaks. Researchers have hypothesized that a combination of causal factors maybe responsible for losses of young oaks including overgrazing, soil compaction, herbivory by small mammals and rodents, and competition from introduced exotics, but a definitive answer has not yet emerged. Researching potential influences from these and other factors can be very complex and difficult to model with accuracy. In order to model these ecosystems or even to begin to look into these four suspected factors requires an ability to inventory and monitor changes in vegetation patterns. Detailed information about other site characteristics such as soils, steepness of slope, slope aspect, microclimate, elevation and hydrology need to be compared and correlated in order to calibrate the research model. Much of this detailed information will best be viewed in spatial form, as maps and diagrams. In the following discussion, tools and techniques will be presented in relation to case studies. Several projects will be described, each corresponding to a different scale of planning, ranging from a 33 mile long greenway plan to a management plan for a 2400 acre natural reserve.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Management, October 31 - November 2, 1990, Davis, California.

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LAND PLANNING IN URBANIZING AREAS

In urbanizing areas, tracts of existing oaks are being lost to the bulldozer, an acre at a time. Individual trees trapped within an urban or suburban area are further threatened by root zone flooding from irrigation. In addition, micro climates are often changed by land form modification, deforestation and the addition of water. Air pollution threatens some types of vegetation in urban areas and disruption of the natural burn cycle has left many stands in a senescent state, choked by an overgrown understory.

Preservation of intact wooded areas is an objective of an increasing number of planning agencies. More information is needed by planners and decision makers to address the problems of loss of oaks and other hardwoods from development. Environmental designers need the same basic capabilities as the biological researcher in order to inventory and evaluate vegetation as part of the planning process. This includes a theoretical and factual knowledge of vegetation characteristics, environmental requirements, tolerances to disturbance and reproductive methods. Again, much of this information is spatial in nature and must be available in the form of maps in order to feed directly into the overlay based geographic information system and the land planning process.

GEOGRAPHIC INFORMATION SYSTEMS

Large scale land planning requires storage and retrieval of thousands of variables and site conditions. Geographic information systems (GIS) are computer data bases with an active link between a map and numerical, textual or pictorial information. They are ideal for storing an inventory and spatial description of vegetation associations and individual trees. Once in a computer data base, sensitive vegetation clusters or individual trees can be identified and located on a map so that development can be directed away from these significant resources. The computer also facilitates tracking resources over time so cumulative impacts can be recognized and mitigation measures monitored to evaluate their effectiveness.

Such a data base was developed to assist in designing the San Joaquin River Parkway and Environs Conceptual Plan, prepared for the San Joaquin River Parkway and Conservation Trust. (Miller and McNiel 1989). The site included a 33 mile section of river bottom at the north edge of the Fresno urban area. The geographic information system was structured to contain 13 categories of data, one of which was vegetation. Each category was in turn expanded into more detailed distinctions. Vegetation was broken into separate map overlays that defined riparian zones, tree canopy and endangered species or species of special concern. Likewise data on soils, hydrology, microclimate, archaeology, history, land use, zoning, land ownership, circulation and aesthetic features were mapped and entered into the data base. This type of data base, which provides maps of hundreds of site features at the same scale, allows the environmental planner to look for spatial correlations such as the overlap of sensitive vegetation, buildable soils and development zoning. This combination would indicate critical areas that should be actively preserved since they are in danger of being developed to the detriment of sensitive vegetation. (fig. 1). In the case of the San Joaquin Parkway it was possible to identify areas that are presently being gravel mined in the river bottom, that when rehabilitated, can supplement the surviving remnants of existing vegetation to form larger areas of desirable wildlife habitat and provide recreation opportunities.

To develop more detailed data bases, traditional arboreal inventory information is collected in field surveys and linked to computer maps that show individual trees or groups of trees. If you point at any group of trees on the map and push the computer's mouse button, the information associated with that particular tree is made accessible on screen. Or, conversely, using Boolean search capabilities, one can ask to see all those trees which meet a specific group of criteria, such as a particular species, age, girth, condition and significance. The GIS will print both a map showing the locations and one or more reports displaying the associated information for those individuals that meet all the specified criteria. These maps, along with the associated information can be used to discern regeneration, change in stand structure and densities, stand decline or other patterns. Because of the cartographic format, these analyses can be fed directly into the land planning and management decision making process.

For example, a detailed computerized inventory was developed for the U.C. Davis Arboretum that helps the arboretum staff manage an inventory of over 35,000 plants. Named The Interactive Curator™, the GIS was designed to provide an easy system for locating individual plants as well as a way to monitor growth and change over time. The Interactive Curator™ provides open access to arboretum collections for U.C. researchers and the public as well as providing a means for the arboretum staff to produce annual reports of recent acquisitions and management costs. In addition, the mapping abilities of the GIS allow for the production of highly detailed maps and work orders to guide grounds keeping. (Dawson, Elliot-Fisk and McNiel 1990).

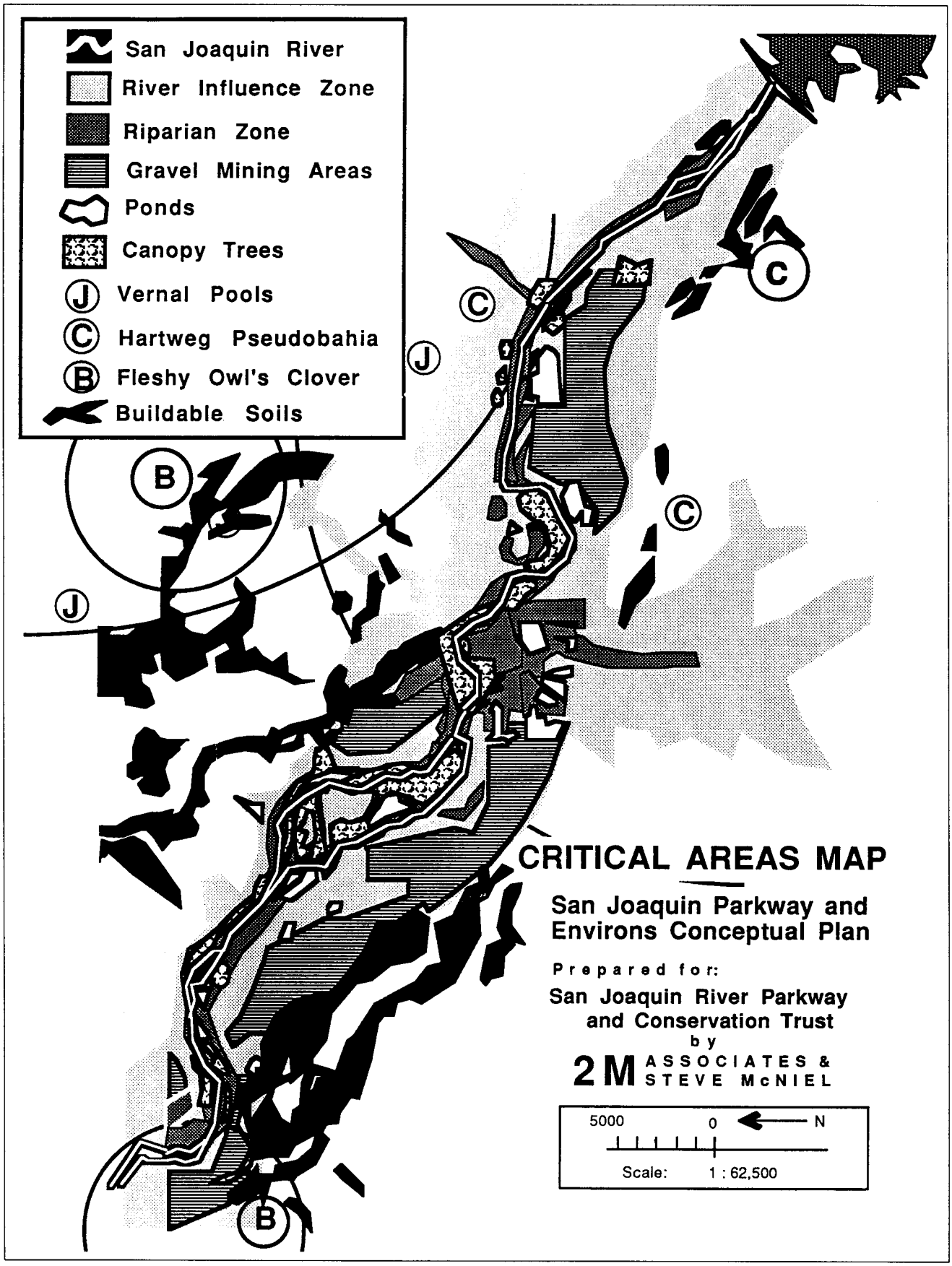


Figure 1—San Joaquin River Parkway Critical Areas Map. This impact analysis predicts areas where gravel mining and housing threaten sensitive biological resources.

DIGITAL CARTOGRAPHY

The spatial distribution of vegetation can sometimes be gathered from existing vegetation maps or even the vegetation tints of a United States Geological Survey (U.S.G.S.) map. However, most often this scale of information is not very useful to researchers or land managers. For example, in the 2400 acre Stebbins Natural Reserve Study several inventory and mapping methods were used, in sequence, to provide an increasingly useful level of information on vegetation for use in a GIS. (Fig. 2).

Originally, gross vegetation associations were determined in the field and mapped from high altitude aerial photographs in the traditional manner, drawing by hand on a mylar sheet placed over the photograph. This information was transferred into a computerized cartographic format by scanning the hand drawn mylar sheet. The resulting TIFF files were adjusted, when necessary, in Image Studio™ or Digital Darkroom™ and resaved as PICT files to save space on the hard disk. The PICT files were then pasted into any one of several drawing applications including Dreams™, MacDraw II™, Freehand™ or Superpaint II™ and redrawn.

However, after a wildfire in the summer of 1988, it was determined that this level of information was inadequate to track the post-fire regeneration of oak woodlands and other vegetation associations. We attempted to map every canopy tree, by species, on the site. The first attempt was accomplished by photographically expanding a portion of a 7.5' U.S.G.S. quad map to a size of 3 ft. by 6 ft. as a base map, and projecting a slide of the aerial photograph onto this map. Expanded to this scale, each tree was marginally identifiable. Small circles were drawn on the enlarged base map by hand to indicate the location and size of each canopy. The large base map was then reduced photographically and scanned into the computer as the mylar overlay had been before. This technique yielded reasonable results, although, it did not identify individual tree species and lacked accuracy due to the limitations of visually interpreting tree canopy from an expanded, grainy image.

IMAGE PROCESSING

As research continued into post-bum regeneration and causal models began to be developed, it became desirable to understand, in greater detail, the history of change within the plant communities. Five different sets of aerial photographs, spanning a 36 year period, were available to do a study of the historic distribution of the canopy, chaparral and grasslands that cover the site. (Fig. 3). With the addition of large amounts of new data, it became clear that interpretation of each set of photographs by hand, as had been done to plot the canopy before, would be prohibitive in terms of time and money.

In order to accomplish the goal we explored the use of computer assisted image processing to provide the needed information. This technique was used to identify and map thousands of trees that could not be reached on foot. The image

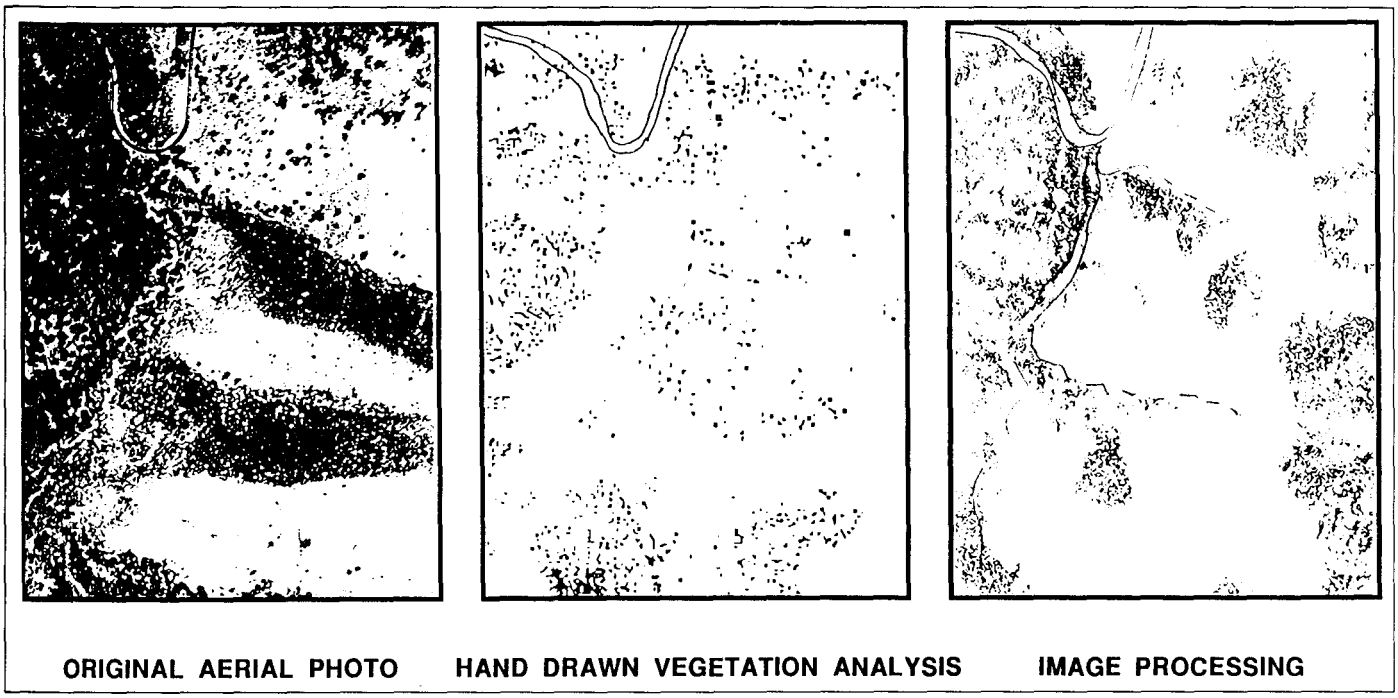


Figure 2—Stebbins Cold Canyon Reserve Vegetation Inventory. A comparison of two methods for inventorying hardwood canopy from aerial photographs.

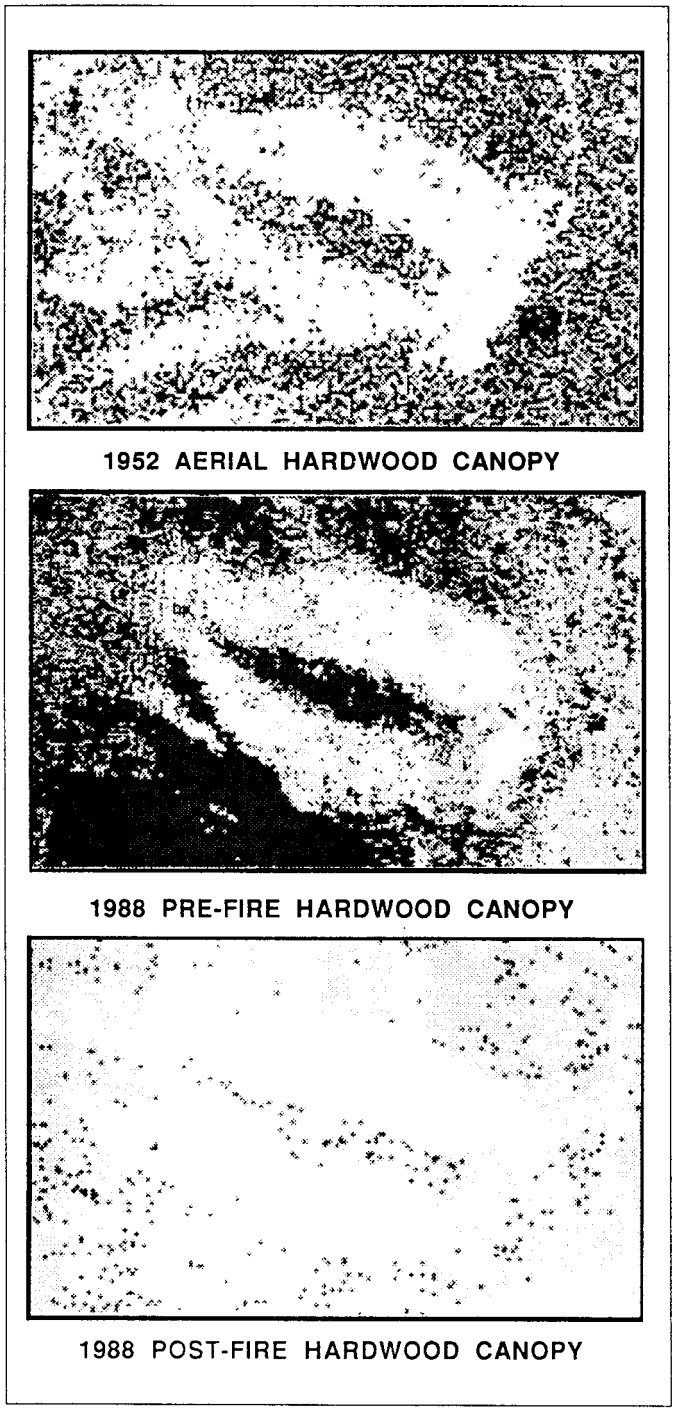


Figure 3—Change in Canopy Over a 36 Year Period in Stebbins Cold Canyon Reserve. Comparisons of canopy coverage as revealed through image processing shows a net gain in canopy between 1952 and pre-fire 1988 images. The 1988 post-fire image reveals the devastation to hardwoods in this particular area.

processing techniques that were developed used false color enhancement of aerial photographs to identify each canopy tree, chaparral area and grassland.

An aerial photo was first scanned into the computer using a half tone setting that yielded 27 shades of gray. Scanning was accomplished on a flat bed 400 dots per inch (dpi) scanner. There is a trade-off to be made with most scanners between the number of shades of gray recorded and the resolution of the image. Since the majority of the scans we used were half-tones and not true gray scale images, we learned to optimize the number of shades recorded to around 27 with a resulting resolution of 300 dpi and a 4 by 4 matrix. The TIFF files were then imported into Studio 8^{TM}, a medium priced paint and photo retouching application, for processing.

General associations were outlined in the field by drawing an overlay by hand on a mylar sheet, as was done originally. However, this vegetation association map was drawn with more accuracy and sensitivity to variations in the size and outline of each tree or stand. A botanist walked the accessible portions of the site and developed a species list for each general mapping zone. At the same time he recorded significant examples of individual trees of known species and located them on copies of the photos. Based on the color or tonal signature of the known tree which the botanist had identified in the field, Studio 8^{TM} was used to highlight all other occurrences of the identical color or tonal signature. For example, on the photos, the indicator trees for valley oaks were made up of four shades of gray. All other occurrences of these four shades of gray were enhanced on the computer image by turning them dark green.

Theoretically, the resulting image located all valley oaks automatically. However, it was found that it took some careful examination of the photos and some additional tweaking of shades of gray to finally arrive at a reasonable estimation of the canopy. This additional tweaking was required because of subtle variations in shadows and atmospheric conditions when the photographs were taken. The results were of reasonable accuracy and consistency to allow us to perform the time series analyses. Although this system does not ensure 100 percent accuracy, it does provide reasonably accurate information where detailed site surveys are prohibitive for physical or financial reasons.

PHOTOREALISTIC SIMULATIONS

During the process of urbanization, clearing land to make way for new construction takes a heavy toll on oaks. While many hardwoods have been lost to development, better planning and education can save the oaks that exist today. One way is to develop new urban forms and alternative methods for retention and mitigation of impacts. In pursuit of this goal, Sacramento and other California communities have adopted legislation



Figure 4—Pruning Simulation. This computer simulation illustrates the result of recommended pruning of the lower branches of an ancient oak tree. It was generated from a slide image using a slide scanner and photoretouching software.

intended to protect existing trees. However, preservation of individual trees will not ensure a stand of trees in the future. Only the conservation of intact wooded areas, seedlings and large tracts of open space, along with a rigorous replanting program on some sites, will guarantee oaks for the future.

In Amador County, suburban growth is beginning to occur at alarming rates and threatens to cover the oak woodlands and pastoral ridge tops with development if a new urban form, protecting these resources, is not adopted. At a recent public meeting photorealistic simulations of future development, under current policies, were used to illustrate the advantages of protecting all ridge tops and riparian zones from development. These simulations were based on actual color photographs that were scanned into the computer and modified with photo retouching software to achieve a final image. Computer simulations require expensive hardware and software but are a very effective visual aid. We use a Macintosh II with 5 to 8 MB of RAM and a 24 bit color video card and monitor. The original scanning is accomplished with a Truevision NuVista™ video digitizer board or a Barneyscan™ slide scanner. The slide scanner provides a much higher resolution image and is preferable to video imagery. Manipulation of images is accomplished with Barneyscan XP™, Photoshop™ or Pixelpaint Professional™ software. There are many other software choices in this area but all are expensive at the present time. Despite current costs, simulations communicating desired visual effects, technical specifications and impending impacts have proven extremely effective when presented to public officials, developers, contractors and citizens.

The computer has also been employed to facilitate the management and mitigation process. Using digital simulations of pruning effects and cabling diagrams helps avoid surprises and misunderstandings between the arborist and the maintenance contractor. These are created in the same way as the Amador County simulations, using photographs, slides or video tape to capture the original image. Output can be in the form of black and white or color paper printouts, slides, video tape or direct projection from the computer onto a screen. (Fig. 4).

In conclusion, the capability of the Macintosh to support high resolution graphics and the availability of software applications such as Filevision IV™ and Studio 8™ provides a relatively inexpensive tool that can be purchased and used by public agencies, special interest groups and individual citizens to help conserve hardwood resources. While the combination of software used here cost just over $1,600, comparable software normally used for GIS, image processing and photorealistic simulations can cost over $30,000 for each application. The most expensive. single application used in these projects was Photoshop™, selling for approximately $500. It is true, that the Macintosh software cannot do everything the $30,000 packages can, but those things the software can do, constitute the vast majority of what is needed to inventory and manage land and hardwood resources. The real savings come in the form of ease of use and learning. Learning times can be measured in hours for these Macintosh programs as opposed to days, weeks and even years for some of the higher end computer software available on other platforms. Filevision IV™ requires approximately 1-4 hours while Studio 8™ requires only about 30 minutes in order to become productive. In doing photorealistic simulations, sophisticated software like Photoshop™ can be learned in a half hour, but requires closer to 4 hours to master.

ACKNOWLEDGMENTS

Mary Burke, Steve Greco and Mary Cunha were instrumental in the development of The Interactive Curator™. I would like to thank Alejandro Espinosa, Botanist and the research staff of the Center for Design Research, University of California, Davis for their assistance with the development of these projects.

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Image Studio™, Letraset, Paramus, New Jersey.
MacDraw II™, Claris, Santa Clara, California.
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NuVista™, Truevision, Indianapolis, Indiana.
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Pixelpaint Professional™, SuperMac Technologies, Mountain View, California.
Studio 8™, Electronic Arts, San Mateo, California.
SuperPaint™, Silicon Beach Software. San Diego, California.

Oaks and Environmental Education[1]

Kay Antunez de Mayolo[2]

Abstract: A number of educational projects which focus on youth awareness and involvement with California oaks have been developed during the last five years. Primarily used in urban areas where oak populations have declined, many of these programs promote seedling propagation, tree planting and help to develop student understanding of environmental issues involving oaks while also promoting acquisition of stewardship values. A review and discussion of programs which feature oak awareness and participatory opportunities are provided. These programs could serve as models for groups involving youth in oak education and resource enhancement.

Recognizing that in some areas of California, native oak populations are having difficulty regenerating naturally due to changes in land use such as urban development and agricultural practices, many individuals and organizations have initiated campaigns and programs to inform and involve the public about the value and importance of oaks and oak woodlands. The State legislature's declaration of 1990 as "Year of the Oak" has helped to focus attention and arouse public concern for local and statewide oak issues. Schools have become involved by planting native oaks; individuals and groups have spoken up about protecting watersheds dominated by oaks; and research on; topics such as propagation and care of native oaks has been shared through a variety of informal publications such as those produced by California Oak Foundation. These projects and programs have reached a large and interested audience. Among the many types of educational efforts, programs which involve Children have special significance, since without a doubt, it will be the next generation of decision makers who will determine the fate of California's oaks. Therefore, individuals and groups concerned about California's oaks should recognize that oak educational programs involving children may have a significant and positive impact on the conservation of the oak resource.

The focus of this paper will be to summarize information on programs designed to include youth in learning about California's oak issues. Also presented is a discussion of how these projects can be considered to be important components of our state educational system's goal to provide children with environmental education lessons and experiences which prepare them to become effective advocates for the careful management and conservation of our state's natural resources.

ENVIRONMENTAL EDUCATION GOALS AND METHODS

During the past two decades, environmental educators have developed many kinds of books, curricula and programs covering a wide range of conservation and environmental education topics. Generally, these materials and programs endeavor to inform and involve students with the goal of strengthening their understanding and appreciation of the complex interrelationships of the natural and physical world. Programs are often designed to engage students in activities or a learning process which helps to focus their awareness, develop knowledge and encourage personal involvement in environmental issues (California Department of Education 1990). Typically students participate in discussions, investigations and hands-on experiences which not only help to develop their understanding of a specific topic or issue, but strengthen their use of communication and critical thinking skills. For example, students may examine how the human use of a natural resource effects the integrity of a natural system. In doing so, they may need to consider the reasons why the resource is used, and the pros and cons of human need for the resource. They may also need to evaluate the social, cultural, economic and ecological contexts of the topic or issue in question.

Another strategy used by environmental educators is to introduce environmental themes of a controversial nature. These topics can also provide valuable opportunities for increasing the quality of a student's ability to solve problems. Since in most cases such issues will have no clear-cut solutions, children can be challenged to consider differing viewpoints which can help them to clarify their own understanding of the problem and how personal values enter into their understanding (Comnes and Sly 1989).

Environmental studies of a complex and controversial nature usually take into consideration the age appropriateness of each learning activity. Children acquire specific thinking skills as they pass through cognitive stages which generally correspond to their ages (California Department of Education 1984). For example, hands-on activities such as planting trees and stream restoration efforts can be useful to early elementary age children in heightening their awareness of the role trees play in reducing soil erosion. This type of experiential education can provide children opportunities to use information processing skills such as making observations, comparisons, and relating information. In addition, they can gain insight and understanding concerning the ecological and societal values placed on

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

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stewardship projects such as tree planting and stream restoration. And with careful assessment of their intellectual abilities related to their age and the breadth of their knowledge and understanding of the issues, children can become effective advocates for a specific environmental issue.

Therefore, organizations developing informational programs and inviting children to share in the labor of a local tree planting can help children participate in learning about resource management and enhancement efforts, and give them many valuable environmental education lessons as well. Also, from an environmental educators point-of-view, these first hand experiences can enable students to construct both informed and reasoned decisions that will help them be able to make personal choices which benefit the environment such as the conservation of and wise use of natural resources. (Hines 1986).

Oak Education Survey

In order to assess the kinds of oak education programs that are available or in development, an informal survey was made between August 1989 to October 1990. Individuals and organizations known to involve youth in oak education and restoration efforts, were contacted and asked to describe their project. Program goals and objectives, delivery systems, use of tools and other methods were noted. Where available, information was noted on: the number of participants and their age grouping, and in the number of trees planted and acres involved.

A summary of information provided by the individuals and organizations active during this survey is presented in the table that follows (table 1).

Important Considerations

The survey brought out several issues which should be of concern to both oak educators and resource managers. These issues should be taken into consideration by groups who are currently involved or considering the development of oak education and restoration projects. Programs which fail to offer information on tree planting techniques or give consideration to the need for the long term care of trees planted by children, may do a disservice to both oak education and tree planting efforts. When trees planted by children die due to neglect or vandelism, children may conclude that their efforts to "make a difference in the world" has little significance. Tree planting projects need careful planning and long-term management strategies.

In addition, efforts to maintain native oak gene pools in urban and wildland tree plantings is of significant biological consideration. In the rush to provide children with hands-on opportunities, it may be a potential environmental disaster to plant trees of widely different genetic inheritance in oak restoration projects. Topics such as gene pool conservation, biological diversity and the process of species endangerment provide valuable environmental education lessons for children to consider in their involvement in propagating and planting oaks. These issues need to be considered by adults planning and facilitating oak education programs.

CONCLUSION

Efforts to both educate children and involve them in conserving and extending the California oak resource have been developed by many groups. Learning about native oaks and planting oak trees has gained widespread popularity as demonstrated by the 29 projects and approximately 17,000 children and adults who have participated in many types of activities during the past year. Acorn planting, seedling propagation and tree planting in urban and wildland settings along with presentations to classroom and youth groups are among the most popular methods used to involve children in learning about oaks and oak issues. Some examples of these activities are illustrated in figures 1-3. These projects can provide useful models for additional groups seeking ways to develop oak education programs for children. An ongoing effort to monitor these programs can also provide additional ideas and useful information for future efforts.

Enabling children to learn about and appreciate California's oaks as well as inviting them to provide the labor needed to extend the oak woodland resources can present many meaningful environmental education lessons. In the long run, the opportunity to educate and prepare future decision-makers and to help them become well informed environmental stewards may prove to have a significant impact on the conservation and future of California's native oak resource.

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Table 1—*Survey of oak education programs involving children for different program objectives (Program objectives—1: Involvement of youth in urban and wildlands oak planting projects for resource enhancement; 2: Environmental education programs focusing on oaks; 3: General information: providing an awareness of oak resource issues.)*

PROGRAM	OBJECTIVE	METHODS/TOOLS	AUDIENCE (age, no.)
"Project Acorn" U.C. Cooperative Extension Browns Valley, Yuba Co.	1,3	Written materials and training hands-on event: acorn gathering & planting	300 youth & adults
"Project Oak" Mid-Peninsula ReLeaf Mt. View, Santa Clara Co	2,3	School assembly Slide show Hands-on event: acorn and tree planting	100 children
Yosemite National Park, Yosemite Elementary School	1,2,3	Oral instructions Hands-on oak seedling planting	80 children
Oak Restoration Projects TreePeople, Arroyo ReLeaf Los Angeles Co.	1,2,3	Written and oral instructions, School presentations, acorn gathering and planting	20,000 acorns collected and redistributed to children/ families to plant in Chatsworth and Pasadena area
Santa Monica Mountain Development Project Let Newman & Associates Los Angeles	1,3	Hands-on acorn collecting and planting (10,000 acorns propagated)	50 children;
California Nature Conservancy Cosumnes River Preserve	1,3	Hands-on acorn seedling oak tree plantings (150 acres, 22,000 trees)	250 adults/children
San Luis Obispo Outdoor School, California State Polytechnic Univ., Natural Resources Management Department, and Atascadero Elementary School.	1,2	Classroom presentation, Hands-on acorn propagation and seedling planting	112 children 25 adults
Tehama Co. Resource Conservation District	1,2,3	Information	100 children
Los Molinos High School Vocational Education Red Bluff		Hands-on acorn gathering, propagation, seedling distribution	30 children
School Tree Plantings Mann Conservation League, San Rafael	1,2,3	Educator workshops; school tree plantings	3,775 children
"Acorn Day" and "Oak Docents" California Oak Foundation California Native Plant Society Napa Co.	1,3	Information; Classroom presentations; Hands-on acorn gathering	700 children
Oak Tree Restoration and Education Project Tehachapi Resource Conservation District	3	Classroom presentations	200 children
Southwestern School Chula Vista McMillian Development People for Trees, San Diego Co.	1,2,3	Hands-on acorn and tree planting	90 children
Oak Planting Project, Girl Scouts, People for Trees, San Diego	1,3	Hands-on acorn and seedling planting (2000 acorns, 250 seedlings)	300 children
Valley Oak Elementary School Davis Senior High School, Davis	2,3	Classroom presentations; hands-on acorn planting and seedling propagation	70 children
4-H Oak Horticultural Project San Diego	1,2	Instructional workshop; hands-on acorn planting and seedling propagation	150 children
Oak Plantings, Sunol Regional Wilderness, Alameda Co.	1,3	Hands-on acorn planting children and adults	500 volunteers
Elkhorn Slough Preserve, Monterey Co.	1,3	Group presentation; hands-on acorn planting	60 children
"Acorn to Oak" Teacher Workshops, Sacramento Co.	2,3	Workshop presentation; Hands-on acorn planting; information	100 teachers
4-H Oak Tree Project Calaveras Co.	1,2	8-page activity guide "Oak Book"; 18 minute video; hands-on acorn gathering and planting	
"Seed to Seedling" Sacramento Tree Foundation Sacramento	2	40-page oak propagation; curriculum; docent program; hands-on acorn planting; seedling propagation; tree plantings	5000 children 300 teachers

(continued)

Table—1, *continued*

PROGRAM	OBJECTIVE	METHODS/TOOLS	AUDIENCE (age, no.)
1990 Earth Day Environmental Nature Center, Newport Beach	3	Informational Oak seedling distribution (150 seedlings)	
Big Tree Contest Yuba Co. Resource Conservation District	3	Informational	General public
Big Oak Contest, Tehama Co. California Department of Forestry and Fire Protection Red Bluff Garden Club	3	Information	General public
University of California, Davis Arboretum	3	Docent tours, information	General public, schools
University of California Berkeley Botanical Garden	3	Docent tours information	General public schools
Sonoma State University, Rohnert Park	3	Teacher materials; Nature Area Guide to Oak Woodland (in development)	local schools
U.C. Cooperative Extension, San Luis Obispo and Santa Barbara Co.	2	4-H Project Guide; "Oak Woodland Wildlife Project" (proposed)	
Irvine Ranch Water District, Irvine	3	"Annie Oak Tree" Oak awareness coloring book	5,000 children
Portola Valley School Oak Project Portola Valley, Santa Clara Co.	1,2	"Seed to Seedling" curriculum Hands-on acorn planting	100 children
1990 Arbor Day Riverside Corona Resource Conservation District, Riverside	3	School Assembly; Oak seedling distribution (500 seedlings)	20 schools
Kimbark Elementary School, San Bernardino	1,2	Hands-on and oak tree propagation; use of wide selection of environmental education materials	850 children



Figure 1—Planting acorns. Sacramento Tree Foundation's "Seed to Seedling" program, 1990.



Figure 2—Six-month old oak seedlings growing in a Sacramento classroom, 1990.

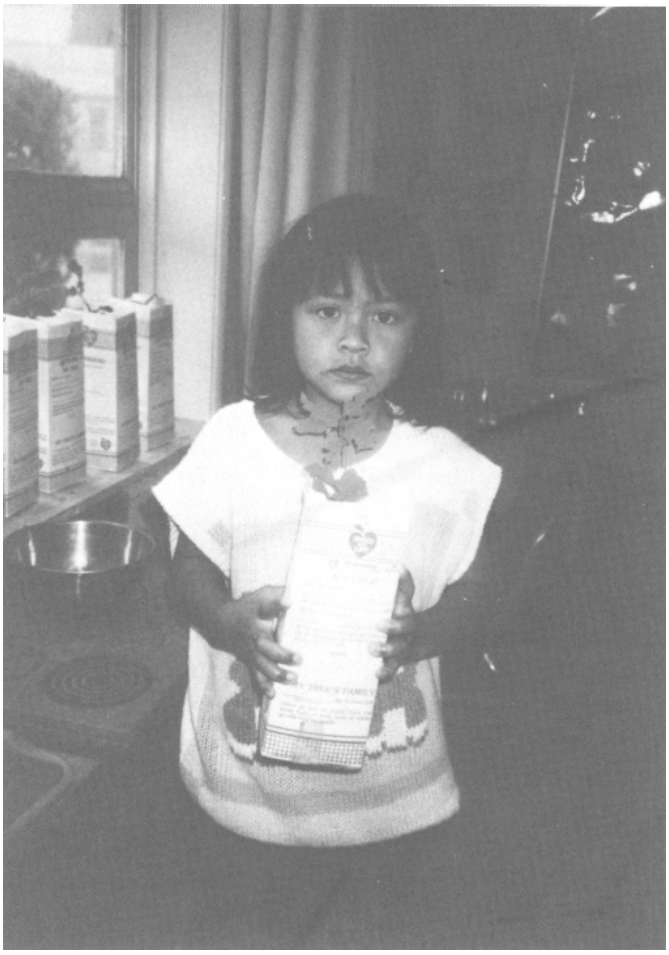
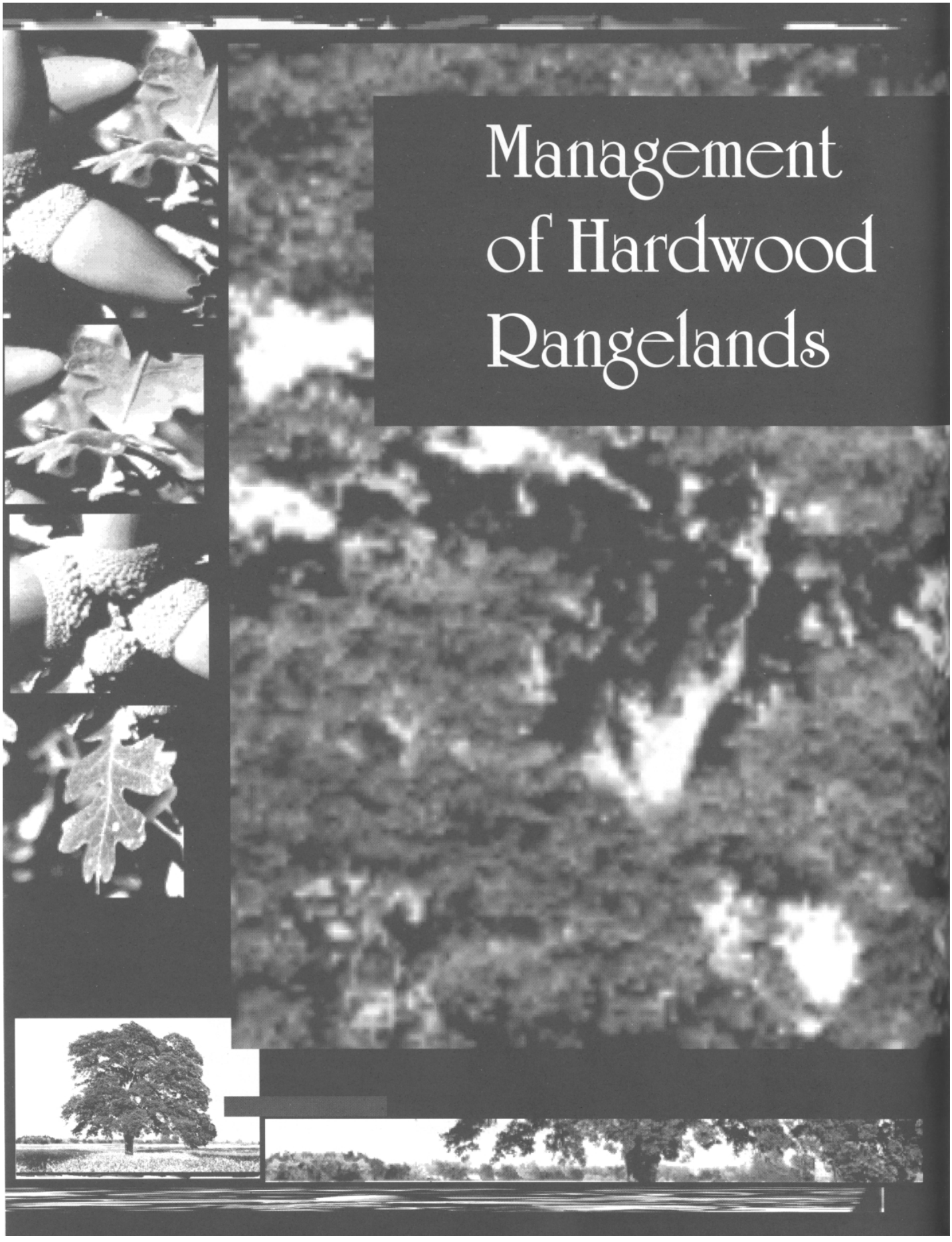


Figure 3—Sacramento area kindergartner showing off her six-month old blue oak seedling. Sacramento Tree Foundation, 1990.



Management of Hardwood Rangelands

A Dynamic Model of California's Hardwood Rangelands[1]

Richard B. Standiford Richard E. Howitt[2]

Abstract: Low profitability of hardwood rangeland management, and oak tree harvesting for firewood markets and forage enhancement has led to concern about the long-term sustainability of the oak resource on rangelands. New markets for recreational hunting may give value to oaks for the habitat they provide for game species, and broaden the economic base for managers. A ranch level optimal control model has been developed to assess optimal oak tree canopy and livestock stocking under different biological and economic conditions. The impact of recreational hunting on management was also assessed. In general, hunting improved the economic return on hardwood rangelands, and resulted in lower oak harvest levels and lower livestock stocking. The policy implication is that public concern over oak tree harvesting may be partially alleviated by new markets for recreational hunting on hardwood rangelands.

California's oak-covered rangelands occupy 7.4 million acres (California Department of Forestry and Fire Protection 1988). Over eighty percent of the area is privately-owned, providing one-third of the forage for the state's livestock industry. The public goods supplied by hardwood rangelands, including wildlife habitat, watershed protection and aesthetics, have led to strong public interest in the management of these private lands. One of the important ecological characteristics of this area is the interconnectedness of large expanses of woodland.

Conversion of hardwood rangelands to urban or intensive agricultural use is one of the leading sources of habitat loss and fragmentation, amounting to around seven percent of the oak woodland acreage between 1950 and 1980 (Bolsinger 1988). Oak clearing for forage enhancement was at one time a major source of habitat loss, however this practice peaked in the 1950's and 60's (George 1987). Rapid increases in firewood prices in the 1970's (Doak and Stewart 1986) suddenly gave value to the oak trees on rangelands, resulting in increased firewood harvest. Poor oak regeneration has also been documented in some areas, leading to some concern about the long-term sustainability of this resource (Muick and Bartolome 1987).

These concerns about the future of this valuable resource have resulted in zoning restrictions and ordinances at the local level, and proposals for statewide regulation of tree removal. However, no empirical estimates have been made of the effect of current and future economic conditions on landowner management decisions for these large expanses of private land. Private hardwood rangeland profitability directly affects the rate of fragmentation due to subdivision. The forces impacting oak tree harvest, such as income from firewood and increased forage for livestock, affect the structure of the tree canopy and its value for different wildlife species. New markets for fee hunting on private rangelands have recently developed in the state. Since many of the game species demanded by hunters are enhanced by oak cover, this new market may serve to provide a market-based oak conservation incentive for landowners.

STUDY DESIGN

The objective of this study is to assess the likely impacts of different biological and economic conditions on oak stands by developing a multiple resource management model for hardwood rangelands. This requires the development of production functions of the basic processes that impact management decisions on hardwood rangelands and reflect the relationship between these resources. In addition, economic models that represent the behavior of hardwood rangeland owners need to be determined.

Figure 1 shows a schematic flow diagram for multiple resource decision-making. This assumes that ranchers make decisions about their level of oak tree retention and cattle stocking based on cattle and firewood markets, the relationship between oak tree cover and forage production, the rate of growth of these resources, and the potential for alternative economic enterprises such as commercial hunting. As this shows, decisions are made annually based on the biological and economic factors of these resource values.

To evaluate this decision-making framework, an approach which addresses both dynamics and interrelated resource values is needed. Traditional methods of analysis in range economics, which often focus on forage as an annual crop with partial budgeting used to compare the costs of range improvements to livestock gains, were felt to be inadequate for this purpose. Optimal control theory provides a powerful tool which can be used to develop the decision rules to determine the optimum pathway of the stocks of oak trees and cattle over time. The pathway is "controlled" by the manager through decision variables, or control variables, that are linked with the tree and cattle capital stock in the system. The amount of oak firewood cut and livestock sold (or bought) are the control variables. The ranch manager makes annual decisions about the level of these control variables.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31 - November 2, 1990, Davis, California.

[2]Forest Management Specialist, Dept. of Forestry and Resource Management, University of California, Berkeley; Professor, Dept. of Agricultural Economics, University of California, Davis.

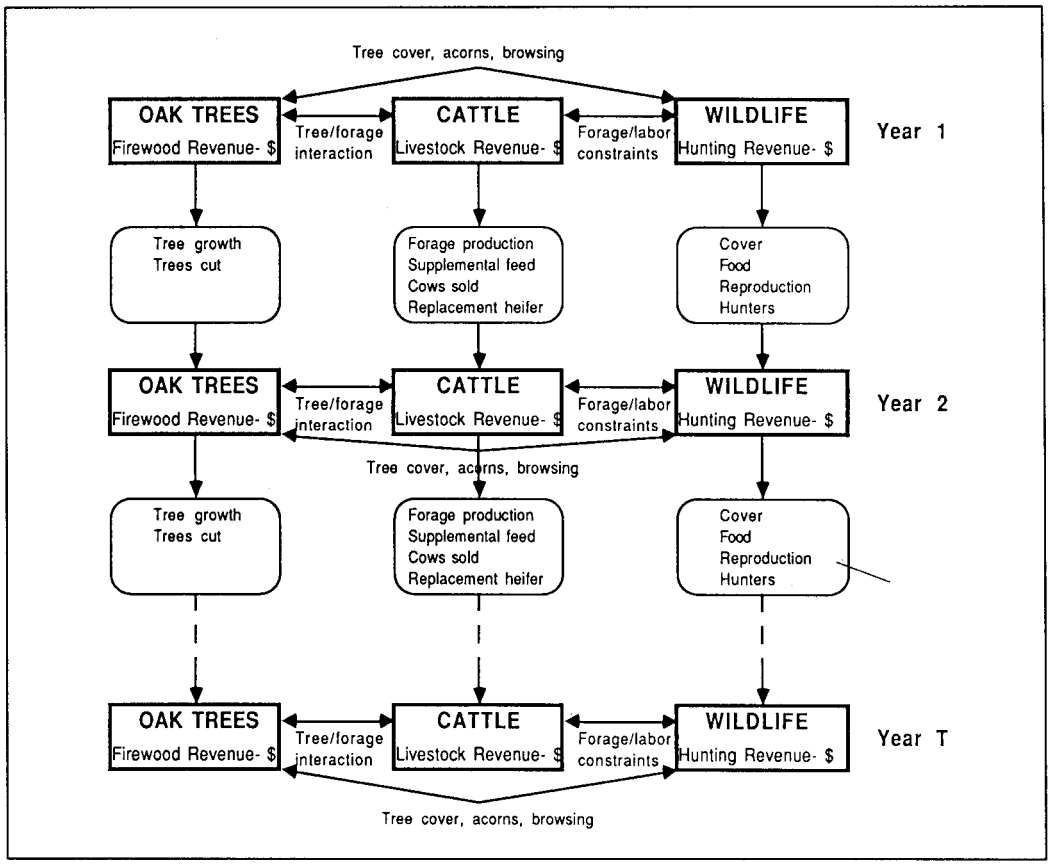


Figure 1—Decision-making flow diagram for hardwood range management.

Equation (1) below shows the general framework used to evaluate management decisions on hardwood rangelands. This is based on a manager maximizing net present value (NPV) over a time period of T years. This shows the decision to be based on firewood revenue, livestock revenue, and hunting revenue. Biological growth functions, known as equations of motion, provide links between years for the capital stocks. The hypothesized interrelationships between the various hardwood range resources are shown below.

(1) Maximize: NPV=

$$\sum_{t=1}^{T} DF_t^* \left(WR_t\left(WDSEL_t\right)+HR_t\left(WD_t, HRD_t, \text{exog.}\right)+ LR_t\left(HRD_t, CS_t, FOR_t\left(WD_t, \text{exog.}\right)\right)\right)$$

such that:

$WD_{t+1}= F(WD_t, \text{exog.})-WDSEL_t$ [Equation of motion for oaks]

$HRD_{t+1}= G(HRD_t, \text{exog.})-CS_t$ [Equation of motion for livestock]

$WD_0= INITWD$ [Initial stock of wood]

$HRD_0= INITHRD$ [Initial stock of livestock]

$WDSEL_t \geq 0$ [Wood cutting nonnegativity constraint]

where:

DF_t= discount factor at time t

$WDSEL_t$ = volume of firewood cut in time t

$WR_t (WDSEL_t)$= firewood revenue as a function of firewood cut in time t

WD_t = Stock of oak trees at time t

HRD_t= stock of livestock at time t

$HR_t (WD_t, HRD_t, \text{exog.})$ = Hunting revenue at time t as a function o" the stock of trees and livestock and exogenous variables (location, wildlife population, etc.)

CS_t= Vector of different classes of livestock sold

$LR_t (HRD_t, CS_t FOR_t (WD_t, \text{exog.}))$= Livestock revenue at time t as a function of the stock of livestock, forage production, and the number of livestock sold.

$FOR_t (WD_t, \text{exog.})$= Forage production expressed as a function of tree canopy and exogenous range productivity factors

$F(WD_t, \text{exog.})$ = Tree growth during time t as a function of the stock of oaks and exogenous site factors

$G(HRD_t)$ = Livestock growth during time t as a function of the stock of livestock and exogenous factors (i.e. cattle breed)

ESTIMATION OF PRODUCTION FUNCTIONS

Production functions were determined for the various components of the hardwood range decision-making model. Complete details on the analysis are in Standiford (1989).

Oak Tree Growth

The dynamic optimization process requires that oak growth can be assessed for differing stand densities in order to evaluate the impact of selective oak harvesting on future stand structure and its impacts on livestock, recreation, and firewood enterprises. Eighty-one study sites were selected in seven locations in stands of pure blue oak (*Quercus douglasii*), mixed blue oak and interior live oak (*Q. wislizenii*) stands in the Sierra Nevada foothills, and mixed blue oak and coast live oak (*Q. agrifolia*) stands in the coastal foothills. Individual tree diameter at breast height (DBH), total height, crown diameter, and five- and ten-year radial growth was measured on 972 individual trees. This was used to develop relationships for oak site index, periodic oak tree growth, and crown cover-volume relationships (Standiford and Howitt 1988).

Forage Production

A data set of 142 observations of forage production in the open and under several different densities of oak canopy was collected from four different studies, representing time series ranging from 2 to 22 years (Jensen 1987; McClaren and Bartolome 1989; Kay 1986; Heady and Pitt 1979). Seasonal rainfall and accumulated annual degree days were included for each study site from weather records. Combined cross-section and time series analysis was used to evaluate variability between sites and years. A seasonal forage yield model was estimated based on overstory oak cover, accumulated julian days, and accumulated seasonal rainfall. In this model, oak canopy has a greater effect in depressing yield on higher rainfall areas, which is consistent with the results reported in the literature (McClaren and Bartolome 1989).

Hunting Production

A random sample of 60 ranches identified as operating recreational hunting programs was surveyed, providing data on the type of hunting lease, price of the hunting lease, number of hunters, hunter success, location of the club, wildlife habitat at the club, and detailed cost summaries. The major game species of interest in these surveys were deer, wild turkeys, and wild pigs. Revenue and cost functions were estimated on a per acre basis using hedonic regression (Rosen 1974) to decompose the costs and revenues to the various physical and biological attributes of the hunting club. Since deer hunting was found on 49 of the 55 usable surveys, analysis was restricted to areas with deer hunting, with the value from pig and turkey hunting that operated jointly on deer areas evaluated.

Oak crown cover, a numerical rating for scenery, the percent of high income hunters, percent of trophy deer harvested, the difference in animal unit months (AUMs) with and without hunting, percent of the hunt club where pig hunting is allowed, and the expenditure for advertising were all positive variables in the hunting revenue function. Acreage had a significant negative sign in the hunting revenue function, which shows that as ranch size increases, net revenues per acre decreases due to more dispersed, extensive type of hunting operations. Family labor constraints are also more likely to be binding on large ranches. Distance to several large cities, availability of cabins, guide services, camping, hunting dogs, and vehicles for hunter use were not significant in explaining variability in hunting revenue.

The cost function per acre for hunting clubs was also evaluated. Advertising cost per acre, a dummy variable for guide service, and a dummy variable for whether deer tags are provided, were all highly significant variables. Care of game, hunt club acreage, transportation services, availability of cabins, and percent of high income hunters, had very low significance in the analysis.

Price Expectations

One of the largest factors impacting hardwood range management is the large year-to-year variability in livestock and hay prices. Price data for different classes of cattle was collected (U.S. Department of Agriculture, various years; and California Department of Food and Agriculture, various years). Fair quality alfalfa hay was used as a proxy for hay prices, and collected for the Petaluma and Madera areas of the state from the Federal-State Market News Service (various years). Firewood prices per cord were collected from data in Doak and Stewart (1986) for delivered prices in the San Francisco Bay Area. All prices were deflated to constant 1977 dollars using the Price Receive Index.

Ranchers were hypothesized to base cattle, hay and firewood price expectations on a weighted average of past observations. To model this, a Box-Jenkins analysis of the time series data estimated the coefficients and variances for price expectation models of cattle, hay and firewood prices. A block diagonal matrix of variances, with off-diagonal covariances between livestock classes, was calculated to evaluate risk due to price variability in the optimal control model. Independence was assumed between firewood, hay, and livestock prices. Since hunting revenue is usually based on a long-term lease, zero price variability was assumed for hunting revenue.

Firewood Harvesting Cost

Dammann and Andrews (1979) report on the costs of harvesting, processing, and transporting firewood in hardwood stands in New Hampshire. This engineering data was used to construct a model of firewood harvesting costs based on the volume of wood sold.

THE OPTIMAL CONTROL MODEL

Based on these production functions and the general optimal control framework shown in equation (1), a discrete time optimal control model was set up with three seasons within a year to model annual range forage production, and yearly time increments for hunting and wood volume production. Complete details on the actual formulation of the model are in Standiford (1989).

Preliminary runs of the optimal control model showed the firewood harvest was either at its minimum (i.e., no wood cut) or at its maximum (i.e., all the wood is clearcut). Since actual wood harvest data shows that partial harvest is the typical method for oak tree harvest (Bolsinger 1988), a procedure to determine missing "costs" of harvesting firewood was used. Ranchers value oak trees for the value they add to their ranch for their own personal aesthetics and for game and nongame wildlife species (Huntsinger and Fortmann 1990) even without a commercial hunt club. A firewood adjustment cost was determined to reflect the net value of the wood harvest to the rancher by calibrating the model to actual oak tree harvest data over a thirteen year period for different hardwood range forest types (Bolsinger 1988). Inclusion of this firewood adjustment cost allows policy analysis to be based upon actual behavior.

The livestock enterprise is assumed to be a cow-calf operation, the predominant type on hardwood rangelands in California (California Department of Forestry and Fire Protection 1988). Livestock revenue in time t is composed of the sale of feeder calves (steers and heifers) and the sale of cull cattle. The price expectation models were used to evaluate livestock price uncertainties. Costs of the livestock enterprise include variable costs based on the herd size (Van Riet 1988), and feed costs based on the amount of feed purchased per season, which is a control variable estimated in the optimization. Hay price uncertainty was modelled using the price expectation models developed.

The seasonal forage model assumes that forage growth on the annual grassland range occurs only in the first two seasons (i.e., September 1 through May 31), with the residual forage left in the summer available as low quality dry forage. Forage availability in a season is based on climatic variables, the number of livestock animal unit months (AUMs) in that season and previous seasons, and the quantity of supplemental feed purchased. Seasonal livestock nutritional requirements in AUMs were determined exogenously using the program COWFLOW (Bell 1988) based on livestock weights, target rates of gain, calving percent, and the percent bulls in the herd.

A terminal value was calculated at the end of the control period to incorporate the value of future earning stream for the firewood, hunting and livestock enterprises.

A chance constrained approach was chosen to incorporate producer price uncertainty into the optimal control model (Charnes and Cooper 1959). Producers incorporate uncertainty into their management decision by setting the probability level that the net cash flow each year is positive based on a combination of indebtedness and interest rate. The higher the probability level, the less a producer is able to take a loss, representing a more risk adverse individual.

SOLUTION TECHNIQUE

The discrete time optimal control model was solved for four control variables, namely forage allocation to hunting, supplemental feed purchased, the number of cattle to hold off the market as replacement heifers, and the quantity of firewood sold. The model was also solved for two state variables, namely the number of cow-calf pairs, and the standing volume of oak trees. Optimal controls were calculated for the situation assuming no price variability (the certainty equivalent case), and for the chance constrained case. Forage variability was considered by including the actual time series of seasonal rainfall for the areas being evaluated.

This system was solved using the GAMS/MINOS system (Brooke and others 1988) for nonlinear optimization on a personal computer. The problem was solved over a thirteen year control period to coincide with the firewood harvest calibration time period.

A low and high quality range site was included in the analysis, as well as poor, medium, and good oak site indexes. Four different initial oak volume levels were evaluated, ranging from 250 to 1000 cubic feet per acre. The effect of hunting was evaluated by solving the optimal control model for average and good quality hunting conditions, and for no hunting. The entire set of policy runs was solved for both the certainty equivalent case, and for the chance constrained case. This range of scenarios resulted in 144 different optimal solutions.

RESULTS

Effect of Hunting on Total Return

The effect of a broadened market base may improve profitability on hardwood rangelands and help reduce conversions. Figure 2 shows the net present value for poor and good quality hardwood range site with 750 cubic feet of oak per acre. On a poor range site, adding hunting as an enterprise increases NPV by 144 percent (from $50 to $122 per acre), and makes hunting the dominant economic enterprise. On a good range site, hunting increases the NPV by 50 percent (from $154 to $231 per acre), although cattle production is the dominant economic value on this site. This figure shows the relatively minor contribution that firewood harvesting makes to the total economic value of the operation. On the poor range site with hunting, firewood revenue is only 4 percent of the NPV, while on the good range site with hunting, firewood harvesting is only 1.5 percent of the total NPV. Including risk in the analysis increases the percentage that hunting and firewood revenues occupy in the portfolio, and decreases the percentage from the livestock enterprise.

Optimal Wood Harvest Levels

Table 1 shows the cumulative firewood harvest over the 13 year control period for three oak site indexes, four initial oak volume levels, with and without hunting, and two different range productivity classes. Slightly less oak firewood harvesting occurs when hunting takes place, especially in stands with 750 to

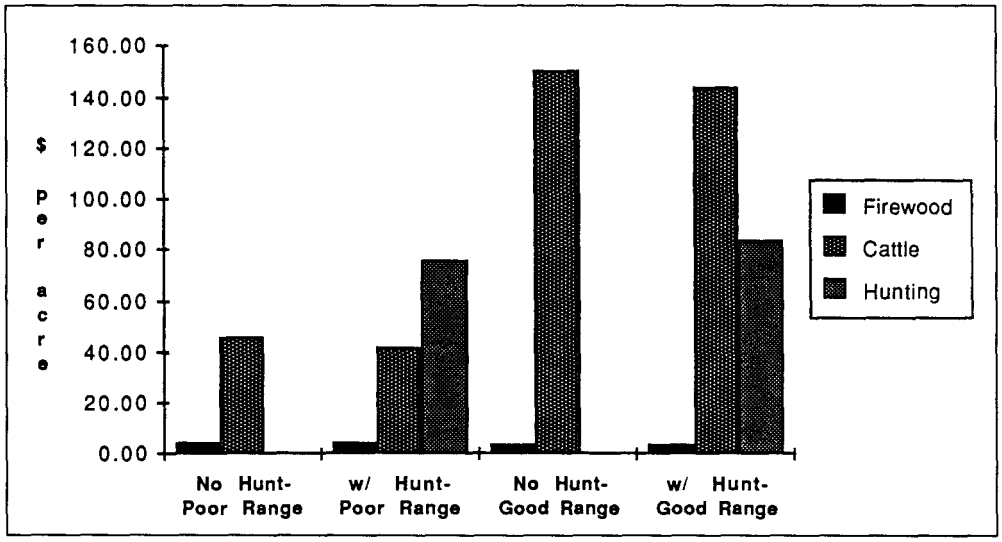


Figure 2—The effect of hunting, firewood harvest, and cattle production on net present value per acre for a medium quality oak site and a poor and good range site, with 750 cubic feet of oak per acre.

Range Production	Initial Oak Volume (cu.ft./ac)	SITE 30		SITE 40		SITE 50	
		No Hunt	Hunt	No Hunt	Hunt	No Hunt	Hunt
Poor Range Site	250	0.00	0.00	0.00	0.00	0.00	0.00
	500	0.00	0.00	71.43	64.88	73.06	67.00
	750	116.42	110.86	117.87	112.62	120.21	115.54
	1000	229.25	222.57	231.48	225.26	235.54	230.29
Good Range Site	250	0.00	0.00	0.00	0.00	0.00	0.00
	500	0.00	0.00	0.00	65.69	0.00	0.00
	750	114.46	104.49	117.62	112.58	123.81	118.43
	1000	225.71	219.19	231.64	224.66	241.33	234.86

Table 1— ***Cumulative firewood harvest*** **in** ***cubic feet per acre over 13 years for the certainty equivalent case.***

1000 cubic feet per acre. This indicates that the marginal decrease in hunting revenue due to oak canopy changes is greater than the marginal revenue from the firewood harvest. Hunting apparently does provide an incentive for hardwood range managers to conserve oak trees. The small difference between ranches with and without hunting may be because the firewood adjustment cost reflects the fact that even without a hunting club, ranchers' utility is enhanced by habitat for game and nongame wildlife, and the aesthetic value of oaks. It is of special interest that no firewood harvesting occurs on areas with only 250 cubic feet per acre. The marginal cost of harvesting firewood exceeds the firewood price at these levels. It is also worth noting that ranchers are not likely to completely clear their ranges for forage enhancement because the marginal revenue of the added forage is less than the marginal cost of cutting trees. Inclusion of the risk term tends to increase the amount of wood cut.

Optimum Livestock Density

Figure 3 shows the optimal trajectory for the number of cow-calf pairs over the 14 year control period on a good range site with initial conditions of 750 cubic feet of oak per acre and 150 cow-calf pairs per 1000 acres. This trajectory shows that livestock density decreases as hunting quality increases. This can be thought of as an allocation of forage to wildlife, and also allocation of management effort to the hunting enterprise. The allocation of AUMs to either the hunting operation or the livestock operation are set so that marginal hunting revenue from the last AUM added to the hunting enterprise equals the marginal decrease in livestock revenue. When risk is included, livestock numbers do not show the same degree of annual fluctuations as the certainty equivalent case.

Purchase of Supplemental Feed

Given the range of hay prices and price variability included in these scenarios, very little hay is purchased to provide supplemental feeding for cattle. The optimal control model shows that only a small amount of hay is purchased and only in 2 out of 13 years. Somewhat more hay is purchased in the certainty equivalent case which suggests that hay price variability has a larger effect than forage variability due to climatic fluctuations.

GENERAL CONCLUSIONS

This study showed the interrelationship between the stocks of oak trees and cattle, and how management decisions about trees harvested, cows bought or sold, hay bought, and the operation of enterprises such as hunting, all interrelate to affect ranch profitability. Relatively low oak firewood harvests are calculated by the model, indicating the low value of firewood and the fact that ranchers already incorporate nonmarket values

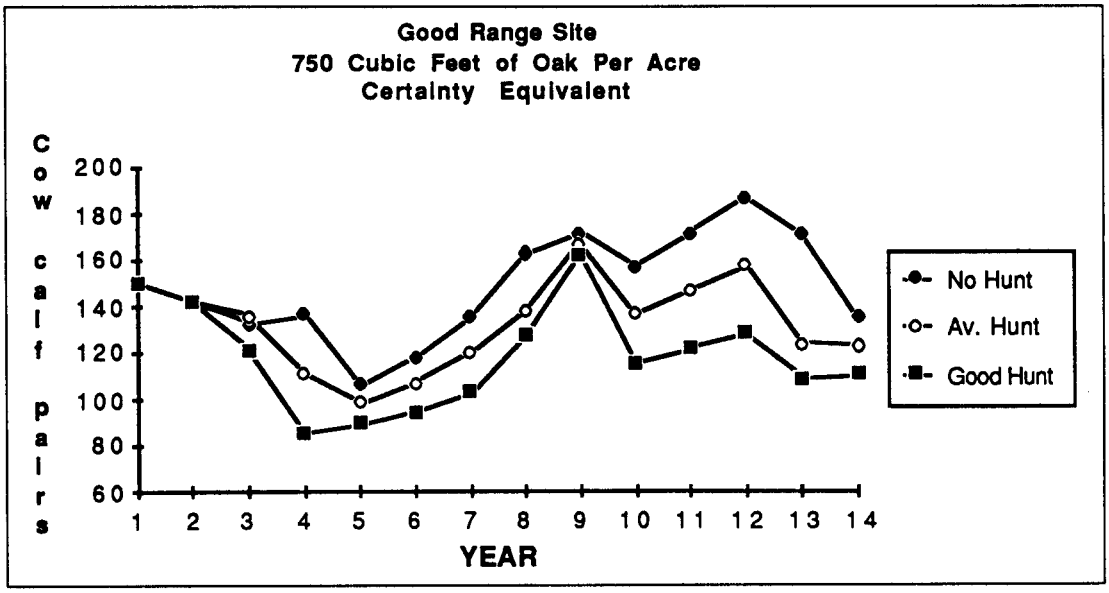


Figure 3—Optimum 13 year trajectory of cow-calf pairs on a good range site with an oak overstory of 750 cubic feet per acre for three hunting levels, and a certainty equivalent and chance constrained approach to risk.

for oaks in their management decisions. Complete oak removal for forage production appears to be an unlikely management practice. This study also showed that operation of a commercial hunting enterprise has a significant effect on ranch profits. In fact, on poor quality range sites, hunting becomes the dominant economic production factor. This suggests that diversification of the ranch portfolio with new economic enterprises may help decrease subdivision pressure by increasing net profits as well as spreading out the risk of production. Operation of hunting enterprises also affects firewood harvest and cattle stocking levels, again demonstrating the importance of evaluating the multiple resources that exist on hardwood rangelands.

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California Hardwood Rangeland Use and Productivity Changes, and the Economics of Regional Livestock Production[1]

Gerald L. Horner James H. Cothern[2]

Abstract: Changes in the availability, productivity and cost of hardwood rangeland affects the production and location of range-fed livestock. The California Range Livestock Model (CRLM) was developed to determine the effect of proposed policies and alternative economic conditions on the range-fed livestock industry generally and hardwood rangeland in particular. Three possible changes in range conditions were analyzed with the CRLM. Eliminating grazing on 9.7 million acres of Federally owned rangeland in California reduced annual livestock production by $80 million and producer's incomes by $9.3 million. Increasing productivity on privately owned and grazed rangeland by 5 pct increased the state's annual cattle production by $70 million. Developing 1.3 million acres of rangeland in Southern California for urban uses would decrease annual livestock production in that region by $50 million. The model has the potential of being used in conjunction with other existing forest and rangeland models to provide more comprehensive policy information for range managers.

The California Range Livestock Model (CRLM) is a spatial and market equilibrium model designed for economic and policy analysis of managing California's hardwood rangelands (CH2M Hill 1989). This model projects how changes in public policy or economic conditions affects the amount of regional livestock production, production costs, producer incomes and rangeland use. Spatial equilibrium models such as CRLM are not designed for probabilistic forecasts of the future, but rather for static analysis of comparative conditions of policies. Comparative statics explains how a contemplated policy or economic change can affect a sectors long term equilibrium production patterns.

CRLM was developed to augment the current planning analysis being conducted by the Forest and Rangeland Resources Assessment Program (FRRAP) of the California Department of Forestry and Fire Protection. The model design is influenced by current issues facing FRRAP. These issues include how the economic and institutional force affect the range livestock industry and the related demand for, and supply of forage from hardwood rangeland. This paper examines this model, whose purpose is to project the effect of alternative hardwood range management and use policies on livestock production. In addition, the movement of livestock among range types, by location, and markets will be estimated.

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MODEL DESCRIPTION

The production of range livestock is specified for cow-calf, sheep and stocker operations for eight California regions (fig 1). The model uses 1987 as a base year and simulates decisions regarding the number of livestock put on available rangeland, specified by five owner classifications and nine cover types.

Range carrying capacities (Animal Unit Months (AUMS)/ acre) were derived for nine cover types, four owner classifications and eight regions by dividing the number of AUMS available for grazing by the number of grazed acres (Huntsinger 1988). Total regional range livestock production was constrained by the amount of rangeland available for grazing by cover type and owner. Grazing fees reported by Bowie and Watson (1986), Bartlett and others (1983), McKean and others (1986) and US Dept. of Interior (1988) were used to derive grazing fees by AUM for each rangeland cover type, owner and region.

Range livestock numbers were estimated by FRRAP for 1985 (Huntsinger 1988). Since this is the last estimate made and the number of livestock remained stable between 1985 and 1987 and the 1985 estimates were used to represent 1987 range use (table 1).

Production costs were estimated for 1987 by size of operation and region. Significant cost differences were observed for small and medium cow-calf herd size operations. Livestock produced in California are assumed to be marketed at five major state markets with varying market prices and transportation costs. These markets are located in Dixon, Cottonwood (Redding), Stockton, Visalia, and El Centro. Stocker calves can be purchased from the same five markets and from two out-of-state markets representing the northwest and southwest regions. Average 1987 livestock prices observed in the five markets were used in the model (Federal-State Market News Service 1987). Cattle produced in any region can be sold in any market depending on varying prices and transportation costs.

Positive Mathematical Programming (PMP) is employed in CRLM (Howitt and Mean 1983). A model used for optimization of problems of this type will optimize subject to exogenously specified constraints. PMP allows the model to reproduce observed activity levels without using arbitrary constraints. This allows the model to seek optimal levels based on economic criteria and not on constraints that may not be justified. Policies simulated in the model are compared with 1987 conditions. A more complete description of the model is given in CH2M HILL (1989).

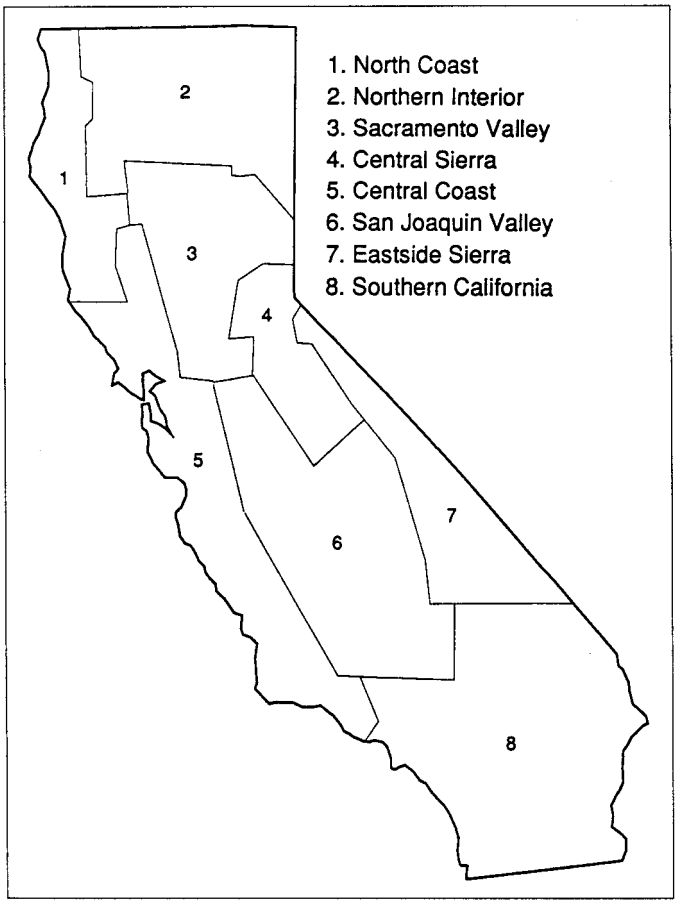


Figure 1—Forest and range Land Resource Assessment Program Regions, California Department of Forestry and Fire Protection.

Table 1—*Range Livestock by Region, 1987*

Region	Cows	Stockers	Ewes
		(*1,000 Head*)	
North Coast	48	26	43
Northern Interior	175	38	23
Sacramento Valley	143	103	207
Central Sierra	74	14	19
Central Coast	247	162	80
San Joaquin Valley	272	412	295
Eastside Sierra	20	4	9
Southern Calif.	36	48	93
TOTAL	1,015	806	769

RESULTS

Three different potential policy considerations were simulated in the model and results compared with 1987 livestock production levels, incomes, and rangeland use. The first considered a withdrawal or elimination of all livestock grazing on Federal lands, the second specified range improvements, while the third considered the problem of urban encroachment. These policies have not been formally proposed by any agency group and policy recommendations are not intended by these results. The scenarios were formulated solely to demonstrate the capabilities of the CRLM as well as the type of information which can be generated by the program.

Eliminate Livestock in Federal Rangelands

BLM and Forest Service grazing permits were assumed to be withdrawn for all cover types in all regions. This amounts to about 9.7 million acres of the 30 million acres estimated to be grazed in California in 1987. Although this represents 32 pct of the total grazing land in the State, it provides only 7 pct of the AUMS grazed. Federal leases are vital to the livestock industry in some regions. About 41 pct of the total grazing land leased by the Federal government is classified as desert land located in Southern California and managed by the BLM. The Forest Service leases large acreages of conifers in the Northern Interior, Sacramento Valley, San Joaquin Valley and the Eastside of the Sierra, and oak woodland and chapparal in Southern California. Federally leased rangeland accounts for 49 pct of the total AUMS in the Eastside of the Sierras, 27 pct in Southern California, and 25 pct in the Northern Interior.

Projected livestock, numbers, production and income levels for the State without Federal grazing are as follows:

	1987 (1,000 Head)	Pct Change from 1987
Cows	1,015	-4
Stockers	806	-17
Ewes	769	<1
Value of Production:($million)		
Cattle	797	-11
Sheep	84	<1
Income:		
Cow-calf	209	-3
Stocker	22	-18
Ewes	32	<1

A $9.3 million decline in California livestock income is projected by CRLM if grazing on Federal lands is eliminated. This represents a 3.6 pct decline for the industry. Cattle production

is projected to decline by $80 million. Income from cow-calf operations is reduced by $5.3 million and by stockers by $3.9 million. The overall impact on the livestock industry is not severe but regional impacts are drastic. Producer incomes in the Eastside Sierra are projected to decline by $1.2 million or 33 pct. A 24 pct decline ($4 million) in Northern Interior incomes is projected due to the large acreage of Federal grazing land and a shortage of alternative range supplies.

Stocker production would be decreased by 60 pct in Northern Interior, Central Sierra, and Southern California if Federal grazing were to be terminated. In the State, about 140,000 stockers and 36,000 cows would be eliminated.

Improved Range Productivity

Increasing productivity of rangeland has been the subject of many research and educational efforts. To estimate the effect of increasing productivity on livestock production and producer incomes, a 5 pct increase in carrying capacity on the 17 million acres of privately owned and grazed rangeland was posed to CRLM. Grazing fees, other production costs and prices were assumed to remain unchanged from 1987.

Projected increases in livestock income and production resulting from increased rangeland productivity are as follows:

	1987 (1,000 Head)	Pct Change from 1987
Cows	1,015	<1
Stockers	806	19
Ewes	769	<1
Value of Production: ($million)		
Cattle	797	9
Sheep	84	<1
Income:		
Cow-calf	209	-1
Stocker	22	18
Ewes	32	-

Total industry income is projected to increase by $3.6 million (1.38 pct) with an increase of nearly $70 million in production with the 5 pct increase in productivity. Again the most significant change is in the production of stocker cattle. In addition, grazing is reduced on some non- Federal public rangelands. Grazed acreage in the Central Sierra is projected to decline by 61,000 acres as cattle are moved from public to the more productive private range. Cattle production in the San Joaquin Valley is projected to increase by 69,000 head. Sacramento Valley cattle production could increase by 17,000 head.

Urban Encroachment

Urban growth can expand into rangeland being used for livestock grazing. Land use policy is currently redirecting development away from prime agricultural land to less productive classes of land. This policy could have important impacts on regional livestock production. The assumption of the scenario is that the supply of all classes of rangeland (nine cover types, five owner classes) would be reduced by 10 pct in those regions which amounts to 1.3 million acres.

CRLM results indicate that livestock production levels would be reduced by $49 million annually which amounts to about $2 million in income. As in the other scenarios, almost all of this reduction is in stocker production with cow-calf operators remaining at the same level of production. This scenario represents a large conversion of rangeland to other uses and it could have a significant effect on the overall viability of livestock production in those two regions even though only stocker production changes are projected. Some cattle operations attempt to split operations between cow-calf and stocker enterprises. Reductions in rangeland will probably reduce cow-calf operations in the long run if the split operational mode is maintained. The split operation is not specified in the CRLM.

CONCLUDING COMMENTS

The CRLM projects that eliminating grazing on 9.7 million acres of Federally owned rangeland in California will reduce annual livestock production by $80 million and producer's incomes by $9.3 million. Model results also indicate that increasing productivity on privately owned and grazed rangeland by 5 pct will increase the state's annual cattle production by $70 million. The model projects a decrease in annual livestock production in Southern California by $50 million if 1.3 million acres of rangeland are developed for urban uses. Such a decline may eventually lead to the demise of the region's live stock industry due to a lack of support services.

CRLM can provide rangeland managers with a quick method of assessing proposed policies and determining the effects of changes in economic conditions on livestock production and range use. The livestock industry has been steadily declining since the 1960's. The industry has been beset by a continued set of institutional, political and natural problems which have continued to make operating conditions difficult and uncertain for the typical livestock operator. Some of the past policies

impacting the industry are the Food and Security Act, the PIK program, the dairy program, particular aspects of the dairy termination program, and tax reform. This model is capable of quickly projecting production, rangeland use and income from such policy changes if they are again contemplated in the future.

The model is also intended to be sufficiently flexible to be able to include firm level management issues that may become more important in the future. One such issue is the recent decline of hardwoods on rangelands and the future possibility of not meeting public needs for open space and wildlife habitat. Whether this trend can be reversed voluntarily or by changes in public policy requires an evaluation of urban land use changes and the profitability of livestock production. Standiford and Howitt (1989) have developed a ranch level dynamic model to determine optimal amounts of oak harvesting, recreational hunting and livestock production. Results indicate that hardwood rangeland owners may reduce oak harvesting to capture returns from hunting. These results can be specified in the CRLM to be able to project the statewide significance of the emerging hunting market.

FRRAP has also developed a model called CALPLAN to assess the current and future condition of the state's forests and rangeland and to identify future policy actions (Davis and others 1987). CALPLAN uses detailed land use data from FRRAP's geographic data system to project the amount and timing of timber and livestock production by county, cover type, owner and owner behavior class. The model uses goal programming to assess the effect of public agency timber production, recreation, and wildlife habitat targets on forests and rangeland. The CRLM provides added detail on the livestock industry which could be easily integrated into CALPLAN.

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Distinguishing the Forest from the Trees: Synthesizing IHRMP Research[1]

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Abstract: A conceptual model of hardwood rangelands as multi- output resource system is developed and used to achieve a synthesis of Integrated Hardwood Range Management Program (IHRMP) research. The model requires the definition of **state variables** which characterize the system at any time, processes that move the system to different states, **outputs** (at the site and the landscape level) which are produced by processes as the system changes state and **values** which are derived from outputs or directly from the system's state. Processes can be further categorized as **intensive** (i.e. involving function within the hardwood system) or **extensive** (involving reduction in the extent of the hardwood system). The **incidence** of processes sets the model in motion. Research projects are evaluated by the extent to which they contribute to the measurement of model components and the elucidation of the relationships between them.

All natural resources management employs models of varying degrees of elaboration to predict the natural system's response to management. This paper proposes a "state-transition" model of hardwood rangelands as a framework for integrating IHRMP research results in support of program goals. Integrated Hardwood Range Management Program (IHRMP) goals can be expressed as desired states of the natural resource system. Research projects clarify the dynamics that produced changes, or transitions, in the system's state. This formulation suggests a set of criteria by which to classify, evaluate and integrate the results of research projects.

A STATE-TRANSITION MODEL OF HARDWOOD RANGELANDS

The model proposed for California's hardwood rangeland sees that landscape as a spatial array of cells (figure 1), just as would a geographic information system (GIS). The condition of the resource base (the system's **state)** at any time is characterized by **state variables.** Examples of state variables include such things as elevation, soil texture, vegetation, ownership, etc. **Processes,** both natural and management, interact with state variables to produce both new values for the state variables and **outputs** from each cell. For instance, a process, such as fire, alters the state variables of vegetation and produces outputs, such as air pollutants. Processes can be classified as causing changes within the system (**intensive**) or reducing the extent of the system (**extensive**) (Doak and others 1988). Outputs can be measured objectively and are tied to individual cells. **Landscape outputs**, such as livestock production and watershed sediment yields, refer not to individual cells but rather to the interaction of numerous cells. State variables, outputs and landscape outputs generate **values** either through the market, for such things as livestock production, or through non-market mechanisms, for such things as biodiversity or visual quality.

This state-transition formulation is not a complete description of reality since it predicts only what would happen if particular processes were applied to particular pieces of land. It does not estimate the probability of particular processes occurring on particular pieces of land. When these probabilities or **incidences** are estimated outside the model or determined within the model as functions of state variables, the model becomes a spatial simulation model.

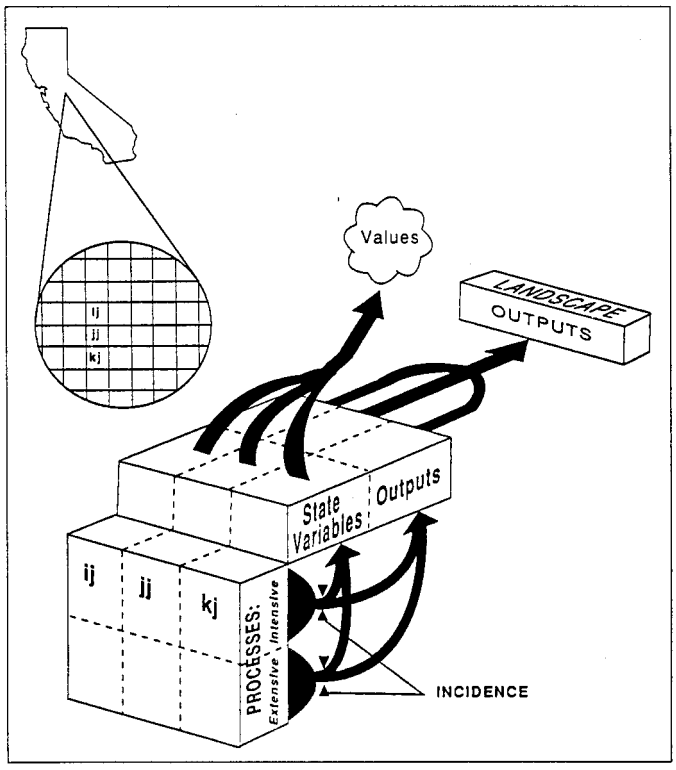


Figure 1—State-Transition Model of Hardwood Rangelands.

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The contribution of individual research projects to the attainment of program goals can be traced through the model structure. For instance the goals of the hardwood program were defined by the State Board of Forestry (1986) as a set of desirable system states involving the state variables relating to hardwood species, soil and water characteristics, and wildlife habitat (table 1). The Board invoked the processes of erosion, grazing, range improvement, and conversion to agriculture or urban use. It specifies outputs and landscape outputs such as income for landowners and water quality. The role of research is to improve our understanding of the operation of the system in both its anthropological and biological dimensions so that the State can deploy its programs with some assurance of moving the system toward the desired state.

How well has IHRMP research improved our understanding of system structure and function? Each research project can be evaluated in terms of the model through a series of questions:

System definition: what are the important state variables?

Current state of the system: how can we affix values to the state variables?

System evolution: how will the system change in the future?

-do we know the important processes?
-can we judge their incidence?
-do we know their effect on state variables?

Outputs and Landscapes: what will changes in the system state mean?

-do we know the important cell and landscape outputs and values?
-can we translate changes in state variables into changes in outputs and values?

Table 1— *Desired State of Hardwood Lands*

"Behind any policy is a vision of the future. ...(T)he following general vision is suggested...:

> The hardwood resource, whether on conifer or hardwood- rangelands, generally should be protected and enhanced. This means that **all hardwood species are regenerating, soil and water quality are preserved and sufficient habitat diversity is achieved statewide to protect the viability of critical wildlife species**.
>
> **Range and timber stand improvement can continue - but such activities should take account to sensitive environmental areas and serious wildlife damage. Additional sources of income to landowners are available** through improved utilization, new markets for products from species that are regenerating well, and programs to compensate landowners for leaving hardwoods.
>
> **Land can continue to be converted to intensive agriculture and residential/commercial development - but it should be directed away from environmentally sensitive areas, avoid serious damage to wildlife and not Interfere with the ability of landowners to manage their land economically.**
>
> **Government Involvement In land management decisions of private Individuals should be minimized** and in so far as is possible, supportive of their needs. Public agencies, federal through local, should understand and be coordinated with each other and with private landowners in their management goals and practices."

from State Board of Forestry (1986); emphasis the author's.

System Definition

Table 2 lists state variables, outputs and processes investigated by several typical IHRMP research projects. Since the state-transition model is spatial in nature, every state variable could, in theory, be mapped. Those that have been incorporated into the California Department of Forestry/Forest and Rangeland Resources Assessment Program GIS are noted in the table as being mapped. The table also shows the general direction of causality investigated by each project.

Research projects generally fall into four categories (table 2). Projects in Group 1 investigate the factors determining a subset of state variables pertaining to oak stand structure (e.g., Muick and Bartolome 1986). These factors are both processes and state variables themselves and relate principally to intensive change. They include location, natural processes, traditional management practices and artificial regeneration.

Group 2 attempts to translate state variables into outputs (e.g., Block 1989). Those that have focused on wildlife habitat relationships have used a range of state variables far wider than that investigated by Group 1. Wildlife investigations have included such measures as the diversity of overstory species within a plot while Group 1 projects generally classified hardwoods into single species categories. Other projects within this second group translate oak canopy cover and other state variables into forage production and erosion hazards. In some cases Group 2 projects have attempted to carry the analysis through to the landscape level in terms of wildlife habitat and watershed function. This second class of projects is concerned again with intensive change.

Group 3 attempts to understand the incidence of management processes, particularly those that reduce the extent of the oak woodland system. Group 3 projects have generated a long list of state variables that are a mix of natural and socioeconomic characteristics of ownerships, the larger market and institutional forces. The relationships between these state variables and the incidence of processes is conceptual at best. These projects do not carry through to an assessment of the impact of processes on state variables or landscape outputs.

Group 4 classifies and measures state variables (e.g. Pillsbury 1990) or otherwise improves the methodology of assessment.

This pattern of research merits several comments. First, **the state variables used to characterize the hardwood resource (oak stand structure) are a small subset of the number needed to predict the outputs included in the vision.** Predictions of changes in wildlife, water quality, and sensitive environmental areas will require a more detailed understanding of the structure of hardwood range vegetation in terms of species diversity, presence of shrubs, presence of large individuals, vegetative cover, etc.

Table 2 —*Typical IHRMP projects: state variables, outputs and processes*

Project	State Variables	Mapped?	Outputs	Processes
Group I				
Analysis of oak regeneration (Muick and Bartolome 1986)	regeneration index		forage	recruitment
	oak species	*	water yield	grazing
	size class density		wildlife diversity	wildlife use
	origin (acorn, resprout)		recreational use	wood cutting
	elevation			
	fire			
	slope			
	aspect			
	canopy			
	position			
	regional location	*		
	presence livestock	*		
Group II				
Habitat relationships in oak woodlands (Block 1989)	oak species	*	avian spp. abundances	
	woody cover		herp spp. abundances	
	shrub cover		mammalian spp. abundances	
	herbaceous cover			
	tree density			
	special habitat elements			
	regional location	*		
Group III				
Legal environment for hardwood land ownerships (Doak and others 1988)	zoning classification			clearcutting
	registration under			conversion to housing
	-CLCA			conversion to agriculture
	-CRP			regulation of use
	-AB580			
	presence of			prescribed fire
	-VMP			reforestation
	-CFIP			soil conservation
	-RCD			
Group IV				
Assessment of CA hardwood lands (Pillsbury 1990)	oak species	*		
	density class	*		

The arrows indicate the direction of casuality, beginning at predictor variables and leading to dependent variables.

Second, while site classification systems (Group 4) may organize this mass of variables, **it is unlikely that a single landscape classification system will capture all the information required to achieve the vision.** A system keyed on existing vegetation cannot contain all the information necessary to predict water quality. Botanical species composition may be necessary but not sufficient to predict wildlife habitat value. While a coarse grain description of vegetation may be sufficient for explaining wildlife species distribution within the state, it is insufficient to explain fire risks where the influence of vegetative ladders and firebreaks, features indistinguishable at the larger scale, govern the phenomenon.

Third, **there has been little emphasis on methodologies that generate landscape outputs from state variables.** Ideally, the state-transition model would predict a future landscape which would then be evaluated as a whole for its provision of landscape outputs such as wildlife habitat, water quality or fire risk. While difficult to calculate, landscape outputs, such as water quality and fire risk, are more evident and more important than the output of any individual cell.

The designation of "critical sites" is an ad hoc means that condenses landscape analysis into a single state variable. A "critical site" designates certain parts of the landscape as having particularly high value and implies that, regardless of the fate of other portions of the landscape, these areas should be conserved.

Fourth, **extensive change remains poorly understood.** While demographic projections convey the scope of potential conversion at a county level, social scientists are only now beginning spatial analysis of development patterns (T. Bradshaw, pers. comm.) Furthermore, the effects of conversion on state variables and landscape outputs are not clear. While the impact on hardwoods of their conversion to parking lots is obvious, the impact on wildlife and water quality of conversion to low density rural residences is not.

Finally a review of individual projects confirms that **hardwood vegetation is not a homogeneous type, but is comprised of at least five classes with different research and policy requirements.** Although regeneration of valley oak and Engelmann oak may be problematic in intact woodlands, the principal threat to their existence appears to be conversion. Their

current extent is quite restricted and located in areas with high development potential. Blue oak on the other hand is quite extensive. It exists within a pastoral economy and its habitats are less threatened than those of the previous two species. However, its ability to regenerate appears problematic. Oregon white oak appears to be somewhat restricted and may regenerate poorly. It exists within a timber economy and its regeneration difficulties appear linked to fire management. Live oaks in general appear to be regenerating well though their habitats may be locally endangered by conversion. Finally, black oak appears to be regenerating well, is linked closely with conifer lands and the timber economy and appears to present economic opportunities completely different from that of the other species.

System Change and Its Meaning

In this paper I wish only to explain the framework suggested by the model for the evaluation of contributions of research projects to our understanding of system evolution, outputs and landscapes. The evaluation itself is pursued elsewhere (Greenwood 1990).

Table 3 portrays how one might analyze studies of intensive processes. The table lists the processes driving intensive change that projects have investigated to date. These include the growth, reproduction and mortality of the herbaceous, shrub and tree layers, since together they determine the structure of the vegetation. Diseases of hardwoods merit special attention since, in the absence of cutting, they are the major killers of mature hardwoods. Similarly, herbaceous growth establishes a competitive situation which may account for most oak seedling mortality. The invasion (or perhaps re-invasion) of woodlands by shrubs is a significant process particularly for wildlife. Grazing, prescribed fire, thinning and artificial regeneration interact with natural processes to drive the hardwood system in different directions.

The model structure forces one to consider how well we understand the incidence of processes as well as their effects on state variables. Table 3 approaches these questions in the simplest fashion - by reporting the number of IHRMP projects that have investigated these issues. It is clear that incidence of reproduction has received far more attention while that of other processes. Even so, our understanding, at least as reflected in our ability to calibration a state-transition model, remains poor: it remains impossible to draw a definitive map of the regeneration status of blue oak, much less explain the geographic pattern. While many mechanisms pertaining to regeneration have been investigated, no single factor appears overwhelmingly important in determining the fate of hardwood vegetation.

The model structure also forces one to consider the impact of processes on cell and landscape outputs. Table 4 provides an example of how fire might effect six important landscape outputs. This framework raises specific questions (e.g., how does fire influence water quality) which serve as criteria by which to judge project findings. In this instance, table 4 includes some of the mechanisms that might mediate the relationship between process and outputs, procedures that can be used to model these mechanisms, and issues raised by each interaction.

CONCLUSIONS

Why is this model framework useful?

First, it allows one to relate research to the goals of the program. Both the goals of the program and the details of research can be expressed within the common framework defined by processes, state variables, outputs and landscape outputs. Research is useful to the extent that it increases our understanding of model function and the means to arrive at the desired state. Questions suggested by the model but not yet addressed by projects are candidates for future research.

Second, the model framework is extremely flexible, thereby allowing new results to be incorporated easily. New processes, state variables and outputs can be added without redoing the entire model. Furthermore, the "grain" of the model is adjust-

Table 3 —*Intensive processes: number of projects elucidating process incidence and effects on state variables by species*

Process	State Variables					Incidence				
	QULO	QUDO	QUEN	QUAG	QUWI	QULO	QUDO	QUEN	QUAG	QUWI
Tree growth	0	1	0	1	1	0	0	0	0	0
Reproduction	-	-	-	-	-	4	4	5	2	1
Mortality	-	-	-	-	-	1	1	1	1	0
Disease	0	0	0	0	0	1	1	1	1	1
Herbaceous growth	0	2	0	0	0	0	0	0	0	0
Shrub growth	0	1	0	0	0	1	2	1	1	1
Fire: prescribed	0	2	2	1	0	0	1	0	0	0
Grazing	1	5	2	2	0	1	1	1	1	1
Thinning	1	1	1	1	1	1	1	1	1	1
Artificial regen.	-	-	-	-	-	2	2	2	1	1

(abbreviations signify oak species: QULO=valley. QUDO=blue, QUEN=Engelmann, QUAG=coast live, QUWI=interior live)

Table 4—*Fire: mechanisms and predictive procedures for outputs and values*

Outputs/Values:		
Water Quality	Wildlife Habitat and Use	Livestock and Firewood Production
#loss of cover	#change in habitat type	#maintenance of "grazing complex"
#change in soil surface	#change in habitat stage	#sprouting response
#fire intensity	#loss of habitat elements	#type conversions: chaparral to grass woodland to grass
#rain intensity	#fire frequency	#elimination of shrub understory
>erosion hazard rating	>WHR	
>USLE		>regional mean change in annual forage quantity and quality
>sediment routing models	?impact of spatial patterns created by fires	
?short term impact of fire itself vs long term impact of vegetative change	?value of landscape rather than single habitat islands	?mediation of woodland-chaparral boundary
		?mediation perennial grass persistence
Wildfire Risk	Biodiversity	Productive Potential of Site
#reduction in fuels	#loss of particular habitats	#loss of nutrients
#fire intensity		#loss of soil
#change in habitat type	>critical site criteria	>
#change in future rate of spread, ease of attack	#increase in habitat diversity	?
>	>	
?	?scale of shifting mosaic steady state	

(# signifies a mechanism or important factor, > signifies a predictive procedure, ? signifies a question or issue)

able. Generic processes, state variables and outputs can be further subdivided as needed without altering other parts of the model. The specificity of the goals will determine to a large extent the grain appropriate to each part of the model. Lastly, the model does not limit the factors that mediate the relationships between processes, state variables and outputs. The only limitation is that the relationships be consistent over time within a cell.

Third, the model is extremely inclusive. An enormous range of questions can be expressed using model constructs. The model generates certain obvious questions involving the effect of a given process on a given state variable. The model itself does not always generate interesting new questions, since many of them involve either adding new processes, variables or output to the model structure, or subdividing these entities in novel ways not derivable from the model itself. Nonetheless, the ability of the model to stretch itself over a wide range of phenomena allows potential divergent lines of research to be viewed together.

Finally, the model organizes knowledge in a form analogous to our technology of expert systems and GIS. The construct of the cell shows the link to GIS while the consistent rules that define the relationships between processes, state variable and outputs are the usual components of expert systems.

A fully calibrated, fine grain model of hardwood rangelands may appear to be an unrealistic goal, a sink for research resources that should be avoided in order to address a few pressing hardwood issues. Yet many of the pressing issues point toward "sustainable development" and "landscape management." This holistic imperative requires new paradigms, such as this model, to achieve a landscape synthesis.

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Soil Aeration and Tree Health: Correlating Soil Oxygen Measurements With the Decline of Established Oaks[1]

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Abstract: Field measurements of oxygen concentration and oxygen diffusion rate (ODR) indicate that ODR is a more reliable indicator of problem sites. In a landscaped area where oak trees are declining, ODR in the upper part of the soil profile ranged between 0.1-0.2 µg $O_2 cm^2$/minute (where µg = micrograms, and O_2 = oxygen) for weeks at a time. In laboratory experiments, we have found low oxygen levels to inhibit oak root growth, and to predispose cork oak roots to extensive colonization by *Phytophthora cinnamomi.* Work is continuing to better define stress thresholds, and the effectiveness of aeration management practices in alleviating root stress.

Trees grown in urban settings are often subjected to environmental stresses. These stresses may result from water deficit, temperature extremes, mineral deficiency or excess, air pollution, defoliation, or poor root aeration. Trees exposed to mild levels of stress may exhibit symptoms such as early fall color and leaf drop, while those exposed to more extreme levels may exhibit symptoms of progressive canopy thinning, limb dieback, and eventual death (Houston 1985). Stress is important not only because of its direct, negative effect on tree vigor, but also because reduced vigor can increase tree susceptibility to pathogenic organisms. For example, oak root fungus *(Armillaria mellea)* has often been reported to be most serious as a pathogen of trees weakened by physiological stress (Rishbeth, 1983). Thus, even when stresses are transient or sublethal, trees may still be severely damaged.

Poor root aeration is one form of stress that is particularly important in urban and park settings. Roots require a continual supply of oxygen, which moves from the above-ground atmosphere to the below-ground atmosphere through soil pores. Several factors which commonly occur in urban and park settings can interfere with this process. One is the movement of soil that typically occurs during construction and landscaping operations. Because oxygen enters soil largely by diffusion, the highest concentrations are near the surface, and they decrease with increasing depth (Kozlowski 1985). Thus, adding backfill soil around trees can suddenly and seriously reduce oxygen levels in deeper parts of the soil profile. Likewise, soil compaction can interfere with oxygen movement into soil because of the loss of macropore space. The large pores in a well- structured soil are important avenues of gas exchange, and they are lost when soils are compacted to high bulk densities. A third factor which commonly limits root aeration is high soil moisture, resulting from excessive irrigation or poor drainage. When soil pores are filled with water, oxygen cannot enter the profile, and the small amounts dissolved in water are rapidly depleted at sites of high metabolic activity.

While species differ, roots generally function best at oxygen levels above 10 percent (Kozlowski 1985). At lower concentrations, roots will cease growth and lose their selective permeability. Key metabolic pathways are modified and cellular metabolites may accumulate to toxic levels. Toxic effects are attributed to accumulation of toxic byproducts of anerobic respiration (Levitt 1980): lactate, pyruvate, and ethanol. Thus, the degree of root injury is proportional to the degree of stress. However, this generalization may not be true if root pathogens are present. Oak Root Fungus, *Armillaria mellea* may colonize root tissues killed by oxygen stress, and from that food base, invade healthier portions of the root system (Wargo 1981). Likewise, accumulation of ethanol in roots may stimulate attack by *Armillaria* (Wargo and Montgomery 1983). In both cases, the resulting damage to the root system is far greater than oxygen stress alone would cause, and could result in tree death.

There are other examples where the effects of oxygen stress are more damaging to roots when pathogens are present. For example, early references to the decline and death of avocados in flooded soils attributed the problem to "water injury," "melanorhiza," "apoplexy," or "asphyxiation." However, research showed that two to three year-old seedlings were not sensitive to flooding per se, and could tolerate up to nine days of continuous flooding with no obvious root damage. But if *Phytophthora cinnamomi* was present, flooding for as little as two days yielded severe root rot. Likewise, safflower roots continuously exposed to 0.5 percent oxygen were damaged only when treatments lasted 48 hours or more (Heritage and Duniway 1985). However, in the presence of *Phytophthora cryptogea,* exposure times as brief as six hours resulted in severe root infection. Well-aerated roots had only minimal infection, indicating that oxygen stress had rendered otherwise resistant tissues susceptible to attack. While brief oxygen stress caused no visible root damage in the absence of *Phytophthora,* there clearly were physiological changes which interfered with normal host defense mechanisms. Thus, oxygen stress may be important even at levels which would not cause direct root injury.

Several practices are currently being used in the landscape and tree care industries to improve aeration in landscape soils. These include high pressure water injection (Hamilton 1984), augered aeration holes filled with porous materials (Hamilton

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1985), soil aeration pipe systems for transport of gasses through overlying fill soils or pavements (Harris 1983), and paving blocks used as substitutes for less porous materials such as asphalt or concrete. These practices have been used for many years with widely varying reports of success. Whether any of these methods significantly improve soil aeration problems leading to direct root injury, or indirect injury through the activity of pathogens, has not been critically studied.

This paper reports on the principal objectives of this research project: to determine the minimum soil oxygen concentrations which must be maintained for optimum root health in landscape trees, and to evaluate the effectiveness of various management practices in maintaining desired oxygen levels.

MATERIALS AND METHODS

Soil Oxygen Measurements Around Established Trees

Measurements of soil aeration status have been done at several field locations. At each location, we installed three replicate monitoring sites. Within each monitoring site, we installed a tensiometer, a gas sampling tube, and five platinum microelectrodes to each of three depths: 6 inches, 12 inches and 36 inches. Soil matric potentials and ODR values were measured daily over intervals of two weeks, and gas samples were extracted for chromatographic analysis at four to five day intervals. After two weeks, all ODR microelectrodes were removed and replaced with clean electrodes. The replacement electrodes were inserted into the same holes, but were pushed 1-2 cm deeper in the soil. Daily monitoring was then resumed for an additional 2 weeks. At the end of the O_2 monitoring period, undisturbed soil cores were collected from each depth from all monitoring sites. A portion of each soil core was submitted for particle size analysis, with the remainder used for determination of dewatering characteristics (between 0-300 mb matric potential) and bulk density.

Six trees at three different locations were selected for study based on tree condition and site features. The first location was a turf area beneath and between the canopy of two closely spaced and severely declining coast live oaks. The turf was irrigated approximately three times weekly. The second location was also a turf area under two cork oaks, one declining and one healthy. The two trees were spaced approximately 60 feet apart and were evaluated separately. The third location was a planting strip where a row of mature cork oaks were growing between the curb and sidewalk. Two healthy trees in the row were selected. Turf in the planting strip is irrigated, but the area outside the sidewalk is nonirrigated.

Effect of Oxygen on Root Growth and Disease Susceptibility

The effects of low oxygen concentration on root growth were studied in three species of oak: Valley oak, *Quercus lobata,* Cork oak, *Quercus suber* and Blue oak, *Quercus douglasii.* These species are believed to differ in their tolerance of low oxygen, with valley oak considered most tolerant and blue oak least tolerant. We have studied oxygen/root growth interactions using 1-2-month-old seedlings of each species, on the asumption that root tips of young seedlings would respond similarly to hypoxia (low oxygen) as those of mature trees.

Germinated acorns with 10 cm radicles were transplanted to mini-rhizotrons fitted with a removable plate surface. Root growth was encouraged along this plate by keeping the containers at a slant. After 10 days the plate was removed and root tracings were made on acetate sheets. The rhizotrons then were incubated in one of three air-tight chambers, each purged with a gas mixture of nitrogen and compressed air yielding a specific oxygen concentration. Oxygen levels between 0 percent (pure nitrogen) and 21 percent (air) were tested. Following a five day incubation period, rhizotrons were removed and the roots retraced. Treatment effects were determined by calculating the amount of root growth which occurred during the various oxygen treatments as a function of total root growth. A root growth value of 50 percent would indicate that one half of the total growth occurred during incubation in the oxygen chamber.

The effect of oxygen treatment on susceptibility to *Phytophthora* infection was determined by inoculating individual roots of cork oak seedlings with zoospores of *Phytophthora cinnamomi.* Inoculations were done at root tips.

RESULTS

Soil Oxygen Measurements Around Established Trees

ODR did not vary with soil matric potential in a consistent manner. In the irrigated turf area (location 1), the soil profile remained quite wet. Matric tensions at 12 inches and 36 inches remained fairly constant at 18 and 22 centibars, respectively (fig.1). In the upper 6 inches, matric tensions fluctuated with irrigation episodes, but generally never exceeded 25 centibar. Within the 15 to 25 centibars range, ODR values ranged from 0.1 to 0.8 for the three depths. Surprisingly, higher ODR values were found in the lower depths (12 inches and 36 inches). Further analysis suggests that low ODR values in the 6 inch depth reflected soil compaction as a limiting factor, rather than matric tension. At the 12 inch to 36 inch depths, where bulk densities were low (1.27-1.30 g/cm^3) and a large proportion of

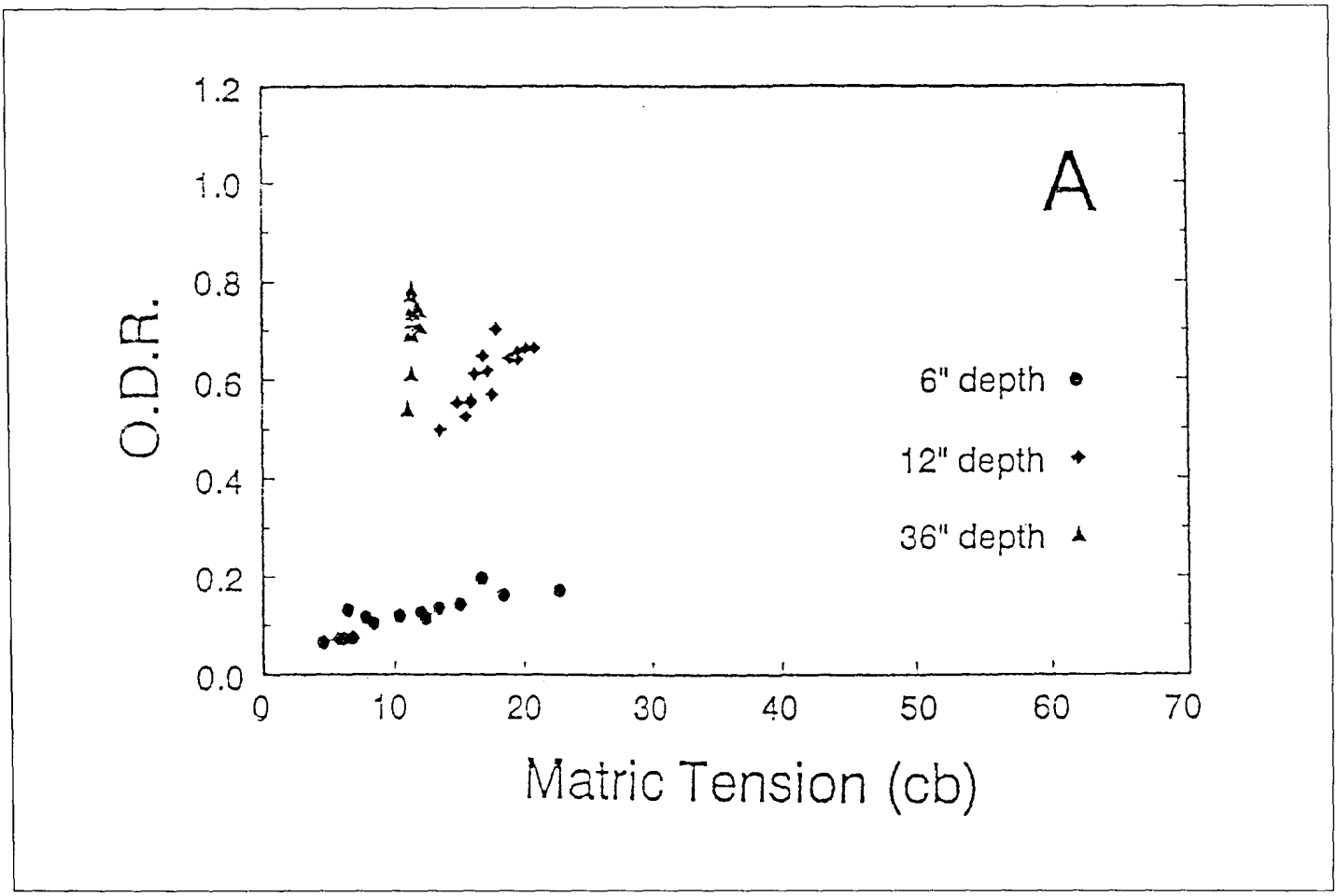


Figure 1—Oxygen diffusion rates (µg 02/=2/min) at three depths in a sandy loam soil, with corresponding matric potential values. Measurements taken under two declining coast live oak trees in Davis, California. ODR values less than 0.3 have been found to impair root function of many species (cb=centibars).

soil pores are drained at 18-22 centibars, ODR values ranged between 0.5 to 0.8 $\mu g/0_2/cm^2/min$.

Similar results were found during preliminary studies at another location. Matric tension in the 6 inch layer increased from 0 to 40 cb and ODR sharply increased from 0.2 to 1.0 $\mu g/cm^2/min$. However, over the same matric potential range, ODR values in the 12 inch layer never rose above 0.2. Soil core analysis showed that soil in the 12 inch layer was compacted and only a small percent of its pores would drain at these matric potentials.

Although differences in ODR could be detected at different locations, corresponding differences in oxygen concentration were not found. Oxygen levels remained around 15 to 18 percent at all locations, depths, and sampling times. ODR seems to be a more sensitive indicator of reduced 0_2 availability in soil than measurements of gaseons 0_2 concentration. As a result, we are now basing our field and laboratory experiments on ODR measurements rather than 0_2 percent.

In comparing ODR measurements taken from the rootzone of declining and healthy oak trees (fig. 2), depressed ODR values in the 6 inch zone were the only measurements that correlated with decline. In general, ODR values less than 0.2 inhibit root function, and less than 0.3 impairs root function in most species (Stolzy and others 1964). Both declining trees were found to have ODR values less than 0.3 in the 6 inch zone. Where values were greater than 0.3 in the 6 inch zone, tree health was good. High and low ODR values in the 12 inch or 36 inch zone were found in both healthy and declining trees. This suggests that shallow root activity may be an important factor in tree health and vigor. We will examine other sites to determine whether there is any consistency in this association.

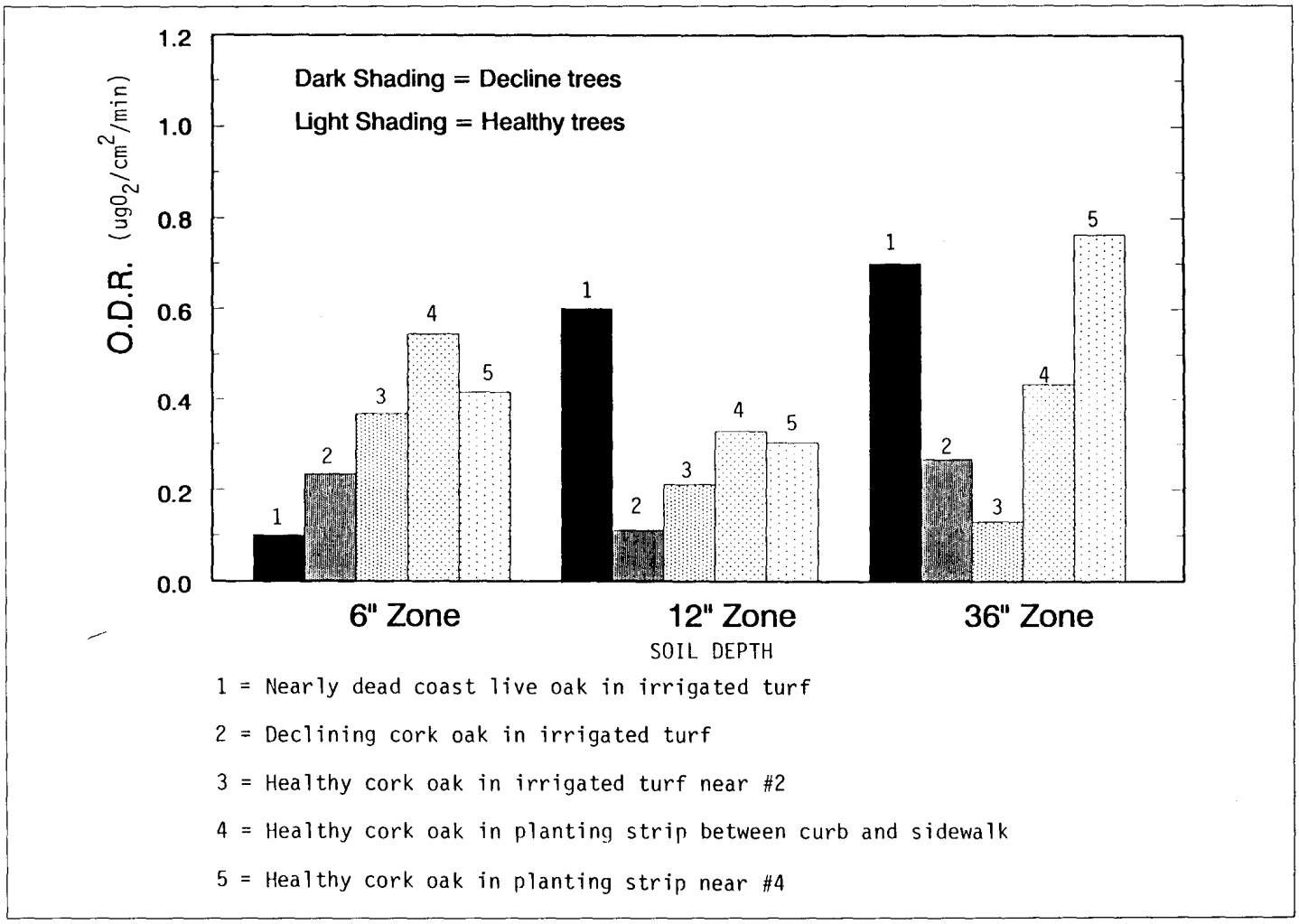


Figure 2—ODR measurements taken at 3 soil depths in the root zone of 5 oaks at different locations. Trees 1 and 2 were declining, while 3, 4, and 5 appeared healthy. Low ODR values in the 6 inch zone correlates with tree decline.

Effect of Oxygen on Root Growth and Disease Susceptibility

Root growth response to increasing oxygen could be significantly described for all species (fig. 3) using a logarithmic growth function (r^2 between 0.61 and 0.87, where r^2 = coefficient of determination). However, the relationship is least significant for blue oak (r^2 = 0.61). Oxygen levels at or below 4-5 percent were highly inhibitory to root growth of all three species causing > 50 percent decrease in growth as compared to that occurring at 21 percent oxygen. Other experiments indicate that blue oak is indeed most sensitive to hypoxia which supports the flood tolerance studies, but further investigation with acorns from this coming season are needed to clarify this point.

We also have measured ODR in the minirhizotrons by inserting probes to the mid-point of the profile. The soil ODR values which caused a 50-75 percent reduction in root growth were 0.3.µg O_2/cm ^{2}/min. This compared to controls where ODR was 0.7-0.8 µg O_2/cm ^{2}/min. Soil ODR values of 0.1 caused 75-95 percent reductions. In separate experiments, we found that vegetative growth of *Phytophthora,* was not inhibited over the same range of oxygen concentrations. Growth in pure culture continued at very low oxygen levels (near zero), and when roots were inoculated prior to exposure to low ODR, the fungus grew extensively in the stressed tissue. This was determined by excising inoculated roots and cutting them into serial segments from the point of inoculation upward toward the crown. Growth in roots exposed to ODR values of 0.1 µg O_2/cm^2/min was far more extensive than in roots exposed to ODR values above 0.3 µg O_2/cm^2/min.

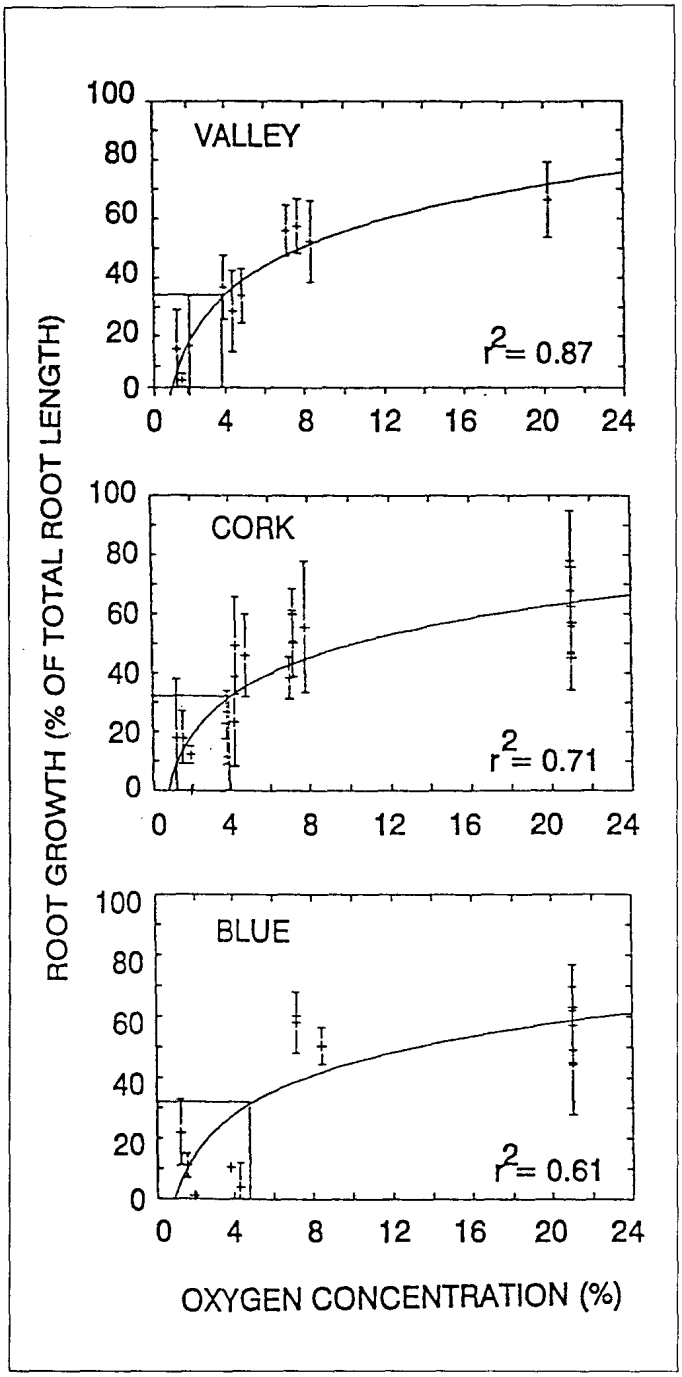


Figure 3—Effects of oxygen concentration on the root growth of three species of oak. Concentrations less than 5 pct inhibited root growth in all species.

Further Research

Research further evaluating soil compaction and moisture content effects on ODR levels is in progress. Future studies will assess other soil conditions which may affect ODR (e.g., grade changes and pavements), and field assessments of declining and healthy trees will continue. Methods used to alleviate low soil aeration conditions will be evaluated.

ACKNOWLEDGMENTS

The assistance of Terry Berger of UC Davis, and Mike and Gary Hutnick of Sta Green Tree Service, Carmichael, California is greatly appreciated.

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A Comparison of Management Strategies in the Oak Woodlands of Spain and California[1]

Lynn Huntsinger James W. Bartolome Paul F. Starrs[2]

Abstract: The characteristics, uses, and management of oak woodlands and savannas in California and southern Spain are compared. There are many similarities between the Spanish dehesa and the California oak woodland. Both are located in Mediterranean climate zones, and are used predominantly for livestock grazing. However the Spanish dehesa is a more diverse and long-standing system of management. Products include cork, acorn-fattened hogs, charcoal, milk, mushrooms, and lucrative hunting. Analysis of this system offers insight into the role of ecological and economic diversity in sustainable resource use for California.

This paper compares the characteristics, uses, and management of oak woodlands and savanna in California and southern Spain (table 1). Although the two woodlands have much in common, the ecological dynamics and hence appropriate management techniques vary in some important ways. Similarities outweigh differences, however, and methods for long-term, sustained management of the Spanish dehesa provide contrast to hardwood woodland management in California.

CHARACTERISTICS

California's oak woodland and savanna covers approximately 3 million hectares of what is generally rolling foothill topography (Ewing and others 1988). The overstory is dominated by one or a combination of five oak species and their hybrids: blue, coast live, interior live, valley, and Engelmann oaks (*Quercus douglasii, Q. agrifolia, Q. wislizenii, Q. lobata,* and *Q. engelmannii*). In southern Spain and Portugal, oak woodland overstory is predominantly one or a combination of two oak species, holm oak (*Quercus ilex*[3]), and cork oak (*Quercus suber*). These two species together cover about 5.5 million hectares in southern Spain and Portugal, including the Andalusian uplands, and extending north toward Madrid and Lisbon (Marañon 1988; Campos 1984; Ruiz 1986).

In both Spain and California, oak woodland soils tend to be shallow and infertile, unsuitable for intensive crop production. In Spain, soils are limestone or granitic. In California, the woodland soils are of metamorphic and sedimentary origins. Climate in the woodlands of California and Spain is typical Mediterranean, with the California woodlands typically having a slightly warmer and drier summer.

The majority of Spanish and Californian oak woodlands are in private ownership - 82 percent private in California (Ewing and others 1988) and 98 percent private in Spain. About half of California's land is public, while in all of Spain, less than 2 percent of the land is public. Population growth is rapid in both areas. Patterns of urban and suburban development appear to differ, however, with a less sprawling, more concentrated pattern of growth in Spain.

In California, the characteristic oak savanna understory is annual grasses and forbs, most of which have emigrated from other Mediterranean regions, including Spain (figure 1). The oak savanna type is considered a stable community that, in the absence of human intervention, changes slowly or not at all (Griffin 1977). Without direct human intervention, the understory of Spanish oak savanna is rapidly invaded by aggressive shrubs, most commonly dominated by rockrose (*Cistus*) species (figure 2). The oak savanna that seems like a natural part of the landscape in Southern Spain is in fact an unstable assemblage carefully maintained by land managers. Oak woodlands are managed to maintain an open savanna understory as part of the sylvo-pastoral system known as the "dehesa" (Marañon 1988). In Portugal the term "montado" is used. Spanish oak woodland ranches, or fincas, are sometimes themselves called dehesas.

USES

In California, oak woodlands produce about a third of the total rangeland forage supply. Cattle consume about 86 percent of that forage, sheep most of the rest (Ewing and others 1988). In Spain, about 50 percent of the grazing is done by *Retinto* cattle, 42 percent by *Merino* sheep, 6 percent by goats and 2 percent by domestic Iberian pigs (Marañon 1988). Meat products and wool are produced in both countries. In Spain, milk from sheep and goats is also an important product.

The California mast or acorn crop is harvested primarily by wildlife, as much as 2 tonnes/ha in some cases (Passof and others 1985). The California acorn crop is probably more variable over the state as a whole than the Spanish crop, as greater variation in

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[3]Sometimes considered a separate species, *Quercus rotundifolia.*

Table 1—*Comparison of the oak woodlands of California and southern Spain*

	Spain	California
Uses:		
Forage	hogs, cattle, goats, sheep	cattle, sheep
Mast	hogs, wildlife	feral hogs, wildlife
Oaks	cork, firewood, mushrooms	firewood
Wildlife	hunting	hunting, recreation
Characteristics:		
Understory	shrubs (*Cistus* spp.),	annual grass
Overstory	annual grass oaks (*Quercus* spp.)	oaks (*Quercus* spp.)
Soils	limestone, granitic	sedementary, metamorphic
Topography	foothill	foothill
Management practices:		
Brush control	disking, hand clearing	control burning,
Forage improvement	seeding, fertilization	disking seeding, fertilization overstory thinning
Grazing systems	herding, season-long	season-long, rotation
Wildlife	privately owned	publically owned
	private reserves, fee per animal high returns	fee for access marginal returns
Oaks	cork harvest	thinning
	high interest in regeneration	moderate to low interest in regeneration
Demographic issues:		
rate of growth	rapid	rapid
Pattern of growth	concentrated	sprawl, fragmentation
landownership	2 percent or less public	50 percent public
landownership (woodlands)	2 percent or less public	20 percent public
neighbor conflicts	arson	vandalism
	access for grazing	lifestyles (pets)
	access for hunting	access for hunting
	envy of hunters	dislike of hunting
	foreign investors	fond of predators
		exurbanites
Duration	1,000 yrs.	200 yrs.

tree species, environmental conditions, and tree densities is found in California. In Spain the acorn crop is highly valued as fattening feed for Iberian pigs, who commonly harvest 600-700 kg/ha (Parsons 1962). It is from these pigs that *"jamon serrano*," (mountain ham) a gourmet air-cured ham that is the premier Spanish meat, is produced. Iberian pigs are herded through the woodlands in fall and winter to harvest the acorns.

Firewood production is important in both areas, but the means and uses are different. In California entire trees are harvested as part of thinning or clearing operations. It has been estimated that an average of about 24,000 ha per year have been partially or completely harvested recent years, (Bolsinger 1988), and marketed to a growing "recreational wood burning" market, or to foothill residents who use wood as a winter heat source. In Spain firewood is most commonly produced as a side product from pruning operations. Pruned small branches and some thinned and cleared wood is used to produce charcoal, as well as for firewood. The intensive pruning that some oaks are subject to results in oaks that to Californians look fairly strange. It is in Portugal that pruning seems to reach its most extreme forms. Oaks are pruned both to produce firewood and to enhance acorn and forage production by opening up the canopy. In times of severe drought, livestock may be fed the green branches from oaks as well, although this practice has declined with the availability of modern supplements.

These pruning regimes are representative of intensity of management practices in southern Spain. Trees are managed as individuals, while on California ranches, it is generally the woodland that is managed rather than the tree.

Cork is another important product from Spanish wood-



Figure 1—Blue oak woodland with annual grass understory in California's inner Coast Range.



Figure 2—Oak woodland with rockrose understory in the Sierra Norte near Seville, Spain.

lands. The typical dehesa has a mixture of cork oak and holm oak. The cork oak bark is harvested every 7 to 9 years (Marañon 1988), resulting in a striking juxtaposition of brilliant red harvested cork oak trunks and grey holm oak trunks in the woodland. Spain and Portugal produce three-quarters of the world's cork (Marañon 1988). Harvesting the cork without damaging the inner layer and hence the tree takes skill. In the Andalusia region, where there is great interest in oak reforestation and the maintenance of dehesa systems, fines are levied for damaging or cutting oaks.

The holm oak is valued for its higher acorn production and "sweeter" acorns, in contrast to the cork oak's larger but more bitter acorns. The higher acorn production of the holm oak partly explains why it is encouraged along with the valuable cork oak, but its high resiliency and resprouting ability also makes it a risk-reducing component in the system. In the event of fire or excessive harvest, perhaps brought about because of drought, the holm oak recovers quickly. It can be used more intensively for livestock forage without risk to the cork crop and without permanent damage to the acorn crop. In addition, oak acorn crops vary highly from tree to tree and year to year and species to species (this is also a well known phenomenon in California). Stands of two species may assure a more consistent acorn crop. Perhaps risk from disease and insects is also reduced.

In California, ranches totalling about 280,000 ha of oak woodland are registered with the state Department of Fish and Game as commercial hunting operations (Ewing and others 1988). There are an unknown number of additional private hunting clubs and ranches. Recent studies have indicated that returns tend to be marginal (Loomis and Fitzhugh 1991; Standiford this symposium), although they can be a significant part of the per hectare value of the woodland, especially when forage values are low, augmenting Net Present Value by about $180.00 per hectare (Standiford this symposium). Hunting seems under siege in California, with recent legislation preventing the hunting of mountain lions and the number of hunters declining in the state.

Throughout the dehesa, hunting is a popular as well as an elite sport. Hunting expeditions, including four wheel drive transport and overnight accommodations, command high prices. Returns to the landowner can be quite substantial. In contrast to California, where all wildlife is the property of the state, in Spain wildlife is the property of the landowner. Accordingly, instead of the fee for access that is charged by California ranchers, the Spanish dehesa owner most often charges according to the type and sometimes the quality of the animal hunted. The meat from the hunt remains the property of the landowner and is marketed for an additional source of income.

In California, deer, wild pigs, quail, pheasant, and wild turkey are commonly hunted. The Spanish hunt a wide variety of species, including wild boar, deer, several wild cats, and both small and large birds, including song bird species that Americans would not consider game. Hunting is a broadly admired form of recreation in Andalusia, and controversies surrounding it have most to do with the elitism of the sport, and conflicts over access to traditional hunting and grazing grounds. Many of these conflicts stem from the nature of the National Game Law of 1970. This legislation was the first that allowed a landowner to exclude all others from uncultivated land by declaring it a game preserve. As a result, almost every scrap of open land in Andalusia is decorated liberally with the sign "Coto Privado de Caza," or "Private Game Reserve," regardless of whether or not it can support any wildlife at all. Prior to the game law, local villagers had certain usufructuary rights to open land, which might have included access for grazing and firewood collection, for example. A 1929 law allowed closure of lands used for cropping, which may account for the past popularity of understory cropping in Spanish oak woodlands. In fact, understory cereal production in Spain has declined since the passing of the Game Law.

Understory cropping also occurs in California, though not as commonly as in Spain, or with such a variety of species. Wheat, barley, oats, and triticale are among the crops that may be grown on moderately fertile Spanish soils, producing 900-1200 kg/ha (Campos 1984). In Spain, dryland crops are sometimes part of an agro-silvo-pastoral system. In the winter, crops are grown in the understory, while in summer and fall, the understory is grazed. In many areas, crops are grown at 4-6 year intervals (Campos 1984). Mushrooms that grow on the oaks are also becoming an increasingly important side product in Spain.

Aside from their value for firewood and cork, the oak trees in Spain are known to reduce drought stress under the canopy. The soils under the oaks have a higher organic matter content. As a result, perennial grasses such as orchardgrass (*Dactylis glomerata*) and ryegrass (*Lolium perenne*) are more common under the canopy (Escudero and others 1985; Marañon 1986). Recent studies in California have shown higher productivity and nutrient content in herbaceous vegetation under the scattered oaks typical of the savanna (Frost and others this symposium). In the dehesa system, the different soil layers exploited by the oaks and understory are fully taken advantage of. When herbaceous vegetation runs short due to drought, browse can be cut from the trees and acorns still provide feed. In this way water supplies far below the surface are tapped for use in livestock production.

MANAGEMENT PRACTICES

The greatest point of contrast between California and Spain is in the intensity of management. To maintain the open savanna, considerable effort is needed in Spain to control shrubs. Disking is the most common practice. Lands are disked every 4 to 6 years, either solely to control shrubs or as part of periodic crop production. Hand weeding may be used as follow-up control, and intensive livestock grazing may delay the need for the next disking.

Even light grazing and infrequent fires are generally sufficient to repress shrub invasion of California oak savanna. California ranchers commonly use prescribed burning. Done at

a low intensity under controlled conditions, damage to overstory oaks is rare. Burning reduces shrubs and excess dry matter, and may also improve forage. Spanish land managers do not use fire as a tool because they believe that fire will damage cork oaks. Fire is also discouraged because there is a serious arson problem in Spain. Both the elitist nature of hunting and the loss of usufructuary rights have resulted in resentment among local residents. Adding fuel to the fire, so to speak, is the fact that some of the dehesas are owned by foreign investors, and many of the hunters that visit them are also foreigners. Arson is the most common expression of that resentment. The worst recorded wildfire year in Spain so far is 1989.

In California, there is also some hostility toward the Fish and Game commercial hunting program among hunters. Landowners who enroll with Fish and Game under the 1985 Act (AB 580) can gain permission to extend the hunting season or exceed normal bag limits if they have an approved wildlife habitat improvement plan. Landowners then charge a fee for access to the land, which can be high. Greater enforcement of "no trespassing" areas may presumably follow. Some hunters feel that this favors the wealthier hunters. However, by far the greatest conflict about hunting results from the differences between those growing numbers of individuals who believe in no hunting at all and those who hunt. The "Bambi syndrome," as it is derogatorily termed by hunting proponents in California, seems unlikely to have much influence in a country where bullfighting is the most popular spectator sport.

There is little direct wildlife habitat improvement effort among Spanish landowners. A greater tolerance for the shrubby understory may be the major effect of the high returns from hunting. Landowners may be more inclined to leave some shrub covered areas on their properties. Rockrose species, however, are for the most part unpalatable to wildlife, so their main value is as cover. Oak woodland with a shrubby understory is of little use for livestock production of any kind in Spain. In California, thinning of stands, maintaining mosaics of shrub/grassland/oaks, prescribed burning, and construction of quail piles and water tanks are all common wildlife habitat improvement practices. Understory shrubs are more diverse and in some cases may be fair browse for livestock and excellent wildlife browse. A scattering of shrubs is not considered entirely undesirable on a California ranch.

In Spain as well as in California, year-long grazing is the most common practice. Seasonal grazing also occurs, although in Spain as in California, changing land use patterns have limited access to traditional seasonal grazing grounds. Herding of sheep and goats is not uncommon in Spain, but is virtually unknown in California oak woodlands. Mixed species grazing is the norm in Spain, but is also unusual in California. In Spain, cattle may graze the herbaceous understory year-long, with pigs herded through in fall to harvest acorns. Various combinations of sheep, goats, cattle, pigs and even horses may graze the same pasture, either serially or concurrently. This presumably leads to greater homogeneity of pasture utilization. In both Spain and California, plantings of subterranean clover (*Trifolium subterraneum*) and other attempts at forage improvement are occasionally employed.

The intensity of management characteristic of the dehesa system carries over into regeneration practices. Both holm and cork oaks resprout and in most soil conditions produce abundant seedlings from acorns. Seedlings and sprouts that are located in appropriate spots are encouraged to grow to trees. Herders guide animals away from young trees, and may pile branches and brush around seedlings to protect them from browsing. Over time, the dehesa oaks have come to be spaced relatively evenly, far apart enough to allow a tractor pulling a disk to pass between the trees and perhaps to maximize multiple resource use (figure 3). In recent years, however, there has been a shift away from close herding of stock toward extensive pasture grazing and enhanced deer and boar populations. As a result, suppression of seedlings and sprouts due to over-browsing has become a problem in some areas. On California ranches oak distribution is irregular, in some places very dense and in others sparse (figure 4). A variety of factors, including browsing, soil conditions, and changes in the California flora, seem to be affecting the regeneration success of some oak species. Landowner interest in the regeneration of individual trees is limited but there is interest in low cost techniques of enhancing or maintaining woodland regeneration rates overall.

CONCLUSIONS

The ecological dynamics of the oak woodlands of Spain and California are different, and it follows that the management practices employed also must differ. Yet similarities outweigh differences, and there is much Californians can learn about long-term, sustained management systems through study of the Spanish system. The management of the dehesa extends back through Moorish times into the distant reaches of Roman history, at least a thousand years. Cervantes' Don Quixote noted the advantages of eating acorns as the staff of life, and in rare cases today, acorn bread or gruel is sometimes eaten. A popular liquor is brewed from acorns. It is the diversity of the system, both in terms of its vegetation components and the products produced, that makes it so stable and enduring.

In California, we like to think that human intervention in oak woodland ecosystems has been brief, about 200 years. We think of ourselves as interlopers in a pristine system, as exploiters. But we really don't know much about the long term management of California oak woodlands. Acorns were the dietary staple of a large population of Native Americans in California. It is possible that California oaks have been managed for thousands of years, and that the present distribution and abundance of oaks is a function of that management to some degree (Heady and Zinke 1978).

Now we are in the process of re-defining our role in the oak woodlands of California. Are we interlopers—a destructive force driving the woodlands to extinction? Will we simply learn to be good neighbors to the remnants of an ecosystem that is best



Figure 3—Holm oak woodland on a Sierra Norte hillside near Seville, Spain. Note the relatively even spacing of trees, mono-specific stand.

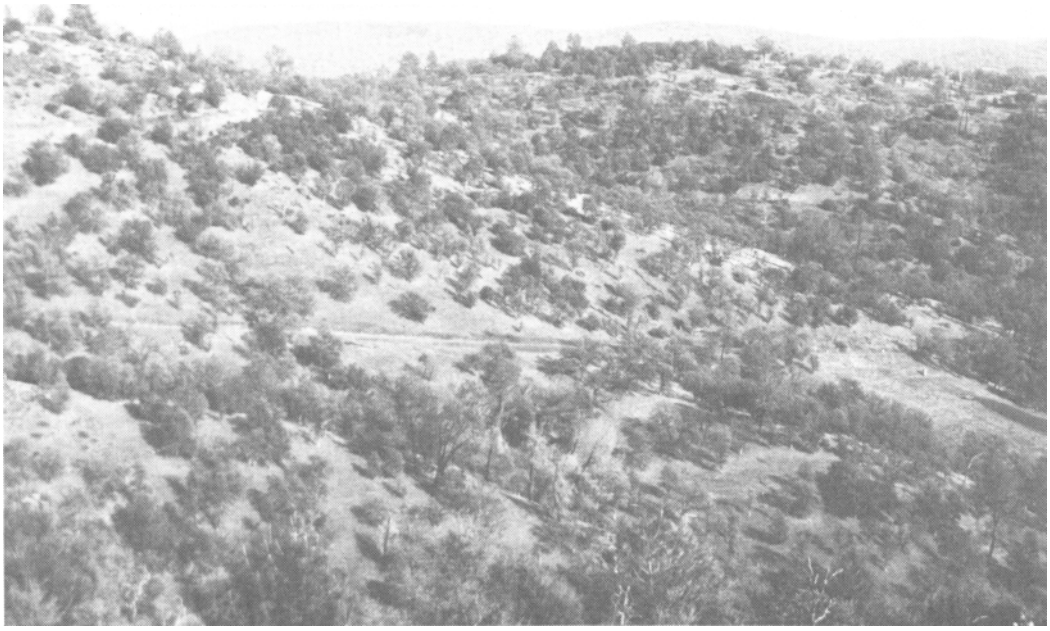


Figure 4—Blue oak woodland on the west slope of the Sierra Nevada east of Marysville, California. Note uneven tree distribution, mix of digger pine, interior live oak, and blue oak.

off without our intervention? In Spain, the dehesa is renowned as a reservoir of biodiversity, and home to a variety of threatened and endangered species (Marañon 1988). At the same time, it produces a variety of products for human use, and support to rural economies and families. In California, questions that will be resolved in the next few decades include whether we will manage our oaks intensively, extensively, or not at all. A lot depends on how we view ourselves and our role in natural systems.

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Blue Oak Canopy Effect On Seasonal Forage Production and Quality[1]

William E. Frost Neil K. McDougald Montague W. Demment[2]

Abstract: Forage production and forage quality were measured seasonally beneath the canopy of blue oak (*Quercus douglasii*) and in open grassland at the San Joaquin Experimental Range. At the March and peak standing crop sampling dates forage production was significantly greater (p=.05) beneath blue oak compared to open grassland. At most sampling dates, the protein content was greater, and at some dates the acid detergent fiber and lignin concentration was lower, in forage beneath blue oak than in open grassland. Increased forage production and better forage quality beneath blue oak canopy demonstrate the value of scattered blue oaks in this region of California.

California's hardwood rangelands are the state's most important source of range forage, supplying about 65 pct of the state's AUM's for domestic livestock grazing (Clawson 1988). Removal of blue oak (*Quercus douglasii* Hook. & Arn.) and conversion to open grassland has been advocated as a method of increasing total annual herbaceous production on oak woodlands in parts of northern California (Murphy and Crampton 1964, Murphy and Berry 1973, Jansen 1987, Kay 1987). These investigators found lower total annual herbaceous production under blue oak canopy than in open grassland. Similar overstory-understory relationships have been reported over a wide range of vegetation types (Hyder 1954, Pond 1964, Clary 1971, Thatcher and Hart 1974, Williams 1976, Woods and others 1982, Thill and others 1983).

In contrast, research in central California has shown total annual herbaceous production to be 15 pct to over 100 pct greater under scattered living blue oaks than in open grassland (Duncan and Reppert 1960, Holland 1973, 1980, Duncan and Clawson 1980). In this region, death or removal of trees has resulted in a gradual decline in annual herbaceous production leading to herbage levels comparable to those of the less productive open grassland (Holland 1973,1980). Greater herbaceous production beneath blue oaks has been attributed to more favorable physical and chemical soil properties and a more favorable, moderated soil temperature under the trees than in open grassland (Holland 1968,1973).

Forage quality has also been found to be significantly different for forage beneath blue oak canopy and in open grassland at the end of the growing season. Holland and Morton (1980) found that herbaceous plants beneath blue oaks had significantly higher levels of crude protein, P and K than those in open grassland. A similar result was reported by Kay and Leonard (1980) and Kay (1987) who found higher levels of N, P, and S present in forage beneath the canopy of blue oaks than in that of open grassland.

The objectives of this study are: (1) Quantify the forage production differences under the canopy of blue oak and in open areas outside the canopy periodically through the growing season; and (2) Compare the chemical composition of forage, both under and outside blue oak canopy throughout the year.

STUDY AREA

The San Joaquin Experimental Range (SJER) is located in Madera County, within the Sierra Nevada foothills of central California, 25 miles northeast of Madera and 30 miles north of Fresno. The SJER is typical of the blue oak phase of the foothill woodland vegetation type (Griffin 1977). The SJER lies primarily between 1,000 and 1,700 feet elevation; predominant aspect is southwest. Annual precipitation averages over 19 inches with recorded extremes of 9 and 37 inches (Coon 1989).

The study area consisted of open rolling sites, classified as blue oak-interior live oak/grass cover type (Allen and others 1989) with southwest aspects and slopes < 15 pct which have been grazed yearly since at least 1934 when the SJER was established. The overstory consists of scattered blue oak, interior live oak and digger pine. Canopy cover within the study area was 6 pct blue oak, 12 pct interior live oak and 3 pct digger pine. The major soil of the study area belongs to the Ahwahnee series (coarse-loamy, mixed, thermic mollic Haploxeralf) developed from intrusive igneous rocks of the Sierra Nevada Batholith.

METHODS

The sample area was exclosed to cattle grazing by using electric fencing until after sampling forage production in May. Cattle were allowed to graze the area from approximately mid-May to late September or early October each year when moderate levels of residual dry matter were reached (Clawson and

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others 1982). Stocking rate in the entire range unit was one cow per 15 acres under yearlong grazing. Cattle were mature English or English crossbreeds.

Standing crop was measured at 8 week intervals during the green forage period and used as a measure of forage production. Standing crop was determined by the comparative yield method (Haydock and Shaw 1975), a double sampling technique, utilizing a 1 by 1 foot frame. Standing crop was measured beneath the canopies of blue oak and in open grassland. Sample size was eight 50-plot transects per overstory category at each sampling date. Sampling was conducted along randomly located pace transects. Sample plots were located along the transects when they occurred beneath the canopy of blue oak and in open grassland. Sampling along each transect was conducted under four to six trees.

Differences in forage production among the canopy categories and years were examined with analysis of variance. Least significant differences were calculated where significant tree canopy effects, area or year differences were detected (Little and Hills 1978). Significant differences were declared at $p \leq .05$.

Forage samples were collected every 8 weeks during the green forage period and and twice during the dry forage period from along the transects utilized in forage production determination beneath the canopy of blue oaks and in open areas. Ten grab forage samples were randomly collected beneath blue oaks or in open grassland and combined into one sample. Four samples were taken for blue oak and open areas at each sampling date. Samples were dried at 55°C, ground and neutral detergent fiber (NDF), on both a dry matter (NDFdmb) and ash (NDFash) basis, acid detergent fiber (ADF) and lignin (LS) concentrations determined using the procedures of Georing and Van Soest (1970) and nitrogen content determined using Kjedahl analysis. Nitrogen results were converted to crude protein values.

Differences in forage quality characteristics among the canopy categories and years were examined with analysis of variance. Least significant differences were calculated where significant tree canopy effects or year differences were detected (Little and Hills 1978). Significant differences were declared at $p \leq .05$.

RESULTS AND DISCUSSION

Precipitation

The years of this study (1986-90) coincided with a drought cycle in this region. Annual precipitation in these years has ranged from 58 pct to 68 pct of the long term average of 19.26 inches (table 1).

Forage Production

Over the 4 years (1986-90) there were significant differences in forage production among years for all sampling dates (table 2). This was expected as the large variation in yearly forage production, due to variations in weather, is well known (George and others 1985).

In the 1 year with adequate fall rains (1987-88) forage production was greater early in the growing season beneath blue oak canopies than in the open grassland (table 3). This follows the pattern found in this region by McClaran and Bartolome (1987). In mid- and late winter virtually the same relationship existed as in November, with fall rains sufficient to allow for relatively normal forage production the differences brought about by the blue oak canopy continued into January and March.

Table 1—*Monthly and annual precipitation (inches) for the San Joaquin Experimental Range.*

	1986-87	1987-88	1988-89	1989-90	40-Year Average
September	0.53	0.00	0.00	1.17	0.27
October	0.28	1.44	0.00	0.76	0.93
November	0.08	0.92	2.29	1.05	2.25
December	0.71	1.89	3.63	0.00	3.17
January	2.10	2.07	0.98	2.78	3.39
February	3.97	0.48	1.69	2.02	3.49
March	3.04	1.66	3.74	1.02	3.22
April	0.10	3.09	0.11	0.90	1.78
May	0.30	0.06	0.46	1.87	0.49
June	0.00	0.00	0.06	0.00	0.13
July	0.00	0.00	0.00	0.00	0.02
August	0.00	0.00	0.00	0.00	0.02
Total	11.11	11.61	12.96	11.57	19.16

Table 2—*Significant relationships in seasonal forage production for the 4 year period 1986-90.*

	Canopy	Year	CXY
September			
November		**	*
January		**	
March	**	*	
Peak	**		

* significant at p = .05

** significant at p = .01

Note:
CXY Canopy by year interaction

In the other years there was no significant difference in forage production between under the blue oak canopy and open grassland until the March sampling date (table 3). In all 4 years, and averaged across the years, forage production was significantly greater beneath blue oaks than in open grassland in March (table 3). The bulk of forage growth on oak woodlands occurs during the months of March, April and May. At this time soil moisture is sufficient in most years and temperatures are warm. It was during this period that blue oak canopies exhibited the largest impact on forage production as average forage levels beneath blue oak increased at a much greater rate than those in the open grassland.

Total forage production was significantly greater under blue oak canopies in all years, and averaged across the 4 years, as compared to that in open grasslands (table 3). These results are similar to earlier findings (Duncan and Reppert 1960, Holland 1973, 1980, Duncan and Clawson 1980, Ratliff and others 1988) but contrary to results of McClaran and Bartolome (1987) which did not show an increase in forage production at peak standing crop.

Table 3—*Forage production (lb./acre) at the San Joaquin Experimental Range.*

Date	Open	Blue Oak
Sept 1986	0a	0a
Nov 1986	126a	148a
Jan 1987	193a	224a
Mar 1987	721b	810a
Peak 1987	1493b	2490a
Sept 1987	0a	0a
Nov 1987	229b	376a
Jan 1988	529b	590a
Mar 1988	729a	818a
Peak 1988	1448b	2381a
Sept 1988	0a	0a
Nov 1988	0a	0a
Jan 1989	301a	343a
Mar 1989	974b	1510a
Peak 1989	1406b	2735a
Sept 1989	0a	0a
Nov 1989	0a	0a
Jan 1990	67a	84a
Mar 1990	423b	1420a
Peak 1990	864b	1963a
4 year average		
Sept	0a	0a
Nov	89a	131a
Jan	272a	310a
Mar	712b	1140a
Peak	1303b	2392a

(Values in a row followed by a similar letter are not significantly different [p = .05]).

Forage Quality

Clear differences in forage quality were measured between the open and blue oak sites (table 4). Under blue oaks the forage was consistently higher in crude protein concentration and lower in ADF and LS. On average the crude protein concentrations under the blue oaks were 54 pct higher than in the open and when combined with the differences in forage abundance between the two situations there was twice the amount of protein available

Table 4—*Forage quality characteristics for forage beneath blue oak canopy and in open grassland at the San Joaquin Experimental Range, California.*

Date	Overstory	NDFdmb	NDFash	ADF	LS	Crude Protein
Nov 87	Open	52.5a	6.7	33.8	8.9	15.17b
	Blue Oak	46.5b	4.7	29.3	7.6	19.61a
Jan 88	Open	52.7	7.8a	36.0a	9.0a	11.66b
	Blue Oak	46.7	2.8b	24.2b	5.1b	24.24a
Mar 88	Open	42.2	4.6	27.3	6.6a	11.58
	Blue Oak	50.3	2.0	27.4	3.7b	13.23
May 88	Open	67.0a	1.1	38.9a	5.4	6.03b
	Blue Oak	59.0b	1.2	33.7b	4.6	10.53a
July 88	Open	66.4	2.7	44.8a	7.1	4.23b
	Blue Oak	67.0	1.4	39.3b	5.5	8.16a
Sept 88	Open	68.4a	2.2a	46.0a	4.3	5.03
	Blue Oak	61.0b	1.1b	39.6b	4.7	6.50
Nov 88	Open	66.7a	1.8a	45.4	4.6	4.67b
	Blue Oak	62.3b	1.1b	41.3	4.8	6.23a
Jan 89	Open	43.9	10.9a	29.3a	12.9a	19.21b
	Blue Oak	40.3	3.4b	22.3b	6.4b	25.58a
Mar 89	Open	46.7	0.9	33.1	5.3	14.94b
	Blue Oak	50.6	0.6	30.5	4.3	21.43a
May 89	Open	66.3a	1.7	45.3	7.9	4.14b
	Blue Oak	71.6b	1.0	43.1	6.7	6.91a
July 89	Open	63.9	1.5	46.6	6.7	3.64b
	Blue Oak	68.4	1.3	44.8	6.5	4.69a
1987-1989	Combined					
Nov	Open	62.0	3.5	41.5	6.0	8.19
	Blue Oak	53.4	2.9	35.3	6.2	12.94
Jan	Open	46.8	9.9a	31.5a	11.6a	16.69b
	Blue Oak	43.5	3.1b	23.3b	5.8b	24.93a
Mar	Open	44.5	2.7	30.2	5.9a	13.25
	Blue Oak	50.4	1.3	29.0	4.0b	17.31
May	Open	66.7	1.4	42.1	6.7	5.06b
	Blue Oak	65.3	1.1	38.4	5.6	8.75a
July	Open	65.1	2.1	45.7a	5.6	3.94b
	Blue Oak	67.7	1.4	42.0b	6.0	6.44a

Note:
NDFdmb = Neutral detergent fiber, dry matter basis
NDFash = Neutral detergent fiber, ash basis
ADF =Acid detergent fiber
LS = Lignins

(lb/ac) under oaks than in the open grassland. While concentrations of NDF were significantly lower in some of the late fall and spring months under the oaks, there was a tendency for high NDF values in the forage beneath blue oaks in late spring and summer.

To estimate the integrated effect of forage abundance and quality on the grazing animal, crude protein intake of a nursing cow was calculated in both situations (beneath blue oak canopy and open grassland) and related to her daily requirements for protein. Values for forage abundance were converted to intake based on the formulation for beef cattle (National Research Council 1987) and intake requirements (National Research Council 1976). Dietary crude protein requirements were calculated for cows nursing calves - average milking ability - during the first 3-4 months postpartum (National Research Council 1976). The results for the two situations show a striking difference in nutritional quality. The open grassland has only one brief period (March) where daily dietary crude protein intake is in excess of the requirement, while beneath blue oak canopies an excess of crude protein is provided from the period from mid-December to May (figure 1).

These results are a comparison of two ends of the spectrum of hardwood rangeland environments: those with complete oak canopy cover and those with none. While most hardwood rangeland habitats represent a mosaic of these two, these data clearly demonstrate the value of maintaining an abundance of oaks for grazing animals.

CONCLUSIONS

The effects of blue oak canopies on forage production early in the growing season of drought years were variable, but not detrimental. By March forage production beneath blue oak canopies was consistently greater than in open grassland, an increase which was also present at the time of peak standing crop. In addition to the increased production, the forage beneath blue oaks was generally of better quality, particularly in terms of protein content. The increased forage production and higher protein content of understory forage reaffirm the value of scattered blue oaks in this region.

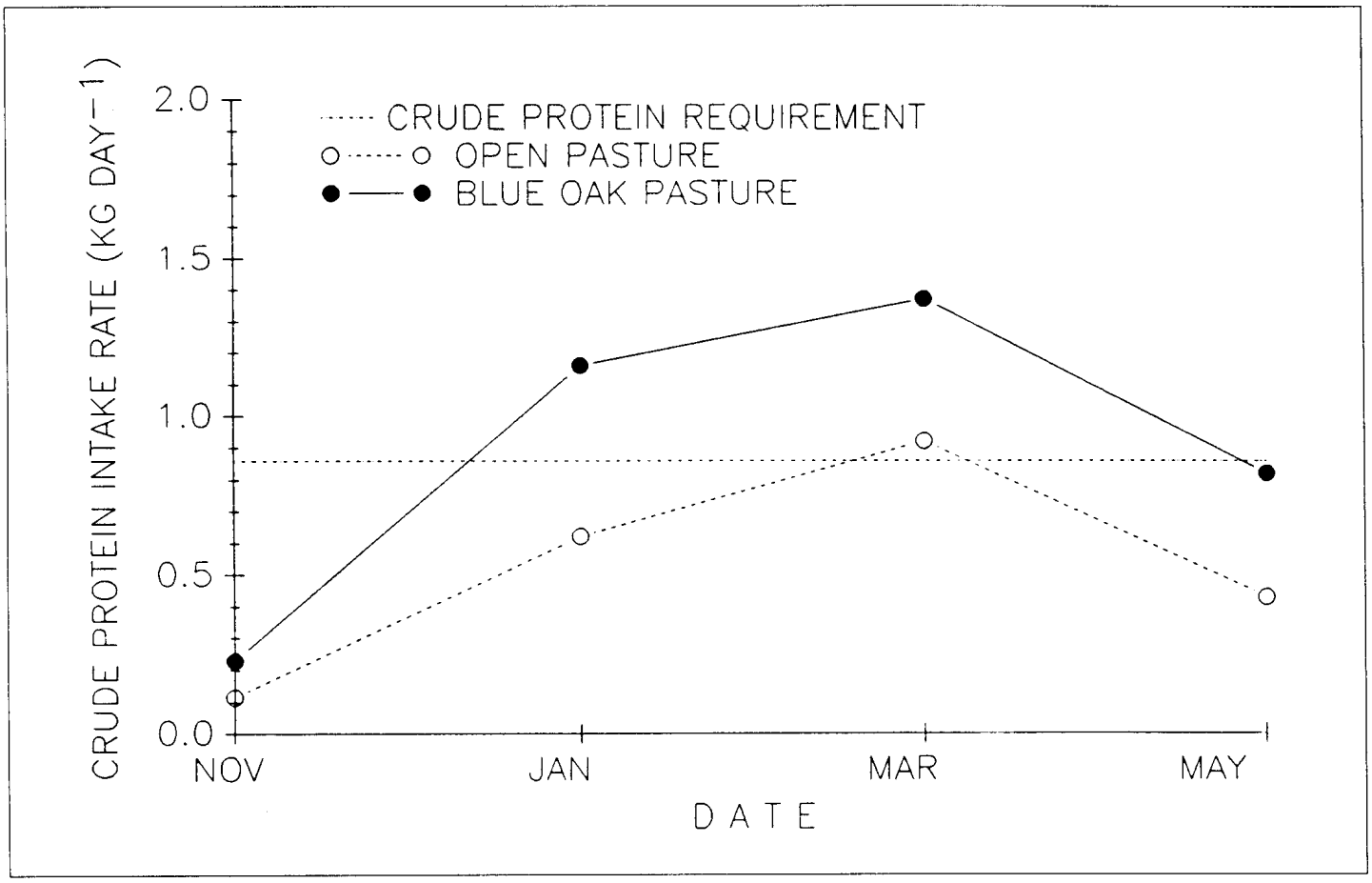


Figure 1—Calculated crude protein intake rate for lactating cows grazing in open grassland and beneath blue oak canopy, San Joaquin Experimental Range, California.

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The Effect of Season and Stock Density on Blue Oak Establishment[1]

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Abstract: Cattle have been faulted as a possible cause for poor oak regeneration in California's hardwood rangelands. This study sought to determine the effects of stock density and season of grazing on blue oak (*Quercus douglasii*) establishment. Year-old blue oak seedlings were transplanted into annual grass/rose clover pastures at the Sierra Foothill Range Field Station. Steers were allowed to graze one plot per week at low, medium, and high stock densities (1, 3, and 6 steers/acre, respectively) during the months of January and April. Results from January indicate that low stock density does not have a significant impact on oak establishment. Grazing damage by the steers and browsing damage by deer increased substantially in April. Trampling damage was usually minimal.

In recent years the fate of native oaks has become the subject of much public concern in California. Studies have shown that blue oaks in particular are not regenerating sufficiently to maintain existing stand densities (Mayer and others 1986; Muick and Bartolome 1986). In the most recent and comprehensive inventory of California's hardwoods, Bolsinger (1988) reports that "seedling and sapling stocking in the blue oak type was usually sparse" and that "blue oak is one of the woodland species generally considered to be declining because regeneration is not keeping up with the removal and natural mortality." There are indications that the transition from seedling to sapling and tree stages is more critical in limiting regeneration than acorn germination and early seedling survival (McClaran 1986).

In the controversy over the future of oaks in California's hardwood rangelands, livestock production has been pointed to as a probable cause of poor oak regeneration (Twisselmann 1967; Franco 1976). Livestock can damage oak seedlings in several ways. They may consume part or all of a seedling while investigating available food sources. Cattle may actively seek blue oaks as a preferred feed or may accidentally consume oak seedlings while eating the surrounding herbaceous material. Seedlings can be nipped, girdled, or completely uprooted. Likewise, cattle can trample and break young trees.

No studies have investigated the effects of stock density and season of grazing on oak seedling establishment. The purpose of this study is to determine the extent of grazing and trampling damage as a result of low, medium, and high stock densities during the winter, spring, and summer seasons. The eventual goal of the project is to be able to give technical recommendations to cattlemen who desire to enhance the regeneration of oaks on their ranches.

METHODS

The study area is an open, rolling site of annual grass/rose clover pastures at the Sierra Foothill Range Field Station, located 17 miles east of Marysville, California. In December 1989, 720 one year-old blue oak seedlings were transplanted into three replicates in three adjacent three-acre pastures. Each replicate contained ten plots corresponding to three seasons by three stock densities and one ungrazed control to determine deer effects. Plots were completely randomized within each replicate. In each plot twenty-four seedlings were planted on ten-foot centers into three feet deep augered holes in which slow-release fertilizer tablets (20-10-5) had been placed. Twelve of the twenty-four tree locations in each plot received a herbicide application of Glyphosate prior to transplanting to eliminate grass competition. Plots were divided by electric fencing.

In both seasons three 700 lb. steers were placed in each three-acre field and were given access to one plot per week as well as the pasture. Grazing pressure was increased by reducing the pasture size each week with portable electric fencing. Week one (low stock density) had the three steers grazing the entire three-acre field which included the 50 foot by 90 foot plot of oak trees for a stock density of one animal per acre. The following week to increase the grazing intensity the field was reduced to one acre to equal a stock density of three steers per acre. Week three, with the highest grazing pressure, the field was further reduced to one-half acre for a stock density of six steers per acre.

Prior to the introduction of the steers, tree seedling height and forage levels (in lbs/acre) were measured using a capacitance probe. Following grazing any grazing or trampling damage was recorded and forage levels were re-measured. After each three week grazing period the steers were completely removed from the fields until the next grazing season. Between grazing seasons all trees were covered with aluminum wire mesh cages to prevent browsing by deer. In spring of 1991, all trees will be evaluated and tree survivability between groups will be compared and analyzed.

Stock densities, seasons, and the herbicide sub-factor were analyzed as a completely randomized design with herbicide

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application as a split plot. Least significant differences were calculated where significant collective grazing and trampling effects were detected. Significant differences were declared at .05 alpha levels.

RESULTS AND DISCUSSION

Season

Grazing and trampling damage was significantly greater ($P<0.05$) in April than in January (table 1). January damage averaged 34 percent while April damage averaged 65 percent. Most grazing damage was caused by nipping off the top of the seedling; often leaving behind several buds. Uprooting in both seasons was not significant (2 percent).

It was hypothesized that when forage is growing and in adequate supply cattle will not be attracted to the young oak seedlings and, therefore, grazing damage would be minimal particularly at the low stock densities. This hypothesis was confirmed in the January grazing season when at low and medium stock densities grazing damage were 6 percent and 25 percent, respectively. Only at the high stock density, when forage selection and space in which to maneuver were drastically reduced, did grazing damage reach 19 percent and trampling damage reach 33 percent for a total of 52 percent. Due to the relatively low grazing damage indices it appears that the steers are grazing the oaks incidentally.

Contrary to the hypothesis, the April damage at all stock densities was much higher contrary to the hypothesis. The April results were surprising because it was thought that the damage to oaks would decrease due to the abundance of tall grasses for the steers to eat. However, during that grazing season the steers were not attracted to the lush grasses. Instead they sought out patches of rose clover, frequently leading them into the oak plots which hadn't been grazed in several months and therefore contained an abundance of clover. It is suspected that the presence of rose clover attracted the steers resulting in greater damage compared to January. This increase could, however, be attributable to the increased activity of deer as well.

Since the area has a resident deer population, control plots to differentiate deer browsing from cattle grazing were essential. Control plots were fenced from cattle and accessible only to deer and other wildlife. The presence of deer in the area, confirmed by deer pellets, hoof prints, occasional sightings, and the amount of browsed oak seedlings in the control plots, may have inflated the amount of grazing damage in the experimental plots attributed to steers during the April grazing season. In January, both deer and cattle grazing indices were low (0 and 19 percent respectively). However, in April, while cattle grazing of seedlings rose from 16 to 59 percent, deer browsing of control plot oaks rose from 0 to 46 percent. It is possible that deer also browsed in the experimental plots, whereby inflating grazing indices.

Table 1—*Percent damage according to season and stock density*

	Winter			Spring		
Stock density	Grazed	Trampled	Total	Grazed	Trampled	Total
Low density	6	6	12(d)	39	1	40(c)
Medium density	25	13	38(c)	61	3	64(b)
High density	19	33	52(bc)	79	14	93(a)
Control	0	0	0(d)	46	0	46(c)

Note: Numbers in columns followed by the same letter are not significantly different.

Although the amount of total damage was quite high, it is worth noting that of the January trees that were grazed or trampled, the damage was usually not fatal. Three months later 95 percent of the seedlings had leafed out. Some researchers suspect that defoliation actually aids oak seedlings during drought years because they have less leaf surface from which to transpire (Welker and Menke 1990).

Stock Density

Analysis of variance revealed a high F value for stock density. The low stock density had an average of 26 percent total damage as opposed to 51 and 72 percent for medium and high stock densities, respectively. Mean separation indicated no significant difference between the ungrazed control and the low stock density, nor between medium and high stock densities. In January at the low stock density, both grazing and trampling damage were minimal. Total damage was evenly divided between grazing and trampling. At medium stock density, total damage rose from 11 to 38 percent with grazing accounting for two-thirds of the damage. At the high stock density, grazing accounted for a little over one-third of the total damage, and trampling damage was responsible for the majority of the affected trees. Thus, there was an apparent shift between the kind of damage inflicted as stock density rose from medium to high.

During the April grazing season, trampling damage was always less than grazing damage. The apparent shift from mainly grazing to mainly trampling as stock density increased did not occur in the spring grazing season.

The results from these two preliminary grazing trials indicate that cattle do indeed feed on young oak trees and that as stock density increases so does the probability that oak seedlings will be either grazed or trampled. Intensity of grazing can influence seedling damage and is a function of two interrelated variables: livestock density and forage levels. As density increases cattle are more likely to accidentally trample trees. Moreover, with higher intensity the preferred forage will become less available and cattle will resort to new and/or less preferred feedstuffs.

Season and Stock Density

Six treatments were statistically analyzed. A treatment is the combination of a season and a stock density. Treatments were denoted winter-low (WL), winter-medium (WM), and winter-high (WH), and the equivalent for the three spring levels. Analysis of variance showed statistical significance for treatment. Mean separation for treatment showed a significant difference between treatments WL and SH, the two extremes, and all other treatments. Treatments WM, WH, and SL were not significantly different nor were treatments WH and SM. Furthermore, no significant difference was found between seedlings which received a herbicide application at planting and those that did not. Replicates and the interaction between treatment and replicate also showed significant F values, but not as high as season, stock density and treatment. There was no correlation between forage levels and grazing damage indices.

CONCLUSIONS

From the results of the initial phases of this three season study, it is clear that cattle damage oak seedlings at medium and high stock densities particularly in the month of April. At low densities, however, it is quite possible that oak regeneration and livestock production are not mutually exclusive. Individuals concerned about the future of blue oaks in California's hardwood rangelands should acknowledge that it is not cattle per se that inhibit oak establishment, but rather the way in which cattle are managed which is the crucial point in this controversy. The detrimental effects of deer at critical times of the year can be just as significant as cattle damage and should not be underestimated. Further investigation representing other seasons will help clarify the effect of livestock on oak seedlings throughout the year so that technical recommendations can be made to ranchers interested in preserving what many consider to be an integral part of California's heritage.

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Grazing and Land Management Strategies for Hardwood Rangelands[1]

Melvin R. George[2]

Abstract: Annual rangelands produce 84 percent of California's range forage which are used all year by sedentary ranching operations and seasonally by migratory operations. Environmental policy, energy and water costs may reduce traditional summer forage sources, resulting in increased grazing pressure on hardwood and annual rangelands. However, the landowner's production goals and society's environmental quality goals can still be attained by subdividing the ranch into management units based on the land's productive potential and resource value and by intensifying grazing management. Pasture subdivision and increased control over grazing time and space has the potential to increase ranch productivity and profitability while facilitating protection of critical areas such as oak regeneration sites, riparian areas, and wildlife habitat.

Most hardwood rangelands and associated annual grasslands are privately owned and produce 84 percent of California's range forage (Forest and Rangeland Resources Assessment Program 1988). These rangelands are the yearlong forage base for many livestock operations. Others make use of high elevation public and private range and pasture or foothill and valley irrigated pastures during the summer (Oltjen and others 1982).

Changes in public land grazing policy and energy costs may reduce the annual migration to high elevation pastures; and higher water costs may reduce the use of irrigated pasture. This will increase pressure on the hardwood and annual grass cover types, creating conflict with society's hardwood conservation goals.

Attempts to solve hardwood rangeland problems have taken a reductionist approach. However, there are problems relating to the management of hardwood rangeland systems which are not amenable to reductionism. The problem of poor oak regeneration on hardwood rangeland illustrates how resolution of some rangeland problems depends on their being seen within the context of a whole ranch. The biological causes of poor oak regeneration or declining wildlife populations are complex. Reductionist research is providing an understanding of the biology of the problem; technological research suggests some potential solutions. This in itself does not solve the problem. A systems approach must place the solution of oak regeneration in a whole ranch context that considers ranch production goals as well as society's hardwood conservation goals. Researchers use systems analysis to highlight deficiencies in the existing system, thus providing research direction. Ranch managers can use systems analysis to develop new tactics for engineering sustainable ranch systems using information generated from reductionist and technological research.

This paper reports how a few ranchers on hardwood rangelands are engineering new ranch systems that require more intensive management of land and grazing and how intensive management of privately owned hardwood rangelands can provide multiple goods and services. Livestock production, oak regeneration, and wildlife habitat objectives need not be conflicting. Planned grazing and land use management can facilitate the rancher's production objectives as well as society's hardwood conservation objectives.

In 1982 we began documenting productivity and management changes on ranches that have instituted intensive grazing management practices. The first ranch was on hardwood savanna in southern Tehama County (George and others 1989). Currently we are monitoring three ranches on hardwood rangelands as part of a case study of controlled grazing funded by the California Energy Commission. These ranches are in Glenn, Alameda, and Santa Barbara counties. Additionally intensive grazing management research is in progress at the University of California's Hopland and Sierra Field Stations.

The objective of this report is to review the benefits that may accrue if traditional extensive range management practices are replaced with more intensive practices that:

1. control livestock so that grazing becomes a controlled management practice.

2. divide the ranch into management units according to the land's productive potential and resource value.

Subdividing the ranch into several pastures or management units facilitates planned grazing management and planned ranch land use. Subdivision is usually achieved using fences. New Zealand fence technology that makes use of permanent and portable, electric and non-electric fences facilitates this subdivision, frequently at lower cost than traditional fencing (Broussard and Gates 1988, George and others 1989).

Ranch subdivision must be thoroughly planned to meet ranch goals. Therefore, prior to purchasing and building fences a ranch plan should be developed. The ranch plan should set goals, inventory resources, select viable management practices, and identify monitoring needs to keep the ranch on course toward its goals. Production goals describe short- and long-term strategies for achieving profitability and sustainability. Environmental quality goals describe the desired ranch landscape required to reach production goals while protecting or enhancing environmental quality. The resource inventory describes the ranch's current status as well as capabilities and constraints.

[1]Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, University of California, Davis.

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INTENSIVE GRAZING MANAGEMENT

While most foothill and coastal ranches are subdivided into a few to several pastures, intensive control of grazing is seldom practiced. Seasonal or yearlong continuous grazing of foothill grasslands is traditional. However, it has also been common to graze different pastures seasonally. Research at the San Joaquin Experimental Range (Bentley and Talbot 1951) suggested that moderate grazing gave the most efficient cattle production, while maintaining satisfactory herbage production. Close grazing reduced range forage production as well as efficiency of cattle production. The effects of grazing intensity were apparent in winter growth of forage and in the yield of mature herbage. The effects of grazing intensity on plant vigor were less apparent during the spring. Differences in grazing during the current season partially obscured the effects of past grazing use. However, differences in forage yield and composition were still apparent in the spring. Currently, grazing management of hardwood range and annual grasslands emphasizes maintenance of adequate residue and efficient utilization of forage to encourage desired forage species and to ensure adequate soil protection (Clawson and others 1982).

Although annual plants do not survive from one growing season to the next, their management in one year can influence productivity the following year. Light to moderate grazing intensities that leave high amounts of dry forage residue in the fall tend to result in more desired forage species during the following growing season. Research has shown that heavy grazing left low amounts of dry residue which tended to produce undesirable species (Heady 1956, Heady 1961, Hooper and Heady 1970, Evans and Young 1970, Bartolome and others 1980). As grazing intensity increased, dry forage residue transferred to the following growing season decreased. As dry forage residues from the previous season increased, forage levels in January increased (Bentley and Talbot 1951).

Specialized grazing management systems adapted to hardwood range and annual grasslands generally have not been used nor have they been the subject of extensive research. Heady (1961) provided extensive circumstantial evidence from the literature to support yearlong grazing as the way to manage annual range. He also showed lamb weaning weights from continuously grazed pastures to be better than those from deferred rotation. However, this was a comparison of continuous grazing to a three pasture deferred rotation where a different pasture was used during each third of the grazing season. In the 1980s the results of this study were cited as evidence that time controlled rotational grazing (Voisin 1959) would have no production advantage over continuous grazing. However, time controlled grazing (TCG) is very different from the deferred grazing used in Heady's study.

During the 1980s a small number of ranchers began to subdivide their pastures and rotationally graze following the concepts developed by Voisin (1959). His grazing rotation principles are based on two simple rules: a) rest periods should vary with pasture growth rate; and, b) individual paddocks should be grazed for no longer than 3-10 days. During periods of slow pasture growth rests are long (60-90 days), and during periods of rapid growth rests are shorter (20 to 30 days).

Several changes in ranch productivity have been documented in our controlled grazing case study. The following production improvements have been documented: increased stocking rate has resulted in increased animal productivity (kg/ha), hay feeding has been reduced during fall and winter, less dependence on hay feeding during the current drought, weed populations have been reduced, and predator losses have been reduced. Increased gross income, reduced variable costs, reduced overhead costs, and improved operational efficiency are associated with these benefits.

Increased Production

Livestock production (kg/ha) can be increased in two basic ways: 1) increased animal performance, or 2) increased stocking rate. Table 1 shows the increased levels of production that have been documented on two ranches in northern California following the implementation of TCG. Table 2 compares pasture subdivision costs and production changes on rangelands with those of traditional range improvements.

Table 1—*Estimated material costs for fence and water development, and production improvements for annual range determined from ranch records.*

		Costs ($/Ha)			Livestock Production (Kg/Ha)			
Pasture Type	Fence	Water	Total	Total Amortized*	Before CGS**	After CGS**	Difference	Stock Type
Annual Range	12.5	0	12.5	2.30	28	54	26	Calves
Annual Range	12.5	0	12.5	2.30	56	84	28	Stocker

*Costs amortized over 10 years @ 13 pct.
**CGS = Controlled Grazing System.

Table 2—*Comparison of pasture subdivision to other common range improvements using conservative estimates of improvement life, costs and production increases.*

Practice	Life (yrs)	Cost ($/Ha)	Amortized Production Cost ($/Ha/yr)	Increase (pct)	Return (kg/Ha)
None	—	—	—	—	56
Subdivision	10	25	4.60	30 - 100	84
Legume Seeding	20	125	17.80	50 - 100	84
Nitrogen Fertilization	2	62	37.50	50 - 100	84

Winter Feeding

Preliminary ranch analyses and observations have suggested that winter feeding can be reduced under TCG. Winter feed costs are one of the larger variable costs on hardwood rangeland livestock systems. Willoughby (1958 and 1959) showed that animal performance increased as forage level increased to 1250 kg/ha. Therefore, increases in forage level due to grazing management may improve animal performance and decrease winter supplemental feeding. Winter forage on offer usually increases as grazing intensity decreases. Bentley and Talbot (1951) showed that winter cow weight gain increased as grazing intensity decreased (table 3). Over a nine year period the average starting date of the winter grazing season was January 29 and the average ending date was March 21. Observation and measurement of winter forage levels indicated that stock in a rotation usually move to a higher forage level than that found in their current pasture. This would suggest that there may be an opportunity to reduce winter supplemental feed with TCG. Limited information from one ranch indicated that winter hay feeding decreased from 450 kg/cow to 91 kg/cow after implementation of TCG. Three ranches that implemented TCG just before or during the current drought appear to have maintained their cow herd with less hay feeding than their neighbors. While these observations are encouraging, only long-term monitoring can substantiate the effect of TCG on ranch operations and profitability.

Weed Control

Pasture weeds are the number one complaint of many pasture owners. Several ranchers have witnessed decreases in pasture weeds following implementation of TCG. Unfortunately, we have not documented these apparent declines in plants such as sour dock, foxtail, and even thistles; however, we have documented a decline in medusahead (*Taeniatherum asperum)* on hardwood range two years after implementation of TCG (table 4). Medusahead declined from 45 percent of the species composition to ten percent, and the heavy litter associated with medusahead patches was reduced (George and others 1989). Studies are currently underway to develop a grazing prescription for managing yellow starthistle (Thomsen and others 1989).

Reduced Predation

One sheep ranch in Solano County, several in Mendocino County, and one in Humboldt County have reduced coyote predation through the use of electric fencing. Jones and others (1990) reported reduced lamb losses when early weaned lambs were grazed in small intensively managed pastures. Pratt (1987) reports sufficient decline in lamb losses following addition of three offset electrified wires to an existing fence to pay for the fence in one year (table 5). Another sheep producer uses a Great

Table 3—*Nine year average winter beef cow gains on foothill rangeland grazed for an average of 51 days ending on March 21 (Bentley and Talbot 1951).*

Grazing Intensity	Grazable Hectares	Grazable Hectares per A.U.*	Gain (kg)
Close	42	2.2	20.7
Moderate to close	54	2.3	29.8
Moderate	65	3.3	53.3
Light to moderate	82	4.2	48.2
Light	103	5.2	45.7
Light	73	3.7	50.3

*Animal Units

Table 4—*Change in species composition (pct) from 1984 to 1986 for four transects in medusahead infestations and one transect in a small ungrazed exclosure.*

	Medusahead			Exclosure	
Composition	1984	1986		1984	1986
Bare Ground	1	8		0	0
Litter	16	25		16	18
Medusahead	45	10	*	8	10
Soft Chess	17	23		16	
Wild Oats	4	0		34	22
Annual Ryegrass	2	5			
Annual Fescue	1	2			
Ripgut Brome	0	0		22	44
Annual Legumes	4	4			
Filaree	10	13			
Other Forbes	2	6	**	4	6
Sample size (n)	4	4		1	1

* ($p<0.01$)
** ($p<0.05$)

Table 5—*Sheep (no.) and financial ($) losses due to coyote predation before and after installation of electric fencing in 1985 (Pratt 1987).*

	1984-85	1985-86	1986-87
Ewes*	50	0	0
Lambs**	200	40	0
Est. Cost	($15,050)	($2,660)	($0)

*$35.00 each
**Avg. 43 kg. @ $1.54/kg.

Pyrennes guard dog to supplement the electric fences. The concentration of the sheep that occurs in a TCG prevented the dog and sheep from being separated and thus less effective.

INTENSIVE LAND MANAGEMENT

Pasture subdivision can have multiple pervasive effects on the ranch system. It facilitates improved grazing management, but more importantly, it facilitates focused management of the whole ranch landscape to achieve a variety of production and environmental quality goals. Subdividing the ranch into management units allows the manager to use each unit to its "highest and best use" for reaching ranch goals. Grazing can then be planned to facilitate management of these units to achieve goals and production targets for each unit. The following improvements in ranch land use management have been documented in the controlled grazing case study: revegetation of gullies, controlled access to riparian areas, increased cover adjacent to riparian areas, increased vigor of native perennial grasses.

While no single ranch has implemented all of these practices, the following are examples of opportunities that could be implemented:

1. Develop riparian pastures that can be managed for riparian values.
2. Develop oak regeneration pastures that will be managed for oaks.
3. Graze some pastures less heavily to leave cover and nesting habitat for wildlife.
4. Thin oaks from some pastures to increase forage production.
5. Seed legumes and fertilize to increase forage production and quality.
6. Mob stock some pastures at strategic times to manage weed species.
7. Use a mix of continuous and rotational grazing to meet animal performance and forage utilization targets and to reduce supplemental feeding.
8. Develop agroforestry pastures where biomass or Christmas trees and forage are produced.
9. Develop perennial grass pastures (native or introduced) to lengthen the green forage season.

This all appears complicated, but ranch planning and planned grazing coupled with ranch monitoring can bring managerial control to this complex process. To help ranchers and landowners plan, Cooperative Extension's Ranch Resource Management Project funded by the Renewable Resources Extension Act and the California Energy Commission has delivered short courses on ranch planning and grazing management to seventeen counties in the last two and a half years. These courses will be conducted in additional counties in 1990-91 and new short courses are under development.

CONCLUSION

California's range livestock industry has adjusted to external pressures throughout its history. Now and in the coming decades grazing management will become more intensive in response to environmental and economic concerns. Changes in grazing and ranch management practices to increase production efficiency will be essential as California's red meat products compete for world markets. Likewise, producers will adjust their grazing and related range operational practices to reduce environmental impacts voluntarily or in response to local, state, and federal regulations.

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Coast Live Oak Thinning Study in the Central Coast of California—Fifth-Year Results[1]

Norman H. Pillsbury John P. Joseph[2]

Abstract: A long-term thinning study was established in ten stands of coast live oak (*Quercus agrifolia* Née) in the Central Coast of California. Information about diameter, basal area, and volume growth and yield has been obtained from unthinned control plots and from plots thinned to 50 and 100 square feet of basal area per acre measured in 1984 and 1989. Both basal area and total volume growth percentages were significantly greater in the thinned plots compared to the control plots. A preliminary economic analysis indicates the potential for modest returns on a thinning operation similar to this study. The possibility of increased production of forage following thinning was less promising due to residual canopy covers of 50 pct and greater on thinned plots.

During the past decade there has been increasing interest in the potential of wood for supplying energy. California's oak woodland are one source receiving increasing pressure for harvesting. These woodlands are an under-utilized resource that could provide a continuous source of wood fiber for energy and wood products, given better management.

Coast live oak (*Quercus agrifolia* Née) was selected for this study because of its extensive range in California covering about 750,000 acres, from San Diego to Mendocino County. Previous studies (Pillsbury 1978; Pillsbury and De Lasaux 1985) involving inventory of coast live oak stands showed that they are typically dense, ranging from 100 to over 700 trees per acre (averages for these studies varies from 300-350) and basal area ranges from about 75 to 250 square feet per acre (averages for these studies is 150-160). Tree spacing ranged from about 7 to 20 feet (average of 12-13) while average tree diameter for the stands varied from about 5 to 17 inches (averages of 10-11). Coast live oak stands are largely between40 and 110 years of age although stands have been measured as young as 28 years and as old as 131 years. Typically they average 60-80 years in age. Site index values varied from a low of 32 feet to a high of 84 feet at 50 years.

We are unaware of coast live oak studies that show the effects of thinning on the growth of the residual stand. Thinnings are normally conducted to stimulate the growth of the trees that remain and to increase the total yield of useful fiber from the stand. The basic objectives of thinning are: a) to redistribute the growth potential of the stand into fewer but larger trees, and b) to utilize all the merchantable material produced by the stand prior to harvest (Smith 1962).

Currently, little is known about site productivity, regeneration, tree growth and the potential effects of harvesting on oak woodlands. Little information is available on different management practices and their effects. By developing a number of permanent plots, growth can be documented over time. These data will prove valuable to foresters and landowners who wish to maximize fiber production in existing stands or want to compare the potential for different management strategies.

The primary long-term goal of this study is to: establish a series of permanent plots to develop long-term diameter, basal area and volume growth and yield information for thinned and unthinned stands of coast live oak in Monterey, San Luis Obispo, and Santa Clara counties.

Other objectives of this study include to: a) evaluate the changes in understory vegetation following thinning, b) evaluate the regeneration of coast live oak (stump sprouts and seedlings) following thinning, and, c) evaluate disturbance of soils during the thinning process and the effects of such disturbance.

Many of the stands measured in previous studies are near rotation age, therefore it is important to know if they could benefit from thinning. This study may help to determine if a thinning of older stands will yield increased fiber while allowing for immediate income from the removed trees.

PLOT ESTABLISHMENT AND INITIAL INVENTORY

Plot Selection

Ten sites were selected for this study and were distributed as follows: Monterey County - four sites, San Luis Obispo County - five sites, and Santa Clara County - one site. Three plots were established at each site consisting of one control plot and two plots that were thinned to 50 and 100 square feet per acre respectively. Plots were established in stands approximately 40 to 85 years old.

Each plot is one-fifth acre in size and surrounded by a two-fifths acre buffer zone for a total area of three-fifths acre. Plots were established by compass and tape; metal rebar was used to monument plot corners.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, University of California, Davis.

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Thinning Prescription

The strategy used for cutting was a combination improvement cut and low thinning. Trees on thinned plots were removed if they: a) were not coast live oak, b) were damaged or defective, c) were less than 6 inches dbh, d) were one stem of a forked tree, e) were of suppressed or intermediate crown class, or f) were of poor vigor (Pillsbury and others 1987).

In most cases further basal area reduction was needed to obtain either 50 or 100 sq. ft. basal area for the plot. Additional trees were removed if they: g) were obviously from a previous stand, h) were not sawlog quality or size, or i) were too closely spaced to an adjacent tree.

An example of how one plot appeared before and after thinning is shown in figure 1. Circles in the plot represent tree basal areas at breast height. Because live oak trees do not always grow straight it is difficult to visualize crown cover from stem maps.

DATA COLLECTION

The following information was obtained for each tree in the study: tree number, species, dbh, total height, merchantability indicator, tree vigor, azimuth and horizontal distance from plot center, crown class, shrubs, ground cover, woody shrub cover, clumps, sprout height, sprout number, stump diameter, stump angle, and stump height. Stand and site information includes: forage (species, extent, weight), other (percent of ground, rock, litter), soil surface condition (erosion), stand and site information (slope, aspect, elevation, soil type, stand crown cover, site age, site index).

Development of Stand, Basal Area and Stock Tables

Basic mensurational data were compiled for each plot before and after thinning and extrapolated to a per acre stand basis. A stand table consisting of the number of trees of a given species per diameter class per acre was developed. Trees were grouped into 2-inch diameter classes (e.g., the 8-inch class includes trees 7.00 through 8.99 inches). Basal area tables were also developed by species and diameter class on a per acre basis. Stock tables, the cubic foot volume of trees of a given species per diameter class per acre, were also developed.

Tree volumes for hardwoods were computed according to three utilization standards, total volume, wood volume, and sawlog volume. Total volume is the total outside bark volume including the stump. Wood volume is inside bark volume from stump height (1 foot) to a 4 inch top (inside bark) for all stems. Sawlog volume is the inside bark volume found in trees having an 11-inch or greater dbh and have straight, sound segments 8 feet or greater in length, from stump height to a 9 inch top diameter inside bark (Pillsbury and Kirkley 1984). Only total volumes were computed for non-hardwood species.

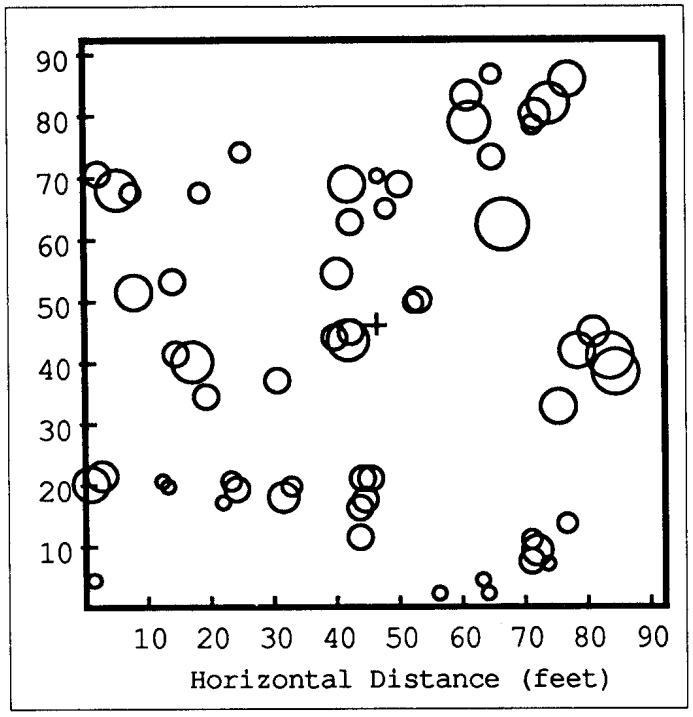


Figure 1a—Stem map for Plot 2-3 before thinning (about 240 ft^2/ac).

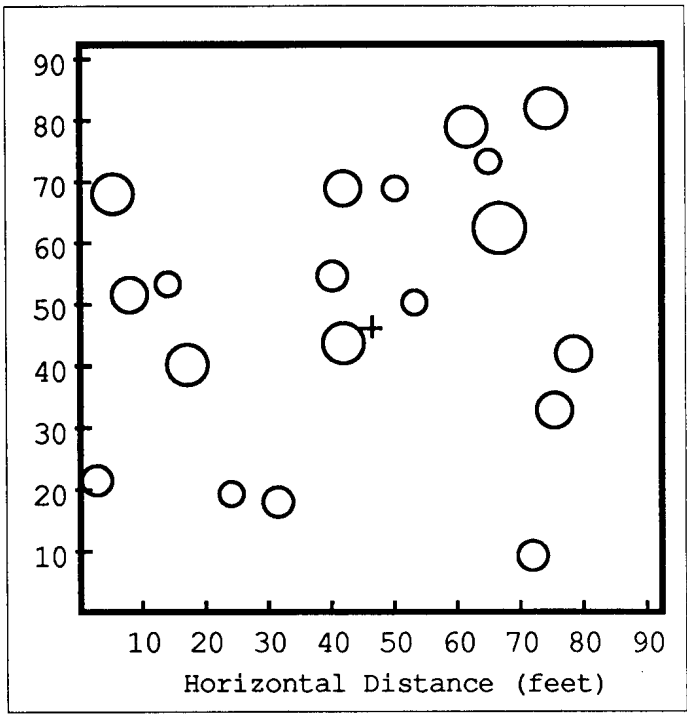


Figure 1b—Stem map for Plot 2-3 after thinning (about 100 ft^2/ac).

REMEASUREMENT OF STANDS (1989)

Analysis

Coast live oak plot data were analyzed for change in stand density and volume growth. It should be noted that thinning studies have traditionally been evaluated solely on change in basal area per acre of the stand. The traditional approach is relatively simple and therefore easily understood. A disadvantage is that it does not evaluate changes in stand volume which is the desired product. The approach used in this study is to look at all five variables to improve our interpretation of the stands' response to thinning: number of trees, basal area, and volume (total, wood, and sawlog).

Using a series of computer programs, a total of 90 stand, basal area and stock tables were developed plus a number of other tables needed to summarize the data. From this array of information we were able to begin charting the course of stand growth and change in the thinned coast live oak plots.

Five-year Results of Thinning Treatments

The effects of the thinning treatments after five years is discussed below for the stand characteristics of number of stems, basal area, total volume, wood volume and sawlog volume. Three treatments were used: control plots (no thinning), plots thinned to 100 ft^2/acre, and plots thinned to 50 ft^2/acre.

At each site a control plot was established and measured to provide a benchmark for comparing the response of the thinned plot.

Number of Stems Per Acre

Any change in the number of stems per acre that would occur would be due to either in-growth or mortality. In-growth, when trees finally reach 4.5' in height and then would be included in the sample, did not occur during this five year period (figure 2). Although hundreds of stumps sprouted vigorously, none attained the necessary height, primarily due to deer browsing. The growth and development of sprouts is examined in a later section.

Mortality, however, did occur and had a definite impact on the study, especially for the control plots (figure 3). The wildfire that occurred during the summer of 1985 produced very intense conditions and was responsible for the majority of tree death that occurred. A total of three of the 10 control plots were affected with an average of 96 trees per acre lost during the interval

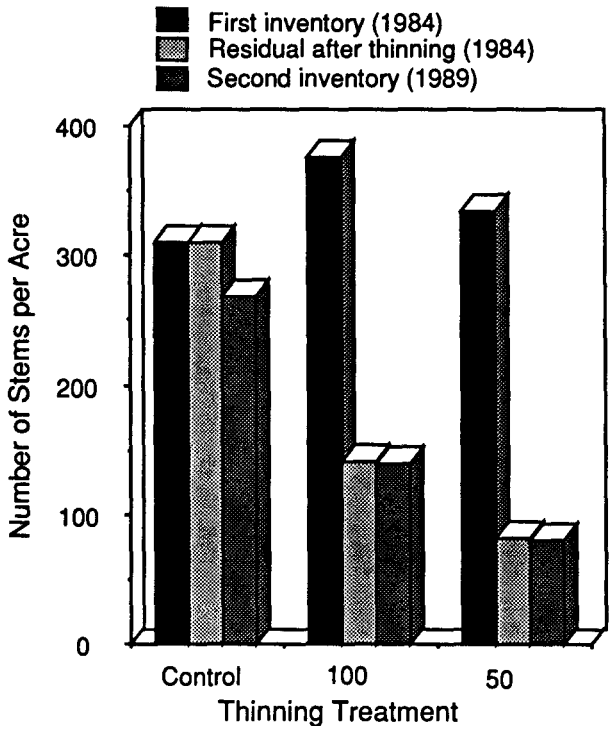


Figure 2—Number of stems per acre by treatment (100 and 50 ft^2/ac).

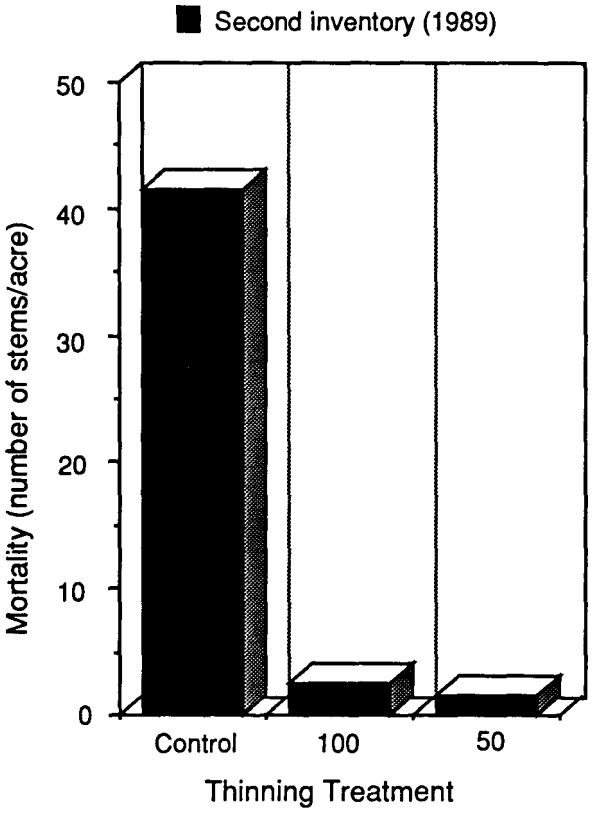


Figure 3—Mortality shown in number of stems per acre by treatment (100 and 50 ft^2/ac).

between inventories. The majority of these were in plot 1-2 which lost an average of 215 trees per acre. By contrast only an average 18 trees/acre died from other causes in the other seven control plots, and only an average of 2.5 and 1.5 trees per acre died in the 100 and 50 ft^2/acre plots, respectively. The greater density of trees in the unthinned control plots may have contributed to the fire intensity and subsequent loss.

In addition to the outright death of trees from fire, a number of factors contributed to tree damage during this period. Again, wildfire played an important role. Many trees had scorched trunks, burned crowns and cracked or swollen bark making diameter measurement difficult. Trees which were defoliated by the flames often produced sprouts along the stem and branches. Although they were classified as a living tree, their rate of growth will be greatly reduced.

Another freak incident, an unusually heavy and wet snowstorm, caused crown and limb breakage. In some plots, nearly every tree was impacted by the storm which struck December 16-17,1988 (table 1). So heavy was the snow weight that nearby residents reported hearing explosions and gunshots as the crowns and boles collapsed.

The 1994 inventory will provide more information on the growth impacts of the wildfires and snowstorm.

Basal Area Per Acre

Basal area was the variable used to design the thinning treatments in 1984. The changes that occurred are shown in Figure 4.

The average increase for all control plots is 2.7 ft^2/acre or about 1.5 pct for the five-year period. The more heavily thinned (50 ft^2/acre) plots increased by about 8 ft^2/acre (13.3 pct) while the 100 ft^2/acre plots increased by 10.4 ft^2/acre (10.5 pct) during the same period. Further, these data show that the 50 ft^2/acre plots averaged twice the basal area growth when compared to the control plots (figure 5) and the 100 ft^2/acre plots averaged three times the growth compared to the control plots.

It could be argued that these ratios and data may be somewhat misleading because of the high rates of mortality in the control plots. On the other hand, one of the reasons for thinning a stand is to reduce the density quickly i.e., speed up the rate of natural mortality, and to improve the vigor and growth rates of the remaining trees. Dense stands will typically have higher rates of natural mortality as well as higher death rates during catastrophic events such as wildfire and extreme snowstorms.

Table 1 — ***Trees affected by snow damage in 1988.***

Plot No.	No. trees after thinning (1984)	No. with snow damage	Percent affected	Treatment
3-1	43	16	37	50
3-2	65	24	37	100
3-3	122	22	18	Control
8-1	22	12	55	100
8-2	9	9	100	50
8-3	54	4	7	Control

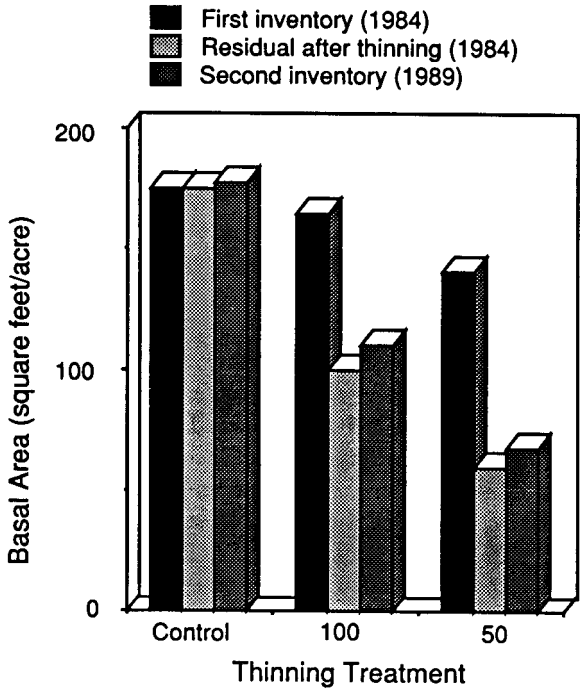


Figure 4—Basal area in square feet per acre by treatment (100 and 50 ft^2/ac).

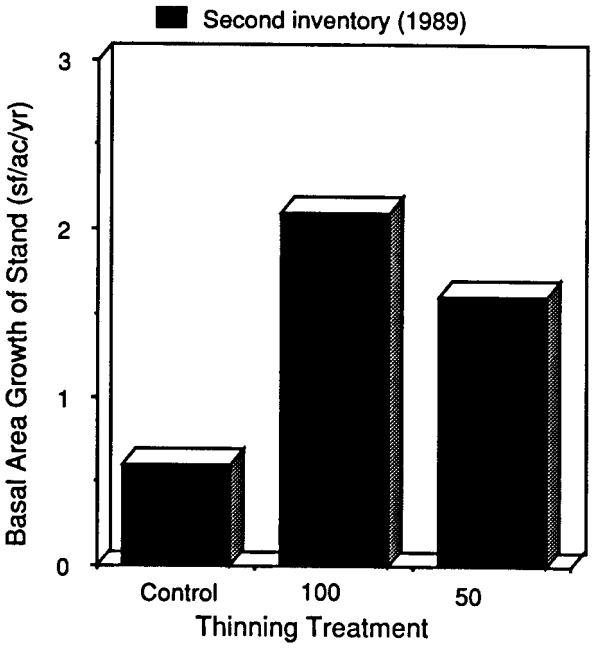


Figure 5—Basal area growth for coast oak stands, by treatment (100 and 50 ft^2/ac).

However, because two schools of thought exist on this topic, the average annual tree growth was calculated based on both, a) all trees in the plot (living and dead) and, b) only on living trees.

As expected there is a rather dramatic difference between the average basal area growth rates for "all trees" versus "living trees" for control plots (figure 6). However, even the growth rates for the "living trees" is only 55 pct of the rate for 100 ft^2/acre plots and only about 40 pct of the rate for 50 ft^2/acre plots.

When the rates for "all trees" is compared, clearly the benefits of thinning are apparent; the 100 and 50 ft^2/acre plots exceeded the control plots by ratios of 9:1 and 11:1, respectively.

Because of the mortality caused by fire and snow, these data show not only the positive results of thinning but also the loss of growth that can occur when stands are not under proper management.

Total Volume in Cubic Feet Per Acre

During the five-year period, total volume increased by 182 ft^3/acre (3.9 pct) for control plots (figure 7). Thinned plots incremented by 329 ft^3/acre (12.6 pct) for the 100 ft^2/acre plots and by 241 ft^3/acre (14.9 pct) for the 50 ft^2/acre plots. The average annual total volume growth rate for the control plots is 32 pct lower than the 50 ft^2/acre plots and 45 pct lower than the 100 ft^2/acre plots (figure 8).

Further it must be understood that control plots contain many more trees than the thinned plots and that the total volume growth could be greater simply due to the total number of trees. In total they could produce more volume even though their growth rates might be slower.

For this reason, a more realistic comparison of growth is to calculate growth per tree, or alternately, volume per square foot of basal area. The results are very similar when using the alternate method volume growth per square foot of basal area.

Annual Volume Growth for "all trees" (cubic feet/tree/year) — All trees remaining after thinning in 1984 are used to calculate this data, i.e., the residual inventory.

Annual Volume Growth for "living trees" (cubic feet/tree/year)—This growth rate is based only on the performance of the living trees.

The data show that the thinned plots out grew the control plots by substantial margins (figure 9). The 100 ft^2/acre plots incremented 74 pct more total volume and the 50 ft^2/acre plots incremented 128 pct more total volume for "living trees" than did the control plots. The difference is even more pronounced when using "all trees" in the calculations.

The U.S. Department of Agriculture-Forest Service, 1977 uses the following definition for Productive Forest Land: "Land which is physically capable of producing crops of industrial wood in excess of 20 cubic feet/acre/year." While the wood products from coast live oak are mostly in the form of firewood, it is interesting to note that the rate of growth of coast live oak exceeded 20 cubic feet/acre/year for all plots.

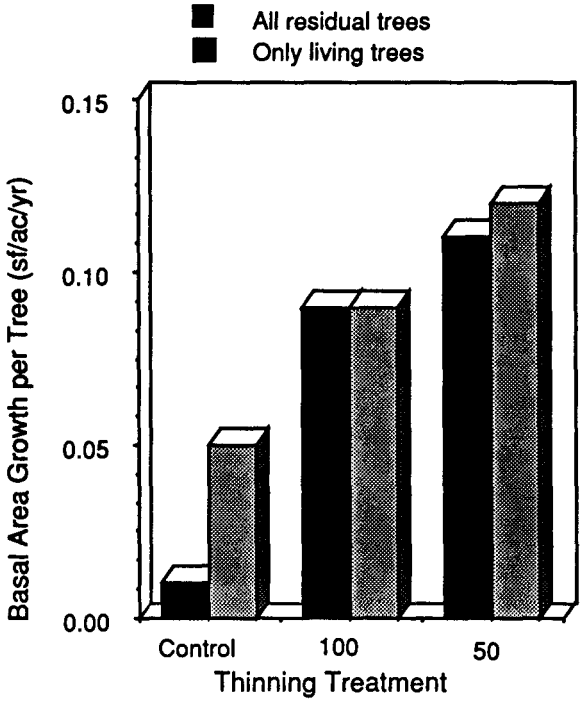


Figure 6—Basal area growth per tree for both residual and "only living" trees, by treatment (100 and 50 ft^2/ac).

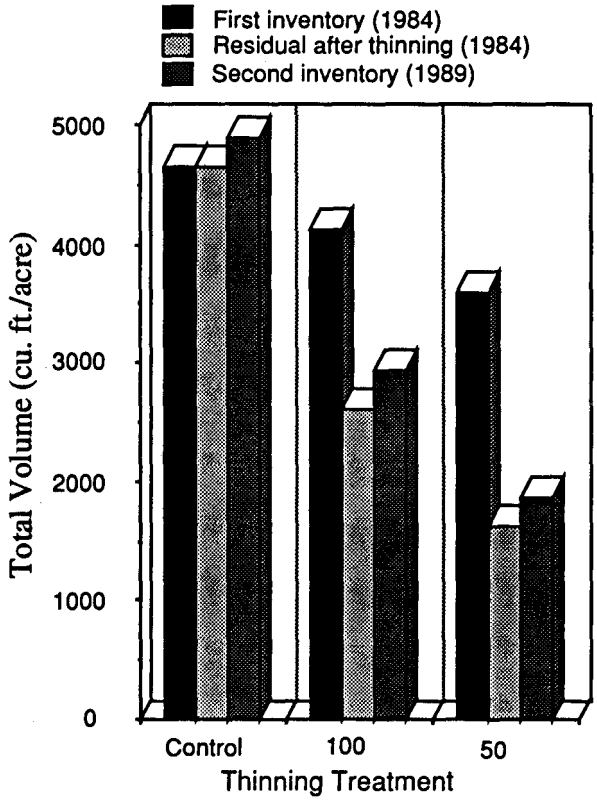


Figure 7—Total volume for coast live oak stands by treatment (100 and 50 ft^2/ac).

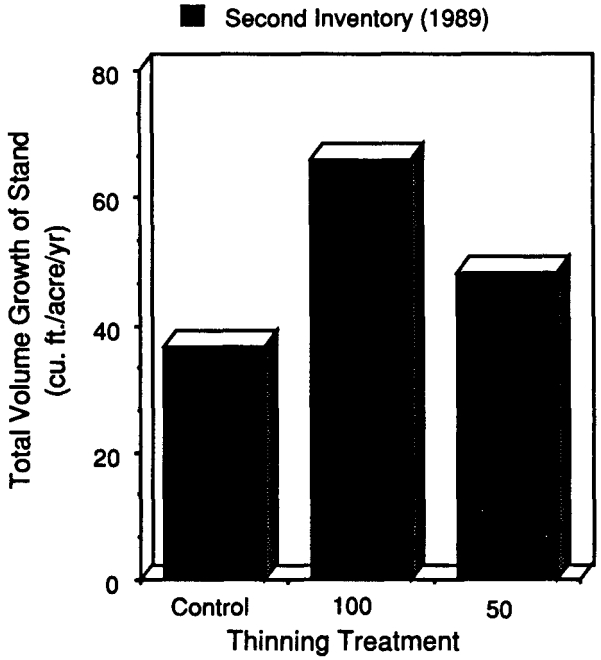


Figure 8—Annual total volume growth for coast live oak stands by treatment (100 and 50 ft^2/ac).

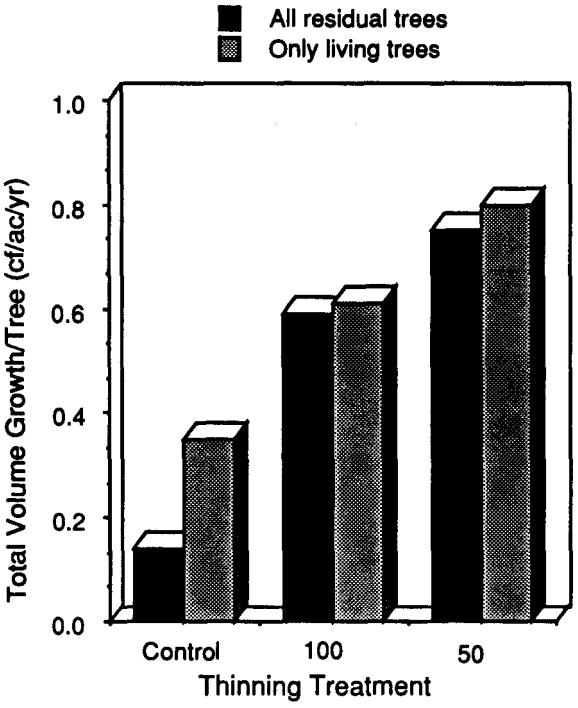


Figure 9—Annual total volume growth for coast live oak stands by treatment (100 and 50 ft^2/ac).

The results of this study were compared with a stem analysis study conducted on 25 plots in 1985 (Pillsbury and De Lasaux) with similar results. All plots exceed 20 cubic feet/acre/year based on the mean annual increment (MAI). When MAI was computed using the last five-years growth, all plots except one exceeded this value.

Wood Volume and Sawlog Volume in Cubic Feet Per Acre

The wood volume in the control plots grew 5-10 pct slower than the thinned plots. However, the sawlog volume in the control plots performed as well as the trees in the thinned plots as the "Percent of volume" data verifies (table 2). This is because trees having sawlog volumes are larger and already dominate the crown and root space in the stand. Consequently their growth rates are not as greatly increased by thinning in the first five-years compared to the changes in total and wood volume. It will take more time before smaller trees will grow into the sawlog category and therefore increase the total sawlog volume.

Greater changes are expected during the 10-15 year inventories. However, it should be noted in table 2 that about 3/4ths of the volume removed in the 100 ft^2/acre plots has already grown back. This is illustrated in figures 10 and 11.

Also the wood and sawlog volumes are calculated based on diameters and heights. A more precise method, when comparing volumes at different intervals, is to only use diameter as this will eliminate the variation observed in height measurement. Until this method is used the wood and sawlog volume data should be considered preliminary.

Table 2—***Preliminary estimates of the effects of thinning on wood and sawlog volume in coast live oak.***

Wood Volume		-------- Five-year growth data -------		
Treatment	Volume Thinned (cf/acre)	Volume Growth (cf/acre)	pct of Thinned (cf/acre)	pct of Vol. (cf/ac)
Control	0	550.9	n/a	17.5
100 ft^2/ac	875.3	482.2	55.1	27.2
50 ft^2/ac	1224.7	256.4	20.9	23.1
Sawlog Volume		------- Five-year growth data ------		
Treatment	Volume Thinned (cf/acre)	Volume Growth (cf/acre)	pct of Thinned (cf/acre)	pct of Vol. (cf/ac)
Control	0	121.1	n/a	17.0
100 ft^2/ac	75.2	55.5	73.8	18.3
50 ft^2/ac	202.7	27.3	13.5	11.6

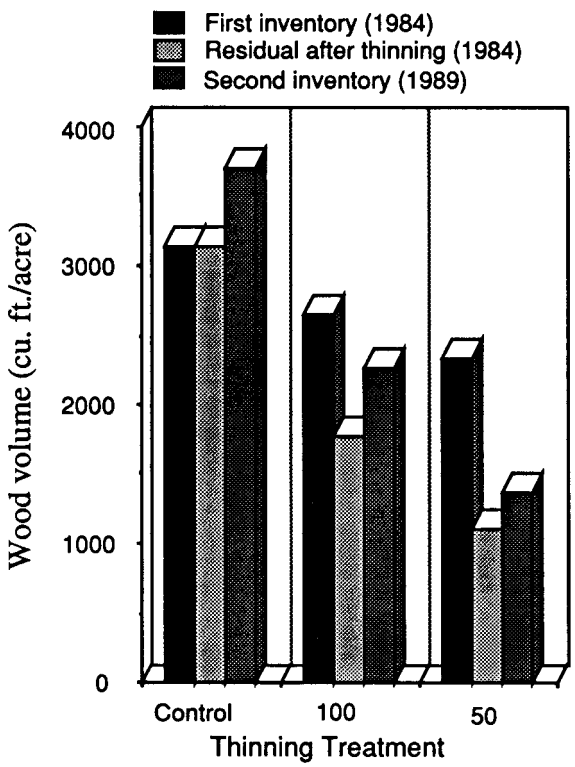


Figure 10—Wood volume for coast live oak by treatment (100 and 50 ft^2/ac).

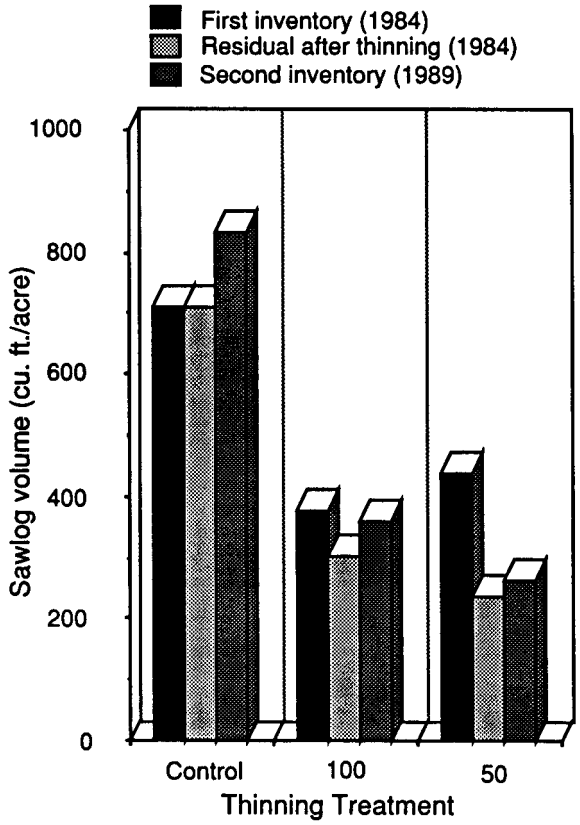


Figure 11—Sawlog volume by treatment (100 and 50 ft^2/ac).

Tree Movement By Diameter Class

Another important facet of the study is to examine how trees "move," that is, how their diameter classes change in relation to the rest of the stand. Figure 12 illustrates the changes that occurred and the regrowth trends that are beginning to appear. Note that the size class removed was primarily in the 2-13 in dbh range. A more thorough analysis will be possible when the 10 and 15 year inventories and growth data are available. At this time, in-growth will also begin to appear.

Preliminary Economic Analysis

At the bottom of every study is the question of cost versus benefit. Although thinning studies are designed for the long-term improvement of the stand, the five-year inventory still allows a rough first-look at the cost/benefit data. The example shown in table 3 is designed to examine the outcome of three separate courses of action by the landowner: a) no thinning, b) thin to 100 ft^2/acre, and, c) thin to 50 ft^2/acre (Richard Thompson, personal communication 1990).

As with any economic analysis a number of assumptions are made to provide a basis for comparison and interpretation. For this example, the following assumptions are used.

1. The property owner, in 1984, thins 10 acres of coast live oak. The average volume on the property is 4150 ft^3/acre which is the approximately the average of the 30 plots used in this study. This is a dense stand that is approximately 60 years old.
2. The property owner employed a Registered Professional Forester who prepared a cutting plan and marked the trees for cutting at a cost of $40/acre for the 100 ft^2/acre option and $50/acre for the 50 ft^2/acre option. The landowner will inspect the operation to insure that the wood cutters are following the guidelines provided by the forester.
3. A local wood cutting outfit will be contracted for the tree removal. Their remuneration will be to keep 2 out of every 5 cords of wood cut (40 pct). They are required to meet all conditions spelled out by the cutting plan such as slash removal, stream-side protection, etc. They will purchase the remaining wood.
4. The stumpage price is $40/cord of wood in 1984 and 1989 and $45/cord in 1994. Obviously as the price of other fuels change, this value will too.
5. The number of cubic feet per standard cord of wood is assumed to be 82. This is based on previous studies by the authors.
6. The percentages of the stand that are thinned to meet the objectives of the options define above are: 36 pct

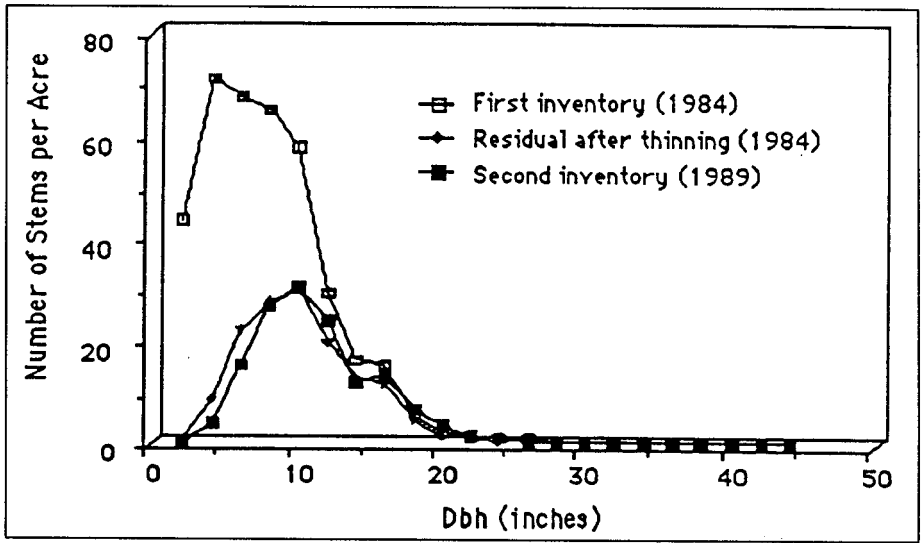


Figure 12—Stand graph showing the distribution of number of stems per acre by diameter class for 100 ft^2/acre plots.

thinned to reduce the basal area to 100 ft^2/acre and 55 pct thinned for the 50 ft^2/acre option. This is based on average percentages calculated from this study.

7. Yield or interest (including inflation) on thinned income is assumed to be 10 pct per year for the period 1984-1989, and 12 pct per year for the period 1989 to 1994.
8. The purpose of the analysis that follows is to show the change in timber valuation for the period 1984-1994. As a preliminary analysis it does not consider taxes, land rent or complex situations that may exist. Also it does not consider the value of other benefits such as increased land value due to the managed condition of the forest, reduced fire risk, and increased forage.

The timber valuation, which includes both the income from thinning and the value of the residual inventory, shows a break-even condition for the three options by the end of the first five-year period. The value based on the thinning options are about $2,120 and $2,050 per acre while the option to not thin yields about $2,110 per acre. In essence, the thinning options have basically paid for themselves in the short span of five-years. In addition, a number of other benefits, discussed above, have accrued.

An estimated timber valuation in 1994 is based on obtaining the same growth rates for the next five-year period. Extrapolating growth and yield data for five- and ten-year periods is common practice. Under these conditions, we estimate that the thinning options provide a valuation to the landowner well ahead of the option to not thin. The 100 ft^2/acre thinning option yields a per acre value of about $2,840 and the 50 ft^2/acre option yields about $3,000. The option to not thin yields a value of about $2,200 per acre.

ANALYSIS OF UNDERSTORY DATA

The Concept of Coppice Management

The revegetation of live oaks through the sprouting of cut stumps, otherwise known as coppice management, is widely used in a variety of forestry and woodlot situations. California coast live oak is well known as a vigorous sprouter. This is especially true when damage is created by fire, wind or harvesting. Most common are sprouts from the cambial layer which form a ring on top of the stump.

In this study sprouts took on two distinct forms: 1) mound or "clump" form, and, 2) sprouting form. Clumps occurred when the succulent sprouts are browsed by wildlife and domestic animals. These sprouts become rounded into a dome or mound shape. The mounds continue to expand outward, growing mostly in diameter rather than height, until an animal can no longer reach the sprouts in the center or until a growing season passes when browsing fails to occur. The center sprouts then will "escape" and grow into a new tree. This process could take anywhere from 2 or 3 years up to 15 or 20 years. If the stump had one or more dominant leaders it was classified as a sprout (as opposed to a clump).

The rapid growth of the sprouts was greatly reduced by browsing of domestic and wild animals. Eight of the sites showed evidence of recent activity by domestic livestock. In plots where domestic and wildlife activity is high, the instance of "clumping" is much higher.

In order to better understand the process of tree development from clumps, they were grouped into three size categories.

Table 3—*Preliminary timber valuation for a l0-year period of woodlot management.*

NET INCOME FROM THINNING (before taxes)

Item	Control (per acre)	Treatment 100 ft^2 (per acre)	Treatment 50 ft^2 (per acre)
(1)Initial inventory (1984); (cf/acre)	4150.00	4150.00	4150.00
(2)Total volume thinned (1984); (cf/acre)0.00		1494.00	2282.50
(3)Number of cords thinned (1984); (cords/ac)0.0018.2227.84			
(4)Share to property owner (60 pct); (cords/ac)0.0010.9316.70			
(5)Income to property owner @ $40/cord =$0.00	$437.27	$668.05	

RESIDUAL INVENTORY VALUE and THINNING INCOME

Item	Control (per acre)	Treatment 100 ft^2 (per acre)	Treatment 50 ft^2 (per acre)
First Inventory (1984)			
(6) Initial inventory (1984); (cf/acre)	4150.00	4150.00	4150.00
(7) Total volume thinned (1984); (cf/acre)0.00	1494.00	2282.50	
(8) Residual (after thinning); (cf/acre)	4150.00	2656.00	1867.50
(9) 1984 Stumpage value @ $40/cord$2,024.39$1,295.61	$910.98		
(10) Income from thinning @ $40/cord (60 pct)$0.00	$437.27	$668.05	
(11)1984 Timber Valuation before expenses =	$2,024.39	$1,732.88	$1,579.02
(12)Cost of cutting plan & tree marking$0.00 $40.00 $50.00			
(13)1984 Timber Management Valuation =	$2,024.39	$1,692.88	$1,529.02
Second Inventory (1989)			
(14)Stand re-growth (cf/ac); (Pillsbury and Joseph 1990)182.50329.00241.00			
(15)Value of re-growth @ $40/cord$89.02$160.49$117.56			
(16)Interest from 1984 thinning income (@10 pct/yr)$0.00$266.96$407.85			
(17)1989 Timber Management Valuation =	$2,113.41	$2,120.32	$2,054.44
Third Inventory (1994)			
(18)Stand re-growth (cf/acre), same rate assumed. 182.50329.00241.00			
(19)Value of re-growth @ $45/cord$100.15$180.55$132.26			
(20)Interest from 1984 thinning income (@12 pct/yr)$0.00$536.86$820.20			
(21)Estimated 1994 Timber Mgm't. Valuation =	$2,213.57	$2,837.73	$3,006.89

Over 83 pct of all clumps are less than 2 ft. in diameter, with 15 pct 2 ft. to 3 ft. diameter. Only 2 pct were greater than 3 ft. in diameter. For the most part, five years is not enough time for clumps to reach diameters of greater than three feet. Until a sprout in the center of the clump can "escape" browsing and obtain a height of four or five feet, little coppice establishment can be expected.

In 100 ft^2/acre plots 32 pct of the stumps formed clumps and 14 pct had advanced to the sprout stage. The percentages for the 50 ft^2/acre plots are 48 and 14. Clump data is presented as descriptive data only at this point in the study. As each five-year inventory is completed changes in their development will be monitored.

The Forage Layer in the Thinning Plots

Part of this study was to examine how the biomass of forage was altered following thinning of the overstory. Forage samples were collected using a 2 ft square (4 square feet) on an area that was subjectively calculated to represent the average of all forage species within the plot. Species were recorded. All above ground grasses and forbs (which an animal would eat) were clipped to the ground. Once air dried, the samples were weighed; and then converted to a per acre basis (lbs/ac). (Stechman 1986).

Wild oats (*Avena fatua*), cheatgrass brome (*Bromus*

tectorum), ripgut brome (*B. rigidus*) and annual ryegrass (*Lolium multiflorum*) were found to some extent on almost all of the sites. It was estimated that they occupied 50 pct or more of the grass layer. The following species represented about 30 pct of the cover: Indian ricegrass (*Oryzopsis hymenoidies*), foxtail fescue (*Festuca megalura*), wheatgrass (*Agropyron* spp.), mouse barley (*Hordeum leporinum*) and needlegrass (*Stipa* spp.).

We found that the species in the forage layer did not vary by treatment as much as by site. The same forage species were usually found in all three plots of the same site, though in different proportions.

For these reasons, treatment averages are not compared. Instead, figure 13 is provided to show the influence of both site and treatment on individual plots. Note that only four sites show the "textbook" pattern where the 50 ft^2/acre plots produce more forage biomass than the 100 ft^2/acre plots which, in turn, produce more than the control plots.

Clawson, McDougald and Duncan (1982), suggest that 700 lbs/acre is considered the minimum or lower threshold level of residual dry matter on gentle to steep slopes in the Central Coast Foothills. Using this value, figure 13 shows that only three sites (all were 50 ft^2/acre plots) exceed this level, while five other sites are just below the suggested threshold.

It is our conclusion that the level of forage production measured at the end of the first five year period is not adequate to allow grazing because there would not be enough residual dry matter for the next year. There are several other important variables which should be considered in the interpretation of the forage data. Most important is the percentage of crown cover on the site after thinning.

This study was designed using basal area as a method to manipulate the stand primarily because of the ease of application and measurement. However the relationship between a stand's basal area and its percent crown cover is not well defined.

The average crown closure (in pct) for the treatments is shown in the following chart and illustrated in Figures 14-16.

1984	1989		
All plots	Con.	100 ft^2/ac	50ft^2/ac
89 pct	83 pct	71 pct	54 pct

Even though a large volume of wood was removed from the 50 ft^2/acre plots the remaining trees currently occupy 54 pct of the crown space. Clearly a further reduction is needed before significant increases in forage will be obtained; perhaps a crown cover in the 35-40 pct range would yield acceptable levels.

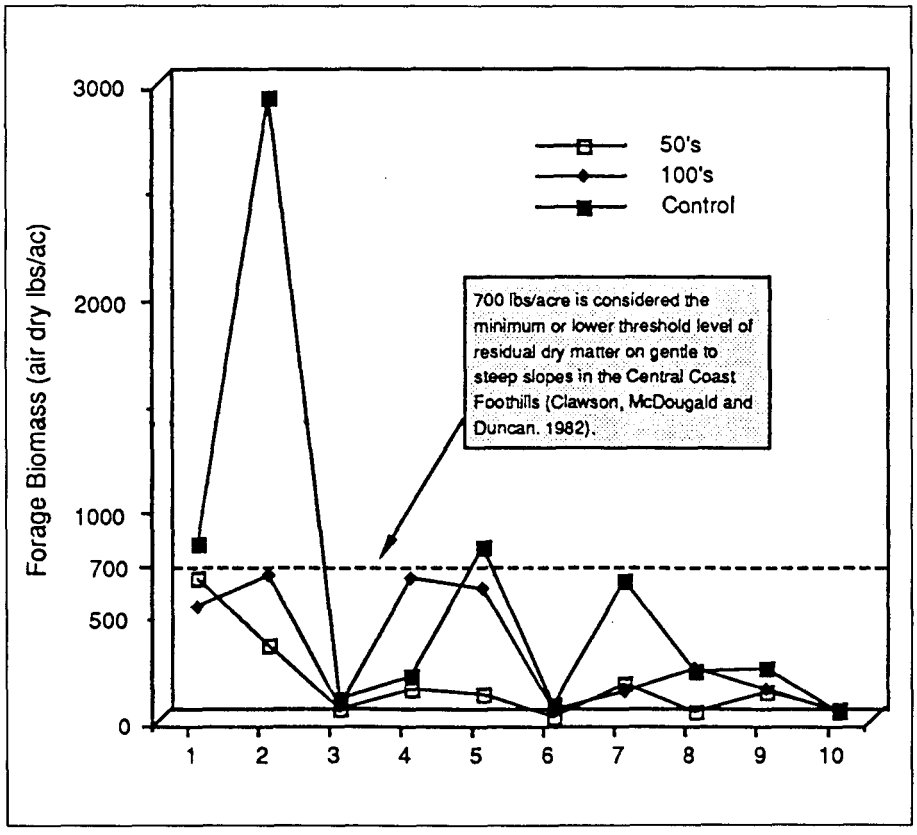


Figure 13—Forage biomass for the coast live oak thinning plots by treatment (100 and 50 ft^2/ac).



Figure 14—A typical control plot of coast live oak.



Figure 15—A plot of coast live oak thinned to 100 square feet per acre basal area.



Figure 16—A plot of coast live oak thinned to 50 square feet per acre basal area.

CONCLUSIONS AND RECOMMENDATIONS

The first five years of growth information has been collected and analyzed for the coast live oak thinning study. The interpretation of this data is discussed below in the form of conclusions and recommendations.

1. Two extremes in weather conditions occurred during the five-year interval which affected the study. First, a major forest fire burned through several plots killing a number of trees and causing the bark to crack and swell. This made measurement more difficult. Our data also shows that the more dense, unthinned plots sustained greater damage from fire than did the treatment plots. Proper care and management of the woodland forest can reduce losses from fire and snow, and, in general, protect the value of the resource.

2. Many of the stands in the thinning study are thought to be near rotation age. Could they benefit from a thinning at this age?

The answer to this question is "yes." The benefits are already apparent even after five years of growth.

Both basal area and total volume growth percentages were significantly greater in the thinned plots than the control plots. This was true even if only the surviving trees were included in the calculations (excluding mortality). Per acre growth rates for the five-year interval ranged between 10 and 15 pct for treatment plots and between 2 and 4 pct for control plots.

Clearly coast live oak stands, even if they are older, respond in a positive manner to thinning.

3. Prior to thinning all 30 plots in the study were measured and and their growth rates were found to exceed the Forest Service definition for Productive Land (20 ft^3/acre/year). In fact they averaged about 70 ft^3/acre/year. An independent site, growth and yield study conducted on 25 plots in San Luis Obispo and Monterey counties in 1985 showed similar results. In that study, coast live oak plots averaged about 60 ft^3/acre/year. In both studies the researchers sampled only moderately dense to dense stands; the typical growth pattern for coast live oak.

This information is significant as it relates to the potential for silvicultural practices and management for commercial products.

4. A preliminary economic analysis indicates the potential for modest returns on a thinning operation similar to this study. A rough first-look shows that after five years the value of the residual trees, plus the thinning income and interest, approximately equal the value of the unthinned forest.

A projection for a ten-year period shows that the value derived from the thinned plots is $600-800/acre greater than the control plots.

This conclusion has very important ramifications to forest and woodland property owners and their stewardship practices.

A landowner can conduct an economically viable thinning operation and accomplish several objectives, including land stewardship. The results show that a forest or woodland will continue to grow and increase in value. The temptation to wholesale harvest all trees (clearcut) can be resisted by knowing that some income can be available immediately following thinning and that the remaining trees are also adding value at a more rapid rate than before. Thus the landowner has not only gained some immediate income and enhanced his or her woodlands responsibly, but by retaining the forest cover on the soil has also kept his or her options open to future decisions.

5. Cut stumps on thinned plots were evaluated for their ability to produce sprouts. While between 30 and 45 pct of the stumps produced clumps (a dome-shaped mass of stems created by heavy browsing) only 14 pct of the clumps were able to "escape" into the sprout stage.

This means that regeneration by coppice methods is not going to occur rapidly following thinning. Some method of protection, such as screens or piling brush on the stump, is necessary to encourage rapid regeneration.

6. The possibility of increased production of forage following thinning was less promising. First a tremendous variation by site was observed. This greatly confounds the effects of thinning and interpretations of treatment effect is not advised. In addition, only three plots produced enough forage to exceed the recommended minimum threshold of residual dry matter.

The lack of greater quantities of forage production is due to the relatively high crown cover that was left after thinning. Even the most heavily thinned plots (50 ft^2/acre) averaged over 50 pct crown cover (54 pct), while the 100 ft^2/acre plots averaged 71 pct. If forage production is a major objective of the landowner, further reduction in crown cover is necessary before enough light will be available to produce usable levels of forage.

7. The condition of the soil was evaluated both in 1984 and 1989. In both years, no type or amount of erosion was observed on any plot regardless of the land slope. Apparently the crown and root density left after thinning was sufficient to protect the site.

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Improving the Sustainability of Oak Woodland Forage and Productivity in San Diego County Through the Exploration for and Introduction of Nitrogen Fixing Annual Legumes[1]

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Abstract: The oak woodlands of San Diego County are below their potential productivity due to the low levels of the most needed plant nutrient, nitrogen, associated with the common soils of this zone. Atmospheric nitrogen fixing legumes could address this deficiency. However, because of limiting environmental constraints, adapted commercial legume cultivars have not been available. By the early 1980's, a modest plant exploration program was begun to identify annual legumes with potential for adaptation to this region, locate them in their native or naturalized habitat, collect and reproduce an adequate number of these legumes' wild types and test them for adaptation. Trials established in 1984 and evaluated over a 4-year period indicate that a number of these wild legumes are adapted and are superior to presently available Australian cultivars. These encouraging results suggest continued testing and screening of legume materials that address the soils' nitrogen deficiency in the oak woodland rangelands of Southern California.

Oak woodlands constitute a small portion of the total acreage of San Diego County (3.9 percent), yet this vegetation type, both a dense phase near streams and a sparse phase of Savanna-type conditions covers approximately 107,000 acres.

These oak woodlands are considered the most valuable range and wildlife habitat area of this region. The common oak trees of this zone are the California black oak (*Quercus kelloggii* Newb.), coast live oak (*Q. agrifolia* Née), canyon live oak (*Q. chrysolepis* Liebm.), and Engelmann oak (*Q. engelmannii* Greene). While reports by Pillsbury and others (1983) and Mayer and others (1986) pointed out that in some parts of the State of California some oak types are not regenerating well, the failure to regenerate is thought to be poorly understood and a catch-all phase to explain this phenomena is, "...long-term trends in climate, fire history, invasion of non-native grasses, cultivation, browsing of cattle and wildlife, and movement of people into wildland areas" (Adams and others 1988).

In San Diego County, fire exclusion may be the most important factor for oak stand degradation and the lack of adequate regeneration (Biswell 1989). Very poor results have been reported with attempts at artificial regeneration from seeded acorns and from nursery stock (Adams and others 1988).

Because cattle and wildlife browsing has been accused of being an important factor in oak regeneration, it is hypothesized that an improvement in the forage component palatability of the grasslands associated with the oaks of this zone would be a good practice to implement to divert the browsing pressure away from oak seedling regeneration and establishment. Yet range studies in this vegetation type show that forage production is low and quality poor during an important part of the year. Important contributing factors are the soils and annual vegetation types in these zones. Soils are usually deficit in nitrogen. Productivity and quality of the naturalized annual vegetation is low. Animal performance is poor without costly external inputs of nitrogen fertilizer.

Production of nitrogen fertilizer, a key element for obtaining high production on these range areas, requires high energy and fossil fuel inputs for its commercial production (Green 1978). Since the energy crisis of 1973, and the Middle East situation of 1990, nitrogen fertilizer produced from natural gas has become a questionable resource for improving range forage production. Still the potential of this vegetation type is at least twice that of its present production due to the low level of soil nitrogen in this zone.

Nitrogen fixing legumes are a vegetative component which could be introduced into this zone to correct this deficiency. The introduction of annual legumes adapted to a Mediterranean climate and capable of biologically fixing significant amounts of nitrogen, is promising. However, our successful early introductions of subclover and other annual legumes to northern California, were highly dependent on adequate well distributed rainfall (Murphy and others 1973). Rainfall amounts and distribution are much less dependable in southern California. Because of this zone's limiting environmental constraints, legume cultivars adapted to this oak woodland zone have not been available (Helphinstine and others 1983).

In order to properly address this interest, a legume germplasm base was needed on which to build a research and development program. Since the initiation of the Plant Introduction program in 1899, the USDA has been quite active in its research for better plant materials on a worldwide basis. Yet, as late as 1979, only a very limited number of range legume introductions had been made that performed well in California's Mediterranean climate (White and Oakes 1979).

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

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By 1980, a modest plant exploration program was begun to identify annual legumes that have the potential for adaptation to this region, locate them in their native and/or naturalized habitat, and collect and reproduce an adequate number of wild strains for adaptation trials in this oak rangeland zone. It is the objective of this paper to report on our legume exploration program and the development and testing of selected accessions for adaptation in the oak- grassland vegetation zone of San Diego County.

LEGUME EXPLORATION AND BACKGROUND

Our initial exploration project was begun in Tunisia and reported in Graves and others (1988). Although this plant collection represented 332 indigenous legume accessions, the plant materials did not cover sufficient enough mountain elevation zones to have the potential for resisting the winter cold of our oak woodland range. We expanded our program in 1983 to include a collection trip to Morocco (Rumbaugh and Graves 1985). We were able to choose collection zones in Morocco by using a climate classification system developed by Emberger (1955) based on average monthly rainfall and temperature. We were able to match with good approximation sites from the oak woodland zones of San Diego County and similar vegetation and climate zones of Morocco. An example of this climatic match is presented in table 1. This collection added another 900 accessions to our national germplasm bank. More than two-thirds were legumes and expanded considerably the diversity of our legume species and their adaptive potential.

These introductions were considered of extreme importance for germplasm preservation in light of Morocco's late 1970's and early 1980's droughts and subsequent vegetation degradation.

Table 1—*Average monthly rainfall and mean temperatures for Wynola,* San *Diego County and Similar Mediterranean climate analog in Morocco (El-Hajeb)*

Month	Average Rainfall-(in)		Mean Temperature (°F)	
	Wynola	El-Hajeb	Wynola	Morocco
July	0.44	0.11	69.5	75.6
August	0.53	0.20	69.6	76.9
September	0.79	0.74	65.7	69.1
October	0.74	2.56	58.4	61.8
November	2.68	3.78	50.5	52.9
December	2.68	3.35	46.2	46.7
January	4.69	2.71	43.7	45.1
February	3.76	2.95	45.1	47.1
March	4.08	3.19	46.1	50.7
April	2.79	3.30	50.4	51.6
May	1.26	2.09	53.8	60.2
June	0.16	0.78	60.9	67.9
Year Ave	24.60	25.78	55.0	59.2
Elev. (ft)	3,655	3,454		
Latitude	33°06'N	33°41'N		

MATERIALS AND METHODS

Seed Increases

At this point we believed that we had adequate legume germplasm to test our hypothesis of adaptability of plant materials from the Mediterranean zone to an analog climate in California. These collections were placed in a seed increase nursery at the University of California Riverside Experiment Station in the 1983-84 growing season. During this initial seed increase year, we were able to make preliminary observations on winter vigour, days to flowering, biomass and seed production that allowed us to screen for accessions that would have the best potential for adaptation in our oak woodland areas. During the summer of 1984, all seed increase plots were harvested, shelled, cleaned, inventoried and targeted for future field testing.

Field Trial

During the 1983-84 season, we solicited cooperators for field testing our legume introductions in a typical oak grassland range area. In early 1984, we selected Spike Alford Ranch in the Mesa Grande area of San Diego County with the USDA Forest Service (Cleveland National Forest) as an interested collaborator.

The test site is located at 3,200 feet elevation and approximately 3 miles of Mesa Grande adjacent to the Mesa Grande Truck Trail. The zone is oak grassland of coast live oak, an occasional black oak and canyon live oak. The associated grasslands species are typical naturalized annuals, mainly filariae (*Erodium* sp.) and annual bromes (*Bromus* sp.). The soils of this area are of the Holland series, fine sandy loam, slightly acid pH, 5-10 percent slope (fine-loamy, mixed, mesic, Ultic Haploxeralfs) with very low phosphate levels. Average annual rainfall, as estimated from the nearby weather station of Wynola, is 24.6 inches for July 1 through July 30. The average seasonal effective rainfall for growth annual species from September 1 through May 31 is estimated to be 23.6 inches. Most of this precipitation occurs from November through the April period with the dry period usually extending from early May through October. Seasonal and monthly precipitation is highly variable in this zone (Graves and others 1988).

The trial consisted of 20 entries of 11 subclover (*Trifolium subterraneum* L.) accessions from Morocco, four Australian subclover cultivars, three naturalized rose clovers (*T. hirtum* All.) from Northern California and two Australian rose clover cultivars. Establishment method consisted of an application of

single superphosphate (0-18-0) at 200 lbs/acre and a light discing of the soil surface to prepare the seedbed. On October 2,1984, seeds of each of the entries were broadcast on replicated plots, 4 ft x 4 ft, in a randomized block design at a 50 lb/acre rate and raked to cover lightly. All the seeds were freshly pellet-inoculated at the rate of 5 lbs of inoculant per 100 lbs of seed (Pelinoc[3] inoculating system, Milwaukee, Wisconsin).

The plots were located in an open range pasture and were not fenced to exclude grazing. The pasture with the test plots received continuous moderate grazing by cattle during the late winter and spring growing season for the establishment year through the 4-year evaluation period. Stand cover evaluations were made near the end of each growing season by visually rating plot cover on a 0-10 scale (0=no plants, 10=complete ground cover). Stand regeneration is thus defined as the annual clover's ability to regenerate its cover within the planted plot. The most recent stand persistence evaluations were made on March 29, 1988. Flowering also was observed on the date of the rating. Stand regeneration evaluations were analyzed statistically for strain differences.

RESULTS AND DISCUSSION

The results from this trial are very encouraging and exciting. Three of the Moroccan accessions of subclover showed exceptionally good adaptation (regeneration) and were covering their seeded plots (see table 2). As one can see from this ranking, the experimental accession GR 508 (PI 517171) and GR 565 (PI 517173) were superior to all other entries, and much better than the Australian commercial subclover cultivars, Seaton Park, Northam, Geraldton or Nungarin.

The Australian rose clover cultivars, Hykon and Kondinin, showed some degree of persistence, as did the naturalized collections from Shasta, Siskiyou and Mendocino Counties. These three naturalized rose clover collections are much later in maturity than the two rose clover cultivar entries and we would expect these accessions to be at a disadvantage in this zone due to its short rainfall season. Thus, we would not expect these accessions to persist and regenerate during years of low rainfall (drought). We believe that these results are a good indication of accession adaptability in this zone, since all entries had an equal opportunity for establishment from the initial seeding (first season plot coverage evaluation ratings were not significant and thus the rating was not reported here). Therefore, we believe that long- term persistence of these accessions will not be affected by initial establishment.

[3]Disclaimer: To simplify information, trade names of products have been used. No endorsement of named products is intended nor is any criticism implied of similar products which are not mentioned.

Table 2—*Subclover and rose clover entries regeneration and flowering evaluations at the Alford Ranch, Mesa Grande, San Diego County, end of fourth growing season*

Variety/Accession	Ranking/Plot Coverage (0-10, 10=100 pct Coverage) Average of 4 Reps	Flowering on 3/29/88 (+=flowers, - = no flowers)
GR 508 Sub (PI 517171)	8.8	+
GR 565 Sub (PI 517173)	7.2	+
GR 567 Sub (PI 517174)	6.2	+
Shasta 4300' Rose	5.8	-
Kondinin Rose	5.0	+
Siskiyou Rose	5.0	-
Mendocino Rose	5.0	-
Hykon Rose	4.5	+
Seaton Park Sub	4.2	+
Northam Sub	3.5	+
GR 435 Sub (PI 517164)	3.2	+
Geraldton Sub	2.2	+
GR 448 SUB (PI 517167)	2.0	-
GR 450 Sub (PI 517168)	1.8	-
GR 316 Sub (PI 517155)	1.8	+
GR 436 Sub (PI 517165)	1.8	-
GR 494 Sub (PI 517170)	1.2	+
GR 519 Sub (PI 517172)	1.2	-
Nungaran Sub	1.2	+
GR 301 Sub (PI 517154)	1.0	+
LSD (0.05)	1.5	

Note: All varieties/accessions that are not flowering at this time will probably no regenerate this year since the effective rainy season is short this year and the plot have not had rain for some 4 weeks.

We present the monthly growing season precipitation information for the 1984 establishment year through the 1988 growing and final evaluation season in table 3. The rainfall totals for the growing seasons were below average in three of the four growing seasons over which evaluations were made. This factor also lends further credence to our belief that the showing of at least three of our Moroccan wild type experimental accessions have the potential for long-term regeneration and adaption to this oak woodland zone of San Diego County.

Table 3—*Growing season (September 1 through May 31) monthly rainfall covering the period of the evaluation (October 1984 to May 1988)*

Year	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
84-85	—	0.5	3.0	7.4	2.3	2.1	2.8	1.1	0.1	19.3
86-86	1.8	0.8	8.6	2.2	1.2	6.0	7.6	0.6	0.1	28.9
86-87	2.1	1.4	1.3	2.2	2.8	2.6	3.7	0.7	0.8	17.6
87-88	0.3	4.6	4.1	3.3	4.0	1.8	1.2	—	—	19.3
Average	0.8	0.7	2.7	2.7	4.7	3.8	4.1	2.8	1.3	23.6

SUMMARY

Several factors are considered important in the successful establishment and persistence of subclover and/or other legume stands in this oak- grassland zone of Southern California. These factors are: the choosing of an adapted cultivar, use of phosphate and sulfur fertilizer, pellet inoculation with specific Rhizobium strains (Jones and others 1978), seeding just prior to the rainy season into a properly prepared seedbed, adequate and timely rainfall and animal grazing during the establishment and subsequent life of the legume stand. Grazing during the growing season is important to enhance its establishment and regeneration. Proper grazing can help to control undesirable weeds, optimize seed production, maintain a proper grass-legume balance and increase nitrogen recycling.

Although numerous Australian legume cultivar introductions have occurred over the last several decades, most have been soft seeded cultivars which have had limited success outside of the more favorable and longer season rainfall zones of northern California. Our results encourage continuation of testing and screening for the eventual varietal release of legume materials to address the soil nitrogen deficiency of the oak woodland rangelands of southern California in order to enhance wildlife and livestock habitat and sustain oak regeneration.

ACKNOWLEDGMENTS

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Nutrient Cycling in Managed and Unmanaged Oak Woodland-Grass Ecosystems[1]

Randy Dahlgren Michael J. Singer[2]

Abstract: The influence of oak trees and grazing on nutrient cycling in oak woodland-grass ecosystems was examined at the Sierra Foothill Range Field Station in the northern-Sierra Nevada foothills of California. Nutrient concentrations in ecosystem waterflows (precipitation, canopy throughfall, and soil solutions) were monitored in a non-managed natural area and in an adjacent grazed area. Grazing increased soil solution concentrations of chloride (Cl) and sodium (Na), but had no effect on major nutrient levels. When comparing between oak and non-oak sites, the oak sites had enhanced soil solution concentrations of Ca, Mg, K, SO_4 and PO_4, and decreased levels of Na. Soil solution pH beneath the oak canopy was 0.5-1.0 units greater than in adjacent grasslands, and appears to be due to neutralization of rainfall acidity by the oak canopy and enhanced base cation cycling by the oak.

Increased land use intensity is apparent throughout California and oak woodland-grass ecosystems are no exception. A large portion of our oak woodland-grass ecosystems is grazed and many woodlands are being cleared to enhance grazing and produce firewood for sale. The potential for site disturbance and land degradation in intensively managed oak woodland ecosystems is great, but little is known about the impact of these practices on nutrient cycling. If nutrients are removed from an ecosystem at a rate greater than they can be made available by natural processes, the productivity of the ecosystem will decrease, forage production or quality may be reduced, and oak seedling reestablishment may be compromised.

To examine nutrient dynamics, ecosystem waterflows were sampled during the period of active growth. These waterflows provide a dynamic pathway for redistribution of elements within different levels of the ecosystem (Likens and others 1977). Because these solutions reveal current processes, their composition is sensitive to management practices and ecosystem disturbances (Cole and others 1975; Dahlgren and Ugolini 1990). Soil solutions also reflect the plant-available nutrient status and therefore provide a basis for comparing differences in nutrient availability between various subsystems within the ecosystem (Wearing and Schlesinger 1985). The major objectives of this study were 1) to examine the role of oaks in nutrient cycling processes, and 2) to determine the impact of grazing on nutrient cycling in oak woodland-grass ecosystems.

METHODS

The investigation was conducted on two study sites in the Schubert Watershed at the University of California, Sierra Foothill Range Field Station near Browns Valley, CA. The two study sites (183 m elevation) are found on adjacent tracts of land, with one site in pasture and the other preserved as a natural area (no livestock grazing in 17 y). The pasture area was grazed by cattle for approximately three one-month periods with a month recovery period between grazings. The study sites have a mean annual precipitation of 73 cm and a mean annual temperature of 15° C. Major tree species are blue oak (*Quercus douglasii* H. & A.) and interior live oak (*Quercus wislizenii* A. DC.) with a stocking of 10-125 trees per ha. Major forbs include filaree, annual clovers and geranium. Common annual grass species are soft chess, ripgut brome, red brome, annual fescue, wild oats, and medusahead. Perennial grasses include purple stipa. Soils at the study site have formed in basic metavolcanic (greenstone) bedrock and are classified as fine, mixed, thermic Typic Haploxeralfs.

Bulk precipitation, canopy throughfall, and soil solutions were collected from January to June, 1990, which corresponds to the period of active growth. Precipitation was collected at two sites using polyethylene containers fitted with funnels (17.5 cm diameter). Teflon wool was placed in the neck of the funnel to act as a coarse filter and reduce evaporation. Canopy throughfall was collected at six sites beneath each oak species in collectors identical to those used for precipitation. Solutions were collected immediately following major precipitation events to prevent evaporation and microbial mediated alterations to the solution chemistry. Soil solutions were obtained monthly by extracting solutions from duplicate soil cores taken from the A (0-7 cm), AB (7-31 cm), and Bt l (31-55 cm) horizons. Distilled-deionized water was added to bring the solution/soil ratio to 1.5/1 and allowed to equilibrate for 2 h. The soil was filtered through a Whatman #41 filter followed by a final filtration through a 0.2-µm polycarbonate membrane.

The pH was measured potentiometrically immediately following extraction. Base cations (Ca, Mg, K, Na) were determined by atomic absorption spectroscopy and major anions (Cl, NO_3, PO_4, and SO_4) by ion chromatography. Ammonium was measured using the conductimetric method of Carlson (1978). Statistical analysis was performed using SAS statistical software (SAS Institute, Inc. 1985). Differences in mean solute concentrations between grazed/non-grazed and oak/non-oak sites were determined using the ANOVA procedure combined with the Tukey test.

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, Davis, California, October 31-November 2, 1990.

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RESULTS AND DISCUSSION

Statistical analysis of mean solute concentrations showed relatively few differences between grazed and non-grazed systems (table 1). However, the effect of the oak canopy on soil solution composition had an influence on most of the solute concentrations. It should be noted that relatively high variability occurred between some of the monthly soil solution samples. This results from both spatial and temporal variability. In particular, large changes in environmental conditions (eg. temperature and moisture) occurred between January and June which strongly affected microbial processes and plant nutrient demands. As a result of the large variability, what appears to be large differences between sites in figures 1-4 are not always significant.

Table 1—*Statistical analysis comparing the effects of grazing (pasture [P] vs natural area [N]) and oak trees (oak [O] vs grassland [G]) on soil solution solute concentrations.*

	A Horizon		AB Horizon		Bt Horizon	
	Grazing	Oaks	Grazing	Oaks	Grazing	Oaks
pH	=†	O>G*	=	O>G*	=	O>G*
Cl	P>N**		=	=	P>N*	=
NO_3	=	=	P>N*	O>G*	P>N**	=
PO_4	=	O>G*	=	O>G*	=	=
SO_4	=	O>G**	=	O>G*	P>N*	O>G*
NH_4	=	O>G*	=	=	=	=
Ca	=	O>G*	=	O>G*	=	O>G*
Mg	=	O>G*	=	O>G*	=	O>G*
K	=	O>G*	=	O>G*	=	O>G*
Na	P>N**	G>O*	P>N*	G>O*	P>N*	G>O*
Si	P>N*	O>G*	=	O>G*	P>N*	=

† = no statistical difference among treatments; *p<0.05; **p<0.10

Base Cations (Ca, Mg, K, Na)

Inputs of base cations in the precipitation were relatively low (fig. 1). Concentrations of K, Ca, and Mg increased by a factor of 8, 7, and 6 times, respectively, in the canopy throughfall, while Na concentrations increased only by a factor of two. Live and blue oak canopies leached similar amounts of base cations except for K, which had higher concentrations in the blue oak throughfall. In the soil solutions, concentrations of the macro-

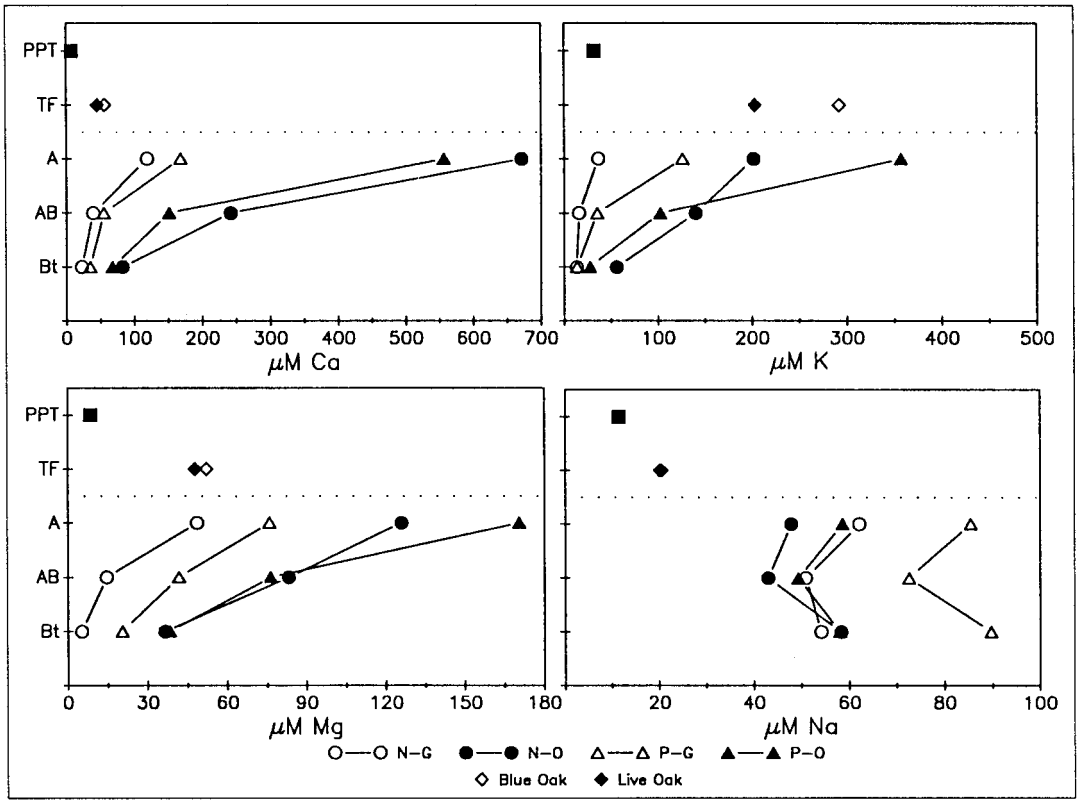


Figure 1—Concentrations of Ca, Mg, K, and Na in precipitation (PPT), canopy throughfall (TF), and the A, AB, and Bt horizon soil solutions. Treatments consisting of non-grazed/grass (N-G), non-grazed/oak (N-O), pastured/grass (P-G), and pastured/oak (P-O) were examined.

nutrients Ca, Mg, and K were highest in the A horizon and showed a progressive decrease in the AB and Bt horizons. This pattern of high concentrations in the upper soil horizons and sharply decreasing concentrations with depth are characteristic for elements which are strongly affected by nutrient cycling. Cycling of essential nutrients maintains an abundant supply of nutrients for incorporation into new biomass while at the same time limiting nutrient losses from the soil profile. Elements which are available in excess of plant requirement are leached from the soil profile in quantities greater than elements which are in short supply. An example of this is shown with Na, a nonessential element. Sodium concentrations remain relatively constant throughout the soil profile and are not attenuated within the rooting zone.

The effect of the oak canopy on increasing base cation concentrations in the soil solution was readily apparent for the essential nutrients Ca, Mg, and K. Differences were greatest in the A horizon and decreased with depth as plant uptake removed cations from solution. An interesting contrast occurred for Na which had higher concentrations in the grassland sites. The oak rooting system may extend well beyond the oak canopy and invade the adjacent grasslands (Thomas 1980). The rooting system may selectively accumulate Ca, Mg, and K leading to a depletion of these cations from the grassland sites. Cycling of Ca, Mg, and K by the oak will lead to high solution concentrations of these elements beneath the oak canopy, which will initiate a mass action displacement of Na from the cation exchange sites. The displaced Na will then be leached from the soil profile.

Sodium was also unique among the base cations in being the only cation to show differences between grazed and non-grazed sites. Sodium concentrations were greater on the grazed sites and may result from additions by the cattle which receive supplemental salt.

Anions (Cl, NO_3, SO_4, PO_4)

Concentrations of NO_3 and PO_4 in the precipitation were greater than the trace levels normally found in non-polluted precipitation (fig. 2). The NO_3 originates primarily from anthropogenic sources while the source of the PO_4 is unknown (Laird and others 1986). Anion concentrations in canopy throughfall were similar to the precipitation levels for NO_3 and SO_4, while Cl and PO_4 concentrations increased approximately fourfold. No significant differences occurred between the live and blue oak canopies. Upon entering the soil, all anions showed an attenuation with depth indicating plant uptake and cycling. There was complete retention of PO_4 within the rooting zone

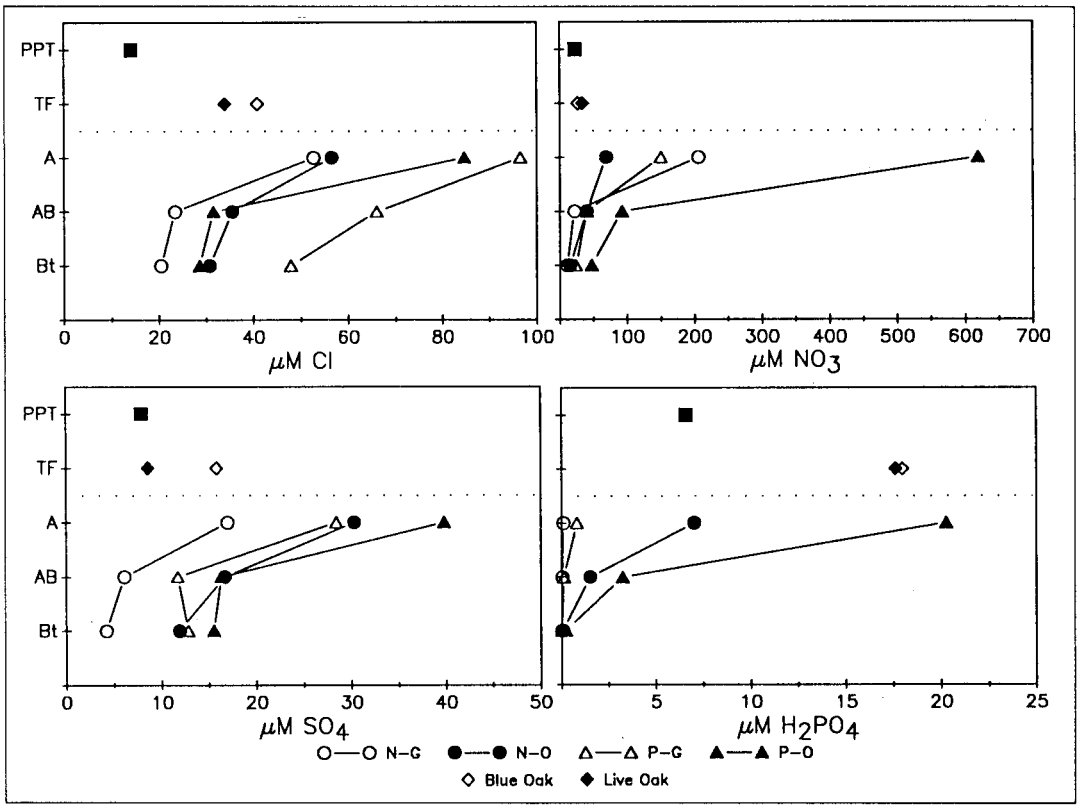


Figure 2—Concentrations of Cl, SO_4, NO_3, and PO_4 in precipitation (PPT), canopy throughfall (TF), and the A, AB, and Bt horizon soil solutions. Treatments consisting of non-grazed/grass (N-G), non-grazed/oak (N-O), pastured/grass (P-G), and pastured/oak (P-O) were examined.

indicating that PO_4 may be a limiting nutrient in this ecosystem. In contrast, NO_3 levels leaching from the soil profile remain in the 15-50 μM range which is similar to the mean streamwater concentration of 20 μM over the same time period. Therefore, N appears to be present in sufficient quantities to meet the plant requirement; the excess being leached from the soil profile into the surface waters.

Grazed sites had increased Cl levels similar to Na. This increase further supports the additions of both Na and Cl from the salt supplement which the cattle receive. Extremely high NO_3 levels in the grazed-oak canopy site may also be due to the influence of the cattle which appear to preferentially use the shaded area beneath the oak canopy. The oak canopy resulted in increased levels of PO_4 and SO_4 as compared to the grassland soil solutions. Increased NO_3 concentrations in the grazed-oak site were also apparent but not statistically different due to the large variability. These data indicate that P and S are being enriched in the soil solutions beneath the oak canopy due to nutrient cycling, while N does not appear to be strongly affected by the oak.

Ammonium

Inputs of NH_4 in the precipitation (44 μM) were approximately twice that of NO_3 (23 μM) (fig. 3). The combined input of these two nitrogen sources represents a nitrogen input of 6.9 kg/ha/yr based on the mean annual precipitation. Ammonium concentration increases upon interaction with the canopy and may reflect leaching of NH_4 from the foliage or washout of dryfall trapped by the canopy and not accounted for in the bulk precipitation. When comparing the two oak species, the blue oak leached 50 μM more NH_4 than the live oak. Concentrations of NH_4 remain relatively constant in the soil solutions. Only the A horizon showed a significant increase due to the influence of the oak canopy. Nitrate was the dominant form of mobile N in the soil solutions of this ecosystem as has been shown for other oak woodland ecosystems (Parker and Muller 1982).

pH

The interaction of the precipitation with the canopy resulted in an increase of the pH from 5.6 to 5.9 and 6.2 for the live and blue oak throughfalls, respectively (fig. 4). The exchange of base cations for H^+ is the primary neutralization mechanism occurring in the canopy (Weaver and Jones 1981). Solution pH was further increased by neutralization processes in the soil profile. There was a clear pH difference between oak canopy soils and grassland soils. The pH beneath the oak canopy was approximately 0.5 - 1.0 unit higher. Soil solution pH also showed a general trend of decreasing with depth in the profile. This trend was more pronounced in the oak canopy site. These data suggest that increased base cation cycling by the oaks is responsible for enriching the base status of the oak canopy soils and in particular the upper soil horizons and thus leads to the elevated pH values observed. Partial neutralization of acidity by the canopy may also contribute to the higher pH by reducing the acidity of the waters incident on the soil surface.

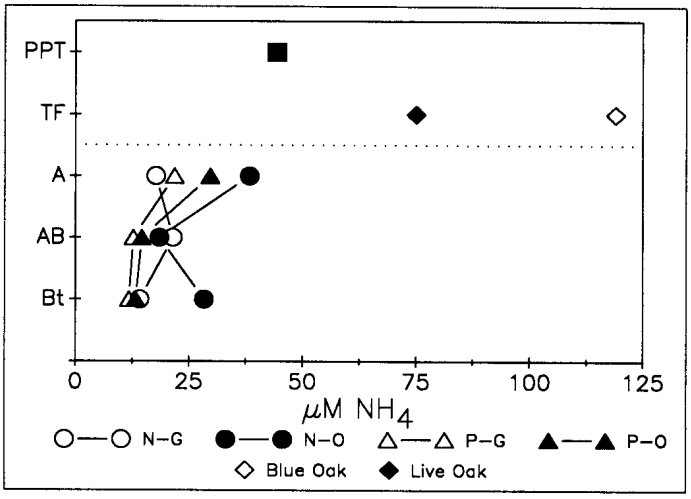


Figure 3—Ammonium concentrations In precipitation (PPT), canopy throughfall (TF), and the A, AB, and Bt horizon soil solutions. Treatments consisting of non-grazed/grass (N-G), non-grazed/oak (N-O), pastured/grass (P-G), and pastured/oak (P-O) were examined.

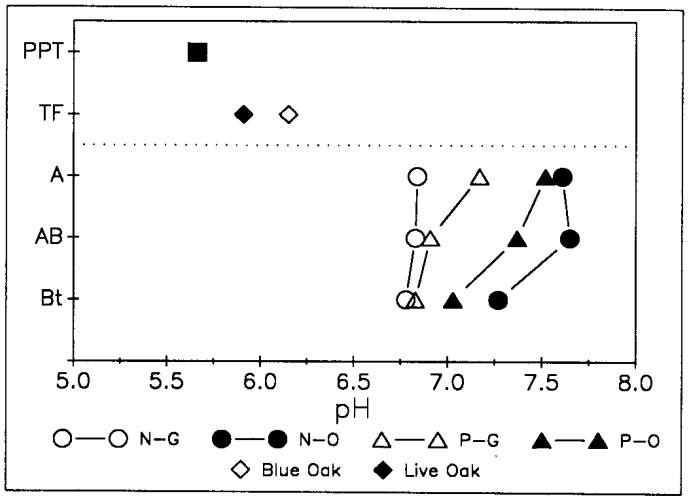


Figure 4—Solution pH of precipitation (PPT), canopy throughfall (TF), and the A, AB, and Bt horizon soil solutions. Treatments consisting of non-grazed/grass (N-G), non-grazed/oak (N-O), pastured/grass (P-G), and pastured/oak (P-0) were examined.

SUMMARY

The presence of an oak canopy resulted in enhanced cycling of Ca, Mg, K, SO_4, and PO_4 and decreased levels of Na. Soil solution concentrations were increased from 2-10 times that found in adjacent grassland sites. Higher nutrient levels suggest greater plant availability of these nutrients. Greater forage nutrient concentrations have been reported beneath oak canopies as compared to grasslands (Holland and Morton 1980; Kay 1987). Decreased levels of Na beneath the oak canopy may result from selective accumulation of Ca, Mg, and K beneath the oak canopy which in turn displaces Na from exchange sites by mass action.

Grazing in this oak woodland-grass ecosystem had no significant effect on major plant nutrient levels. Only Na and Cl concentrations were increased in the soil solutions. Supplemental salt feeding to the cattle could account for these increased levels. High NO_3 levels in the grazed-oak canopy site, although not significantly different, may also be the effect of preferential cattle use of the shaded area beneath the oak canopy.

Based on the degree to which nutrients are retained within the ecosystem by nutrient cycling, it appears that P may be the most limiting plant nutrient. Phosphorus is reported to be in short supply in many foothill ecosystems (Dunn 1980). This ecosystem receives an input of 6.9 kg/ha/y of N in the precipitation and loses 5.0 kg/ha/yr in the streamwaters draining the watershed. The loss of N suggests that N is present in excess of that required by plants. All other nutrient levels appear to be adequate to support the present vegetative regime.

ACKNOWLEDGMENTS

We are very grateful to Bill Allardice, Peter Janitzky and Wayne Verrill for their help in field work and laboratory analysis. Financial support from the Integrated Hardwood Range Management Program made this study possible.

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Fire Effects in Blue Oak Woodland[1]

Patricia K. Haggerty[2]

Abstract: Mortality and resprouting of shrubs and trees were assessed in one recent fire and 11 older burns in blue oak woodland in the southern Sierra Nevada foothills. This poster reported results for blue oak. Survival following fire was high; with a 93 percent two year postfire survival rate after one intensively studied fire, despite a large number of trees with 100 percent crown scorch. Differences between sites accounted for most of the variability in mortality. Tree diameter was a minor component in mortality variability. Diameter was more important in resprouting, with most resprouting occurring in trees 20 cm DBH or less.

Blue oak (*Quercus douglasii* H.& A.) in the southern Sierra Nevada foothills exist in a highly flammable environment. Despite this fact, relatively little is known about the effects of fire on blue oak woodlands. Two recent studies (McClaran 1986, Mensing 1988) found strong relationships between known fire dates and establishment of new trees, as determined from fire scar histories and age/size relationships. Both studies suggested an important role for postfire resprouting of blue oak in maintaining blue oak in the stands. McClaran (1986) found a positive relationship between fire dates and new establishment on two Yuba County sites. Mensing (1988) reported that more than half of the trees on his Tehachapi Mountains study site established as sprouts in a single year.

This study looked at a recently burned stand and an adjacent control, and 11 other sites which had burned within the last ten years. All sites were within the Kaweah River watershed of the southern Sierra Nevada, Tulare County, California. Land ownership included Bureau of Land Management, National Park Service, and private properties. Most sites (eight) were within Sequoia National Park, where 60 percent or more of the blue oak woodland has burned within the last thirty years, much of that within the last ten years. Elevation of the sites ranged from 390 m to 951 m. Rainfall at the National Park Service Ash Mountain Headquarters, a National Oceanic and Atmospheric Administration weather station, averages 65 cm. A strong elevational gradient in rainfall exists in the Kaweah River drainage.

The fires which burned the sites ranged from low intensity prescribed prescribed burns to high intensity wildfires resulting from arson and accidental ignitions such as car fires or powerline failures. Blue oak is found in open, nearly pure stands, in mixed woodlands with other trees, or with a significant brush component. These fuel characteristics influenced the severity of each fire, as did existing weather, ignition source and direction of fire spread.

METHODS

Following an arson ignited wildfire in Sequoia National Park, a sample of trees was selected by the point centered quarter method to be followed for two years. Variables measured shortly after burning were species and size of tree, live or dead, degree of crown scorch and bole char and such damage factors as prescence of fire scars, mistletoe or insects. Subsequent visits in 1988 and 1989 recorded new mortality, sprouting and formation of new fire scars.

RESULTS AND DISCUSSION

Over a two year period blue oak had a 93 percent survival rate, despite a large number of trees with complete crown scorch (table 1). Interior live oak (*Quercus wislizenii*) had a 79 percent survival rate and a lower tolerance to complete crown scorch (table 2). However, 50 percent of the interior live oak individuals resprouted basally within the first year while only 15 percent of the blue oak resprouted in the first year.

Many blue oak developed crown sprouts within the first year (fig. 1) and crown sprouts were observed as soon as two weeks after the burn. New scars formed on a majority of the trees (fig. 2). Larger trees showed less scarring, but fire scar studies have shown intact trees can hide a number of old fire scars (McClaran 1988).

Table 1—*Survival of crown scorched blue oak after Ash Mountain fire (no. of live trees).*

	Percent Crown Scorched			
Year	<25	>25-50	>50-95	100
1987	39	20	22	36
1988	39	19	22	36
1989	39	19	21	30

[1]Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31-November 2, 1990, Davis, California.

[2] Forestry Technician, Sequoia and Kings Canyon National Parks, Three Rivers, California, and Graduate Student, Graduate Group in Ecology, University of California, Davis.

Table 2—*Survival of crown scorched interior live oak (no. of live trees).*

Year	Percent Crown Scorched <25	>25-50	>50-95	100
1987	9	7	7	8
1988	9	7	7	2
1989	9	7	4	2

A more extensive survey of 11 other sites which had burned within the ten years prior to the initiation of the study was also conducted (table 3). All sites were sampled by means of circular fixed area plots .05 ha in size. Tree and shrub species composition, size of trees, counts of shrubs and seedlings by species, and prescence of resprouts, scars and native grasses were recorded

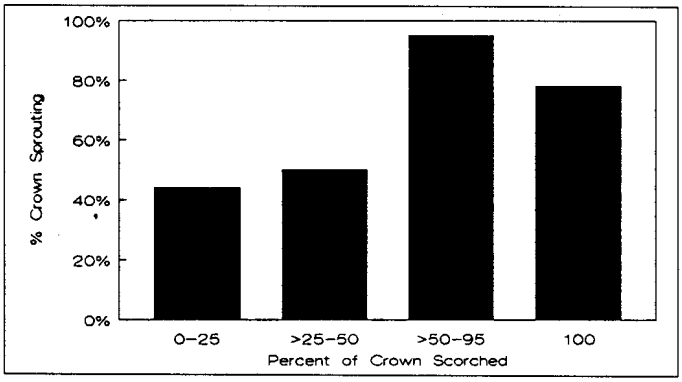


Figure 1—Crown sprouting in scorched blue oak, Ash Mountain fire.

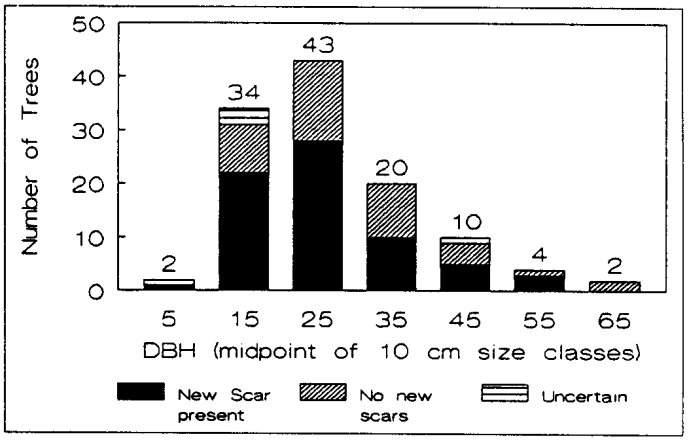


Figure 2—New scar formation on blue oak following Ash Mountain fire.

Table 3—*Physical and vegetative characteristics of sites.*

Number	1	2	3	4	5	6	7
Site	Ash Mtn	Control	Moore	Lagoon	Potwisha	Three Rivers	Stewart
Elevation (m)	579	585	390	523	732	488	829
Aspect	SW-SE-E	E-SE	N-NW	S	S	NE-NW	S-SE
Slope (pct)	45-80	40-60	30	16	45	45	43
Size (ha)	68	—	20	<2	52	238	46
Year Burned	1987	—-	1980	1984	1981	1984	1984
Tree Density in numbers/ha (pct Blue Oak)							
Live	144(76)	212(82)	62(85)	248(98)	120(92)	67(100)	38(95)
Dead	95(5)	16(80)	82(71)	12(67)	158(75)	90(98)	40(60)

Number	8	9	10	11	12	13
Site	Shepherd	Buckeye	Min. King	Yucca	Dinely	North Fork
Elevation (m)	701	951	640	646	390	610
Aspect	S-SE	S-SE	NE	W	SE	NW-SE
Slope (pct)	50	50	40	25	48	20
Size (ha)	50	1245	23	23	53	61
Year Burned	1979	1988	1987	1979	1984	1979
Tree Density in numbers/ha (pct Blue Oak)						
Live	78(78)	328(92)	148(57)	378(94)	58(76)	357(95)
Dead	49(49)	190(84)	123(15)	8(100)	49(69)	33(85)

for each plot as well as general site information. Observations were made on a total of 1481 trees, over 1200 of which were blue oak.

Mean mortality of blue oak was quite low, with the smallest (≤ 10 cm DBH) and larger (≥ 40.0 cm DBH) size classes experiencing greatest mortality (fig. 3). Topkill, defined as death of the bole with successful resprouting, generally did not occur in trees over 20 cm DBH (fig. 4). In trees 5 cm DBH or less topkill slightly exceeded mortality.

Preliminary data analysis by ANOVA found significant differences in blue oak mortality between sites ($p < .001$). In blue oak, site accounted for 98 percent of the variation in the mortality response, with 2 percent attributable to size. Further analysis will look at the site characteristics which resulted in variation in mortality and resprouting responses.

CONCLUSION

Despite an emphasis on blue oak, a community wide perspective to fire effects is the final goal of this study. An understanding of fire interactions in the foothill region will be important to the National Park Service in its efforts to 1) where possible, restore fire to a more natural role in the preservation, or restoration and maintenance, of the foothill woodland and chaparral communities, and 2) provide an adequate level of fire protection within developed areas and adjacent to land management boundaries while acknowledging the repercussions of fire suppression.

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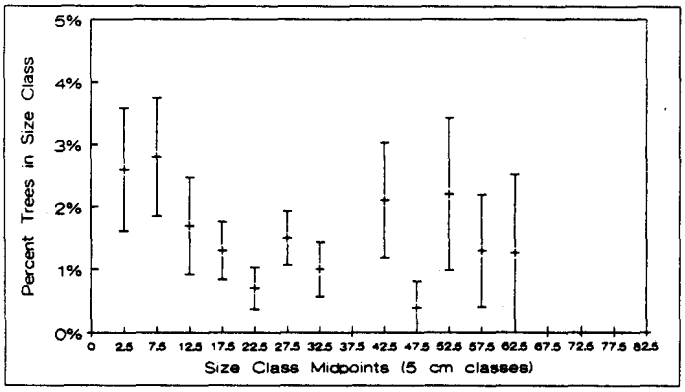


Figure 3—Mean and standard error of blue oak mortality by size class on burned sites.

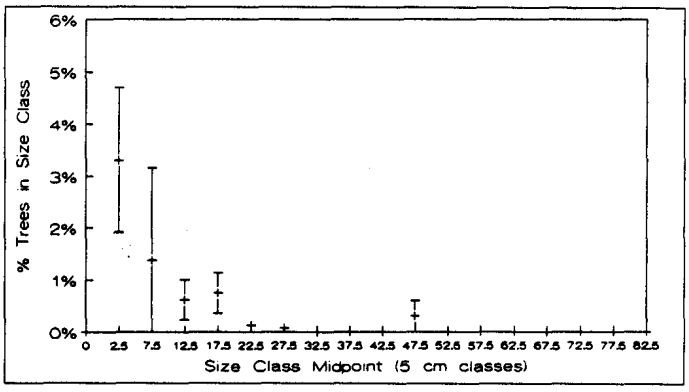


Figure 4—Mean and standard error of topkilled blue oak by size class on burned sites.

Rangeland and Oak Relationships[1]

Dick R. McCleery[2]

Abstract: Hardwood rangelands are becoming an endangered resource on the Central Coast of California. Straightforward inventory processes and management guidelines on which to base sound management decisions provide the landowner the tools to protect and utilize these important hardwood resources. Utilizing a WOODLAND INFORMATION STICK and a ZIG ZAG TRANSECT, landowners can inventory their hardwood range without formidable plot establishment procedures. Utilizing the D+X method of expressing woodland stocking, the inventory results can relate the size of the trees to the growing space available to them. The guideline of forty to sixty percent canopy cover optimizes woodland growth and understory forage productivity. These procedures and stocking guides will assist the landowner to properly manage dense stands of hardwoods to promote hardwood health and a sustained use of the resource for both livestock and wildlife.

This paper outlines inventorying methods, interpretations and application guidelines for the management of coast live oak and blue oak. These methods and management outlines are those used by the US Department of Agriculture Soil Conservation Service. The figures and tables used in this paper are from Soil Conservation Service Handbooks and field investigation, unless otherwise noted.

OAK (*QUERCUS* SPP.)

The oaks are common trees on chaparral and woodland ranges and belong to the beech family. Depending on the species and site conditions, they vary from low shrubs to magnificent trees. The simple, alternate leaves are toothed or lobed, and attached singly on branches. Some oaks shed their deciduous leaves every year, but the leaves of evergreen species persist for two or three years. The flowers are very small and green. The male flowers are hanging tassels, and the females are in clusters at the base of young leaves. The fruits are acorns requiring one to two seasons to mature in the autumn. Nearly all of the oaks produce sprouts after cutting or burning.

Palatability of oak foliage varies with the species, season, and animal. New growth is preferred, and the foliage of deciduous oaks is more palatable and nutritious than that of evergreen species. The acorns of all oaks are a basic feed in the fall and winter for deer, pigs, doves, quail, turkeys, squirrels and variety of other birds and small mammals. Although the acorns are relatively low in protein, they are high in energy-giving fat and carbohydrates. Both the foliage and acorns are eaten by livestock but are considered only fair as forage. They are high in resins, waxes and tannins which may harm livestock if consumed as a large proportion of their diet.

There are three species of oaks that are of primary concern on the rangelands of this area. Two of these species are discussed in this paper the coast live oak and blue oak. The valley white oak does not normally occur in dense stands. Therefore valley white oak does not require thinning as a management tool to increase both woodland and understory forage production.

Why Is Management Needed?

The occurrence of "dog hair" thickets of both coast live oak and blue oak are too numerous to ignore. They are not always economical to treat, but when they are treated resource productivity increases greatly. Forty to sixty percent canopy cover is optimal to maximize woodland growth and health and understory forage productivity. Oak regeneration is a concern of many landowners today. Seedling and saplings that exist in the "dog hair" community do not mature and often die while still in the sapling stage. Thinning of these stands can be difficult, especially when slopes can exceed 50 percent. The soils can be extremely fragile and highly erosive.

EQUIPMENT

The Woodland Information Stick contains scales for measuring tree diameter and height. This 25 inch woodland management tool also has a table for determining trees per acre from spacing information. A Woodland Information Stick can be obtained from the Yamhill Soil and Water Conservation District, 1120 S. Baker Street, McMinnville, Oregon 97128.

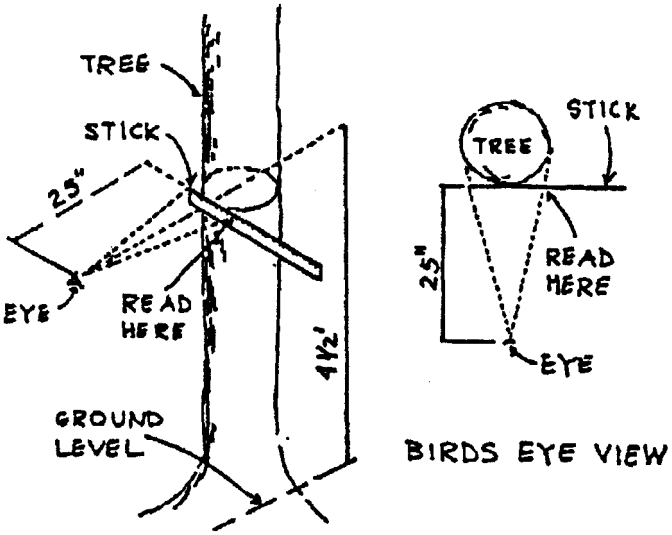
[1] Presented at the Symposium on Oak Woodlands and Hardwood Rangeland Management, October 31 - November 2, 1990, Davis, California.

[2] Resource Inventory Specialist, U.S. Department of Agriculture, Soil Conservation Service, Davis, California.

THE INVENTORY

How to Measure Tree Diameter

1. Use the "TREE DIAMETER SCALE"



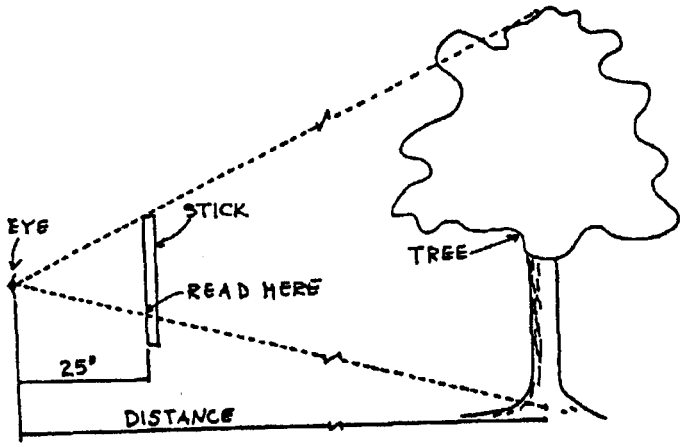
2. Hold the stick horizontally against the tree at 4.5 feet.

3. Adjust the stick so that the left end is even with your line of sight to the left of the tree.

4. Turn your eye, not your head, and read on TREE DIAMETER SCALE the figure crossed by your line of sight to the right side of the tree. This is the diameter of the tree. Many trees are not round in cross-section. Measure them from two sides and use the average.

How to Measure Tree Height

1. Stand where you can see the top and base of the tree.



2. Hold the stick vertically, 25 inches from the eye, the "top" end even with your line of sight to the top of the tree. Where the line of sight to the tree base crosses, the scale reading will be the height of the tree —if you are 100 feet from the tree. At any other distance multiply the scale reading by the distance and point off two places (divide by 100).

Identify Main Stand

The trees which form the main stand are usually the larger ones, the dominant and co-dominant trees. Underneath the main stand, there is a secondary stand, and usually an understory stand made up of suppressed trees, advanced reproduction, and brushy species. Sometimes, there is a secondary stand of trees smaller or larger in size than the main stand. An occasional tree may be borderline between the main stand and the secondary stand. If in your opinion, the tree offers significant competition to the trees in the main stand, consider it as part of the main stand. Don't separate larger trees as a secondary stand unless they are considerably larger and clearly of an earlier generation than the trees of the main stand. If the larger trees are fairly numerous, there may be a question as to which is the main stand. In the case of doubt, consider the larger trees as the main stand.

Stand Examination by Zig Zag Transact

1. Choose a direction of travel which will take you through the woodland so as to see a good cross section of it. You could elect to go in a cardinal direction or toward a visible landmark. On a sunny day, use the sun as a direction marker. Go toward it, away from it, or at some angle to or from it.

2. Select a starter tree. This may be any tree which is a part of the main stand. No measurements are made on the starter tree. It serves only as a point of beginning.

3. At the base of the starter tree, face the chosen direction, and place heels together with feet making a 90 degree angle. A line along the direction of travel bisects the angle (see figure 1).

4. Locate the closest main stand tree, the center of which is within the angle defined by your feet. This is tree one (see figure 1).

5. Pace the distance from the center of the starter tree to the center of tree #1. Determine the species of the tree and measure its diameter with the information stick. Measure tree height and estimate or measure crown diameter. Make any notes regarding tree health and condition.

6. Standing at tree #1, repeat steps 3, 4 and 5, to select, measure and rate tree #2. Continue in this manner until 10 to 20 trees have been examined. The line of travel will continue in a zig zag fashion as shown in figure 2.

7. Skip over openings and clumps or patches of trees not part of and decidedly different in kind or size from the main stand. Do not include spacing measurements to or diameter measurements

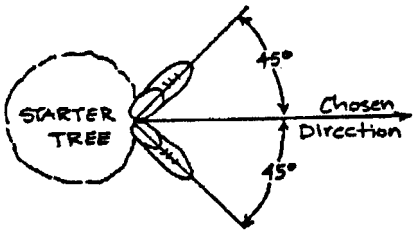


Figure 1—Forming the Angle at the Starter Tree

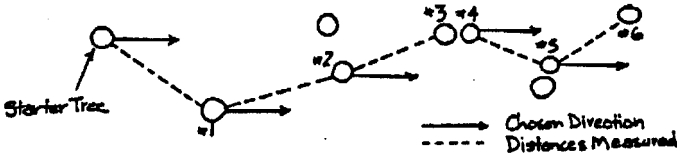


Figure 2—Sequence of Trees and Rules of Tree Selection

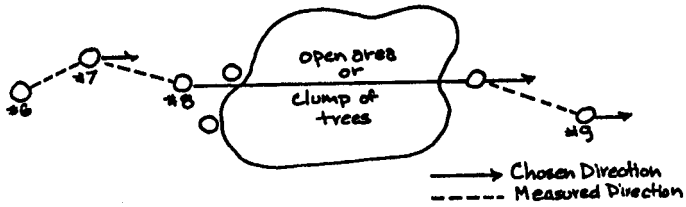


Figure 3—Openings or Clumps of Trees Not Part of the Main Stand

of trees on the edges of openings or clumps. Pass through them on the chosen direction of travel. Commence measurements on the opposite side. See figure 3. Record frequency of openings or groves encountered.

8. Measuring trees with forked bases follow two rules. When the tree forks below the ground, the two forks are counted as two separate trees and are counted or not depending how they occur in relation to your direction of travel. When the tree forks between the ground and 4.5 feet you record the fork with the largest diameter.

Taking a Zig Zag Transact

The closest main stand tree standing within the 90 degree angle projected by the feet, is selected as tree #1. This process is repeated at tree #1 to select tree #2, and so on.

1. Measure each distance from tree center to tree center.

2. When two eligible trees are equidistant, select the one closest to the direction of travel as shown at tree #2.

3. Trees joined at base are considered separate and individual. Both may be counted as #3 or #4. Only one is counted in a situation as shown at #5. Record the fork with the largest diameter.

3'-4840	11'-360	19'-121	88'-55
4'-2722	12'-304	20'-109	30'-48
5'-1742	13'-258	21'- 99	32'-42
6'-1210	14'-222	22'- 90	36'-34
7'- 868	15'-194	23'- 83	40'-27
8'- 681	16'-170	24'- 76	45'-22
9'- 538	17'-151	25'- 70	50'-17
10'- 436	18'-135	26'- 65	60'-12

Figure 4—Spacing and No. of Trees Per Acre.

species	dist.	dbh	height	crown	notes
coast live oak	12	12	40	25	split trunk w/12" & 8"dbh
coast live oak	10	14	35	30	past small dead snag
coast live oak	24	8	20	18	
coast live oak	10	5	15	12	80% dead
coast live oak	25	8	25	15	
coast live oak	10	7	20	12	split trunk w/ 7" & 5"dbh
coast live oak	29	6	18	10	past understory w/ 2"dbh
coast live oak	18	9	22	20	
coast live oak	10	9	18	22	
coast live oak	21	16	30	35	
totals	169	94	243	199	
ave	17	9.4	24	20	

Figure 5—Field Notes of the Zig Zag Transact.

Table 1—*coast live oak gross volume* in *cubic feet (Hardwood volume and weight table for California's central coast, Norman H. Pillsbury & Jeffery A. Stephens, CDF, April 1978)*

DBH	HEIGHT IN FEET										
inches	5	10	15	20	25	30	35	40	45	50	55
4	0.6	1.1	1.6	2.0	2.4	2.8					
6	1.2	2.2	3.1	3.9	4.7	5.4	8.2	6.9	7.6		
8	2.0	3.5	5.0	6.3	7.5	8.8	10.0	11.1	12.3	13.4	14.5
10		5.1	7.2	9.1	11.0	12.7	14.5	18.2	17.8	19.4	21.0
12		7.0	9.8	12.4	14.9	17.3	19.6	21.9	24.2	26.4	28.5
14		9.0	12.6	16.0	19.2	22.4	25.4	28.4	31.3	34.1	36.9
16			15.8	20.0	24.1	28.0	31.8	35.5	39.1	42.7	46.1
18			19.2	24.4	29.3	34.1	38.7	43.2	47.8	51.9	56.2
20			22.9	29.1	34.9	40.6	46.1	51.5	56.8	61.9	67.0
22				34.1	41.0	47.6	54.1	60.4	66.6	72.7	78.6
24				39.4	47.4	55.1	62.6	69.9	77.0	84.0	90.9
26				45.1	54.2	63.0	71.6	79.9	88.1	96.1	103.9
28				51.0	61.4	71.3	81.0	90.4	99.7	108.8	117.7
30					68.9	80.0	90.9	101.5	111.9	122.1	132.0
32					76.7	89.2	101.3	113.1	124.8	136.0	147.1
34					84.9	98.7	112.1	125.1	137.9	150.6	162.8
38					93.4	108.6	123.3	137.7	151.8	165.8	179.1
38						118.9	135.0	150.7	166.1	181.2	196.1
40						129.5	147.1	164.2	181.0	197.5	213.8
42						140.5	159.6	178.2	196.4	214.3	231.8
44						161.9	172.5	192.6	212.3	231.6	250.8
46						163.6	185.8	207.5	228.7	249.5	269.9
48							199.5	222.8	245.8	267.9	289.8

THE RESULTS

Summarize the Transact in this Manner

One method of expressing woodland stocking is in terms of D+X and is a spacing term which relates the size of the tree to the growing space available to it. In this formula "D" equals tree diameter and "X" is an added quantity in feet. In the following example the trees average 9" diameter and are spaced 17 feet apart, we say they are spaced at D+8 (9+8=17).

The number of trees present per acre is by using the spacing and number of trees table.

Here the spacing was 17 feet. That would be 151 trees per acre. The measured crown diameter averaged 20 feet which calculates to 314 ft. sq. per acre. Now multiply the 314 by trees per acre (151), divide by 43560 feet/acre and multiply the results by 100. This calculates to 109 percent canopy cover.

Utilizing the volume table (Table 1) for coastal live oak, the gross wood volume for the average tree is 8.8 cubic feet. Trees per acre times 8.8 calculates to 1329 cubic feet per acre. The 85 is the volume conversion from the calculated solid wood cubic feet to the stacked wood cord measurement.

Management Guides for Blue Oak and Coast Live oak

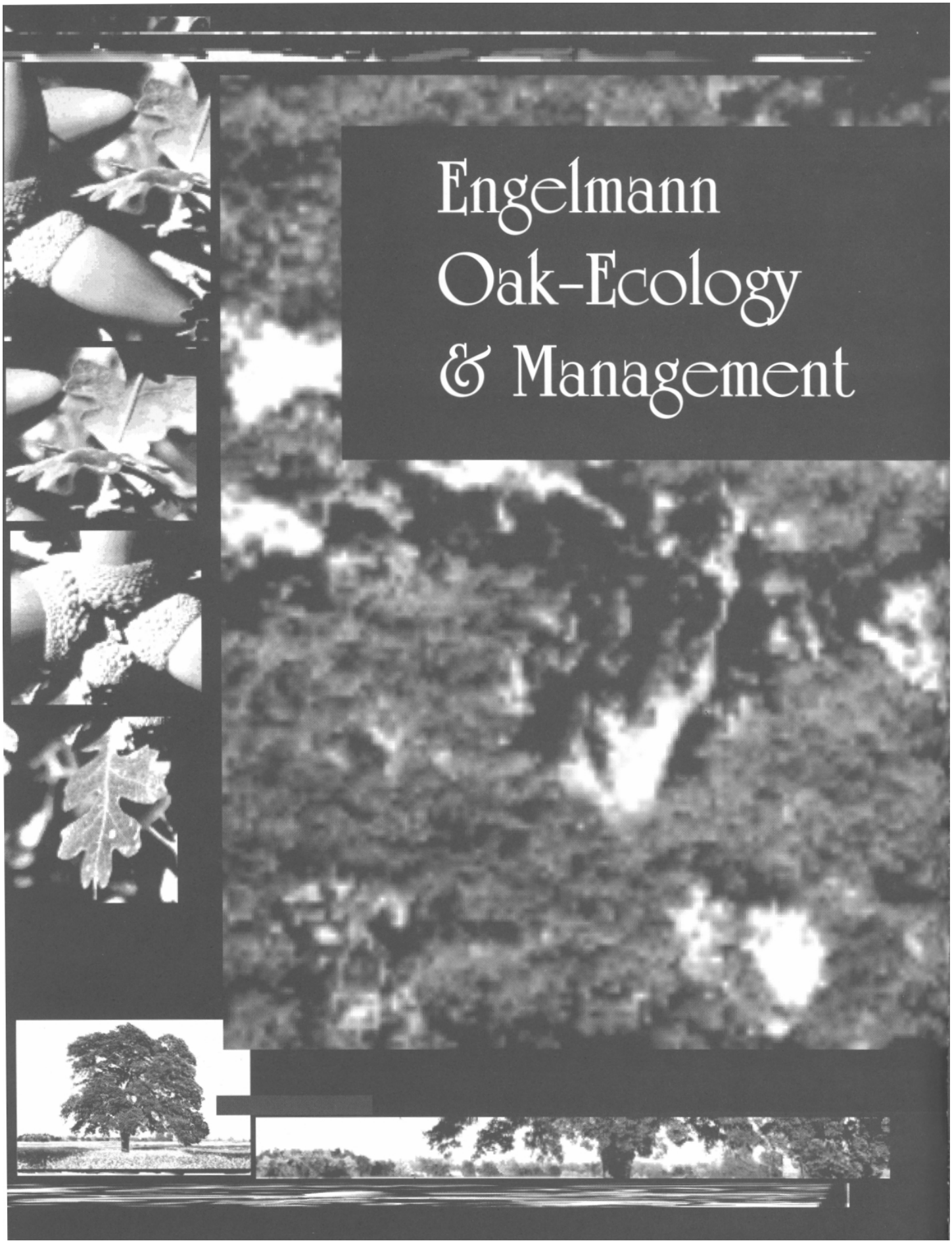
These guides are for management directed at full resource productivity:

Recommended Stocking Range	
6 to 10 inches	D+15
10 to 15 inches	D+20
15 to 20 inches	D+30

Three major uses of the resource must be kept in mind. These are woodland, livestock forage, and wildlife habitats. Fine tune these guides with the information gathered for crown cover. Remember that a canopy cover of 40 to 60 percent is most desirable to accommodate these three uses simultaniously.

In the example average diameter is 9". Our target is D+15 using the management guide. Tree spacing would need to be 24 feet. Using the spacing and number of trees table we find 76 trees per acre. Thinning objectives for this site would be to remove 75 trees per acre (151-75=76).

When trees are harvested, the trees remaining should be healthy, straight and well formed. Trees that remain should not all be of large diameter. Remember your objectives for the land. You are not after even spacing between oaks. Groupings of oaks or groves are usually best for wildlife habitat concerns. You may also want to consider planting some shrub species. These are most commonly absent from the oak woodland in this area due to grazing and dense canopy cover. The last question to ask is, "Do I have free water in the area?" Water is required both for wildlife and well managed livestock grazing.


Engelmann
Oak-Ecology
& Management

The Distribution of Engelmann Oak (*Quercus engelmannii*) in California[1]

Thomas A. Scott[2]

Abstract: Engelmann oaks (*Quercus engelmannii*) only occur in the foothills of San Diego (93 pct of extant stands), Riverside (6 pct), Orange (0.5 pct), and Los Angeles (<0.1 pct) counties, covering the smallest range of any oak species in California. The overall distribution of the species covers approximately 31,500 hectares of woodlands, although they are subdominant (contributing <50 pct of canopy area) to coast live oak (*Quercus agrifolia*) over about 52 pct of that area. Individual stands across the species range were mapped at 1:24,000 scale into a geographic information system (using 1:20,000 scale aerial photographs). Stands were separated into 6 classes of Engelmann oak canopy dominance: (one) 0 to 5 pct of canopy area; (two) >5 to ≤25 pct; (three) >25 to ≤50 pct; (four) >50 to ≤75 pct; (five) >75 to ≤95 pct; and (six) >95 to ≤100 pct. All areas were field checked for accuracy in boundary and canopy classification. There are approximately 7,300 ha of woodlands in categories five and six; 14,000 ha in categories three and four; and 9,200 ha in categories one and two. Combining these data with USGS Digital Elevation Models suggests that Engelmann oaks are most concentrated on 0° to 10º slopes with southwestern aspects between the elevations of 700 m to 1250 m above sea level. They tend to occur at higher elevations and slightly steeper slopes (5° to 10°) than coast live oaks, but there are no differences in the distribution of the two species relative to slope-aspect. The largest landholder of Engelmann oak stands is the Cleveland National Forest (24 pct of all stands), followed by Spanish Land Grants (29 pct; unbroken large land holdings), Native Americans (7 pct; on Indian Reservations), and the US Marine Corps (6 pct; Camp Pendleton). A large number of small private parcels control the remaining 31 pct of Engelmann oak stands.

This study was undertaken to define the distribution of the Engelmann oak (*Quercus engelmannii*). It is the first step in conserving and managing this oak resource in a rapidly urbanizing part of California. Wieslander and Jensen (1946) mapped part of the Engelmann oak range in the 1940's; if it were not for the rapid conversion of wildland habitats and the increased interest in woodland, these maps probably would have been sufficient to typify the species distribution. The U.S. Forest Service maps (Anderson 1969) are more up to date and at a finer scale than the Wieslander maps, but still did not provide the data for private lands outside the Cleveland National Forest. Bolsinger (1986) provided the best estimates of Engelmann oak area, but these data were neither location specific nor retrievable by geographic unit.

The goals of this paper are threefold: (1) to define the extent of Engelmann oak woodlands, (2) to make broadscale predictions on the occurrence of the species relative to topographic features, and (3) to outline the ownership, administration, and management control of Engelmann oak woodlands.

METHODS

Photographic Imagery

I used 1980 color imagery at 1:20,000 scale to map the woodlands. Areas with rapidly changing (urbanizing) landscapes in the northern half of the species range were mapped with 1989 color infrared imagery at 1:20,000. Engelmann oak woodlands in the aerial photographs were traced onto 46 USGS 7.5 minute topographic maps using a zoom transfer scope or drawn directly onto maps using stereoscopic glasses and stereo-paired photographs. Engelmann oaks in aerial photographs were separated from other trees by: (1) the open canopy and growth form of *Q. engelmannii* and (2) lighter green color of *Q. engelmannii* in infrared imagery. Oak woodlands that did not contain Engelmann oaks (i.e., pure stands of coast live oak) were not mapped.

Woodland Mapping

Polygon boundaries were drawn by connecting the canopies of oaks on woodland perimeters; woodland areas with less than 10 mature oaks per hectare (10 to 30 pct canopy cover) were not mapped. When woodlands were interdigitated with or bisected by other vegetation, I followed two conventions: (1) if the distance between two canopies exceeded 75 m, the space between was not mapped as woodland, and (2) stands smaller than 0.5 ha were not mapped unless they occurred in isolated areas (greater than 3 km from nearest stand) or they occurred along the edge of the species range. We used the GIS ARC/INFO to calculate the area and perimeter of each polygon.

[1]Presented at the Symposium on California's Oak Woodlands and Hardwood Rangeland, October 30 - November 1, 1990, University of California, Davis.

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Categorization of Woodlands

A releve method was used to classify woodlands containing Engelmann oaks into six categories of species dominance. The dominance of Engelmann oak within polygons was ranked into six categories: (one) 0 to 5 pct of canopy area was Engelmann oaks; (two) >5 to ≤25 pct; (three) >25 to ≤50 pct; (four) >50 to ≤75 pct; (five) >75 to ≤95 pct; and (six) >95 to ≤100 pct. A specific woodland was subdivided into separate polygons only when a clear division could be drawn between two dominance categories. I did not attempt to separate woodland areas into canopy cover-density classes (oak canopy area/total area), because this categorization clouded comparison between live and Engelmann oak. Categorization of the woodlands was done in the field during the spring and summer months of 1987 through 1989. Stands of hybrid *Quercus engelmannii* x *dumosa* and *Q. engelmannii* x *cornellius-mullerii* were not mapped unless they contained single stemmed trees with predominantly Engelmann oak leaf and bark characteristics (Scott 1990).

Overall Topographic Distribution of Woodlands

Engelmann oak woodland polygons were overlaid onto topography to calculate the distribution of woodland areas among elevation, slope, and aspect. Categories of dominance were maintained so the relative distribution of live oak and Engelmann oak dominated woodlands could be calculated for each of the variables. I used Digital Elevation Models (DEMs) created from United States Geological Survey (USGS) data files for twenty-five 7.5-minute quadrangle data. These data were available for approximately 70 pct of the distribution of *Q. engelmannii,* but did not cover some stands in the southern and eastern portion of the species distribution. The DEM data were divided in the following manner to maximize computer efficiency: (1) elevation was divided into 25 m intervals; (2) slope data was divided into 5° intervals; (3) slope-aspect data was divided into 45° intervals. The Very Important Points (VIP) program of the GIS ARCO/INFO was needed to reduce the number of points in the DEM data set.

Land-Use Boundaries

The distribution of Engelmann oak woodlands was overlaid onto a coverage of the boundaries and county, state, and federally administered lands (take from USGS quadrangle maps and County of San Diego base maps). These categories were used to divide woodland areas into private, county, state, and federal holdings. Federally owned parcels smaller than 2.5 km^2 (1 mi^2) were not mapped.

Deviations from Random Distributions

I compared the observed topographic distribution of woodlands against random distributions in nine of the 46 quadrangles where Engelmann oaks occur (figure 1). Because the computer time required to calculate DEM data limited the number of quadrangles that could be used, I selected nine representative quadrangles: three from the northern end, four from the central portion, and two from the southern end of the Engelmann oak distribution. DEM data were calculated for the entire surface of each quadrangle and the frequency distributions of elevation, slope, and aspect were calculated to describe the available landscape in the sampled area. I then measured the deviation in the observed woodland elevation, woodland slope, and woodland aspect from the distributions that would be expected if woodlands were randomly distributed across the nine quadrangles.

Statistical Analyses

The majority of data presented in this paper are derived from GIS map polygons. In nearly all cases the spatial areas (measured in hectares) of these polygons have been grouped in categories and their summed values among these categories were then compared against an expected (random) distribution. At present, there are no statistical techniques for calculating the significance of the differences in two distributions of summed (rather than enumerated) categorical data. Although the tests used here represent trends, they cannot be compared to standard tests of statistical significance. To be conservative, I used average woodland polygon size (15 hectares) as the operational geographic (sample) unit (Crovello 1981) rather than my unit of measurement, which was the hectare. Summed data in categories were divided by this geographic unit to approximate sample size for estimating the appropriate critical values in Kolmogorov-Smirnov comparisons (P_{est}) summed values within cells were divided by the geographic unit to approximate the frequency values for Chi-square comparisons.

RESULTS

Overall Distribution of Woodlands

I recorded 31,512 ha of woodland containing Engelmann oaks in 2,150 GIS polygons. These stands were concentrated in the cis-montane foothills of San Diego and southwestern Riverside counties (figure 1) (for general description of distribution see Scott 1990). The western edge of the species range averages

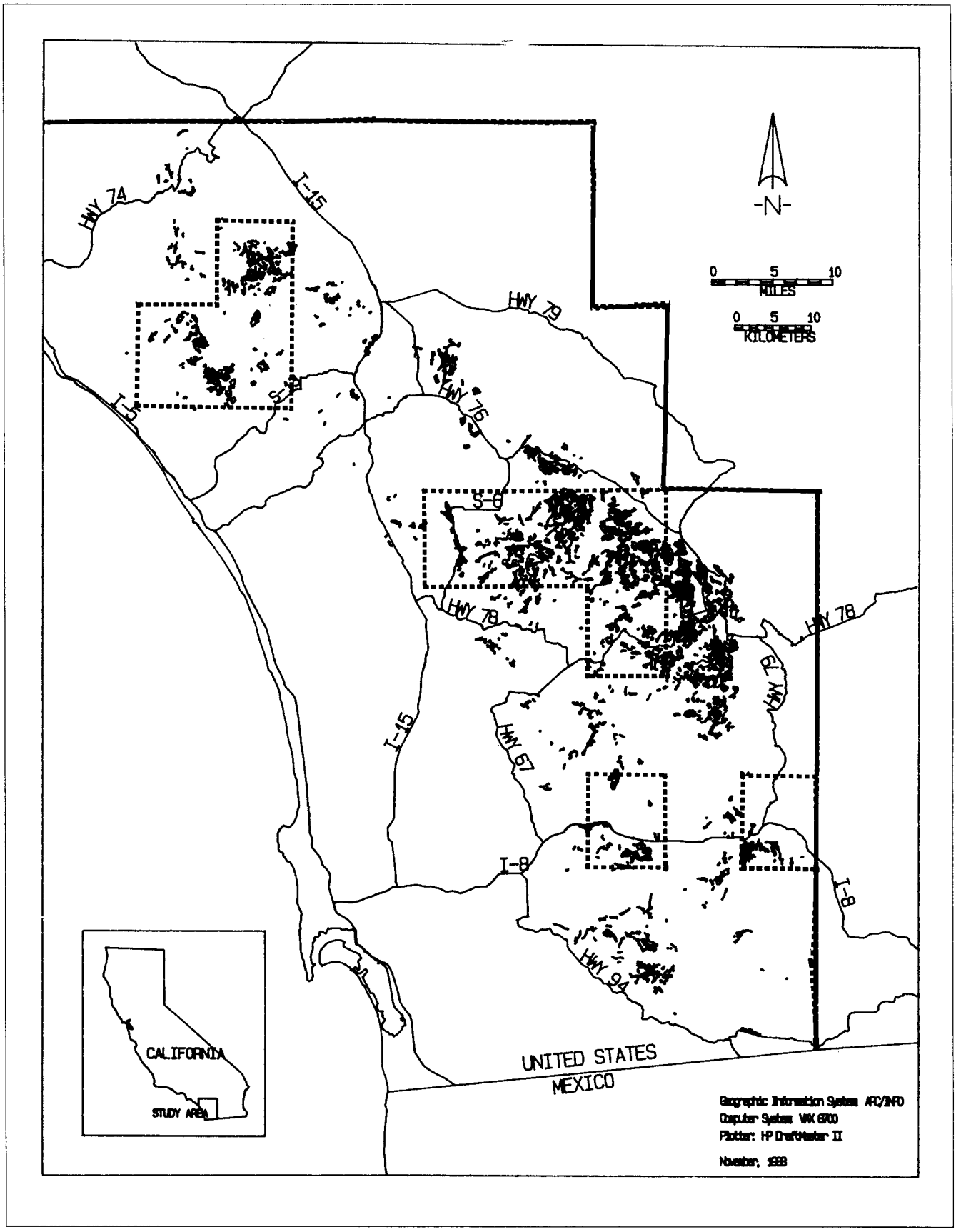


Figure 1—The geographic distribution of Engelmann oak (*Quercus engelmannii*). The dark line represents USGS quadrangles where topographic data was collected on woodlands; the dashed line outlines quadrangles where topographic data was collected for both woodland and landscape.

22.0 ± 1.6 km (13.7 ± 1 mi) (measured on 50 polygons at 2.5 km north/south intervals) from the coastline; the species range comes within 7 km (4.5 mi) of the coast at Camp Pendleton (north end of the range) but is 30 km (19 mi) from the coast at the Mexican border. The east-west width of the species range is 20 km (12.5 mi) at the Mexican border and reaches a maximum width of 40 km (25 mi) between the cities of Escondido and Julian (33º 7' latitude); north of this latitude the range splits into a narrow western (20 km; 12.5 mi) band in the Santa Ana Mountains and a diffuse pattern of small (0.2 to I ha) stands across the Perris Plain and the foothills of the San Jacinto Mountains. I found only scattered Engelmann oaks south of the Mexican Border and north of California State Highway 74. The proportion of USGS (7.5 minute) quadrangle area covered by Engelmann oaks varied from 2 pct of quadrangles at the western fringe of the species distribution to 29 pct of quadrangles in the center of the species distribution. Engelmann oak woodland area averaged 8.1 ± 7.6 (SD) pct of quadrangle area in the 18 contiguous quadrangles where the majority of the species distribution occurred.

Distribution Among Woodland Types

Only 1.6 pct of the woodland area was classified as pure stands of Engelmann oak woodland (category six) (table 1). A slight majority of woodlands (52 pct) occurred in stands where Engelmann oaks were subdominant to live oak. There were no strong patterns of spatial segregation among the different categories of woodlands other than the elevational differences (see beyond).

Polygon Size and Shape

Polygons averaged 15.9 ± 49 ha, with a wide range of averages among woodland categories (table 2). The high variance to mean ratios in all six woodland categories indicates that the pattern of a few large woodlands and a large number of small woodland stands is consistent across all categories of Engelmann oak woodlands. Woodlands in categories four and five had the largest average woodland areas, measuring 20.3± 53 ha and 20.1 ± 76 ha, respectively. Pure stands of Engelmann oaks averaged 9.1 ± 18 ha. About 22 pct of the woodlands had area/perimeter ratios of less than 0.125, which approximates the ratio for a linear or strongly interdigitated woodland.

Elevational Range

Engelmann oaks in the sample quadrangles ranged from 50 m (160 ft) to 1,375 m (4500 ft) (a.s.l.), with 60 pct of woodland area occurring between 475 m (1,640 ft) to 1075 m (4,000 ft) (a.s.l.). The distribution was bimodal, with peaks occurring at 600 m (1,950 ft) and 1075 m (3,500 ft) (figure 2).

The elevational distribution of Engelmann oak deviated strongly from the elevational distribution of the nine sample quadrangles. In general, there were more hectares of Engelmann oak woodland between 700 m (2,300 ft) and 1,275 m (4,200 ft) than would be predicted by random distribution (Kolmogorov-Smimov test; $P_{est} < 0.01$)(figure 3) across the nine quadrangles; conversely, there were fewer hectares of woodland above and below this range than would have been predicted.

Woodlands dominated by Engelmann oak showed a strong tendency to occur at higher elevations than woodlands dominated

Table 1—*Total area of Engelmann oak woodland in hectares.*

CATEGORY[1]	PRIVATE PARCEL[2]	LAND GRANT	NATION FOREST	INDIAN RESERV	MILITARY BASE	STATE/ COUNTY	TOTAL
SOLITARY TREES	2354	937	1441	378	145	20	5273
SCATTERED GROUPS	2003	440	1025	275	254	5	4001
SUB-DOMINANT	2140	2624	1244	426	190	2	6626
CO-DOMINANT	2137	2062	1546	939	657		7341
DOMINANT	2254	1939	2088	140	269		6690
PURE STAND	141	258	38	41	2		481
TOTAL	11029	8260	7382	2198	1516	27	30412

[1]The ratio of Engelmann oak (*Quercus engelmannii*) canopy area to coast live oak (*Quercus agrifolia*) canopy area within these 6 woodland categories are; Scattered trees, 0 to 0.05; Scattered groups, >0.05 to ≤0.25; Sub-dominant, >0.25 to ≤0.5, Co-dominant, >0.5 to ≤0.75, Dominant, >0.75 to ≤0.95; Pure stands, >0.95 to 1.00.
[2]Includes Nature Conservancy property.

Table 2—*The mean and standard deviation of woodlands (polygons) containing Engelmann oaks.*

CATEGORY[1]	PRIVATE PARCEL[2]	LAND GRANT	NATION FOREST	INDIAN RESERV	MILITARY BASE	STATE/ COUNTY	TOTAL
SOLITARY	10.80[3]	12.49	18.71	12.59	8.51	4.60	12.49
TREES	8.63	27.46	55.90	20.22	12.24	4.70	30.42
SCATTERED	11.64	8.62	16.27	14.45	11.04		12.18
GROUPS	18.13	13.36	34.34	19.15	18.32		29.44
SUB-DOMINANT	13.38	24.76	13.82	9.90	10.54		15.89
	20.94	99.61≤	18.89	12.53	11.80		53.08
CO-DOMINANT	16.31	32.21	15.01	22.91	28.56		20.28
	27.14	99.32	34.73	54.31	38.49		3.16
DOMINANT	14.09	26.57	31.64	10.77	12.79		20.09
	27.26	83.55	139.72	10.05	22.92		76.50
PURE STAND	6.72	12.89	7.63	6.87	2.32		9.07
	8.64	26.83	10.83	8.43	0.00		18.15

[1]The ratio of Engelmann oak (*Quercus engelmannii*) canopy area to coast live oak (*Quercus agrifolia*) canopy area within these 6 woodland categories are: Scattered trees, 0 to 0.05; Scattered groups, >0.05 to ≤0.25; Sub-dominant, >0.25 to ≤0.5, Co-dominant, >0.5 to ≤0.75, Dominant, >0.75 to ≤0.95; Pure stands, >0.95 to 1.00.
[2]Includes Nature Conservancy property.
[3]Data are presented as mean (top) and standard deviation (bottom) for each category and land-use type.

by live oak (figure 4). Over 45 pct of live oak dominated woodlands occurred below 525 m (1,700 ft), while only 5 pct of Engelmann oak dominated woodlands occurred below this area. These two types of woodlands have similar patterns of distribution above 1,150 m (3,900 ft); only 4 pct of live oak dominated woodlands and 6 pct of Engelmann oak woodlands occur above this elevation.

Slopes

Approximately 62 pct of Engelmann oak woodlands occur on slopes of less than 10º inclination, and approximately 94 pct occur on slopes of less than 20° inclination (figure 5). The Chi-square comparison (test for contingency; $P_{est} < 0.01$, 3 d.f.) suggests that more woodlands occurred in areas with 0° to 10º slope than would be predicted by a random distribution across slope categories; approximately 68 pct of the woodlands occurred on slopes of 0º to 10º, while only 54 pct of the landscape area had slopes of less than 10°.

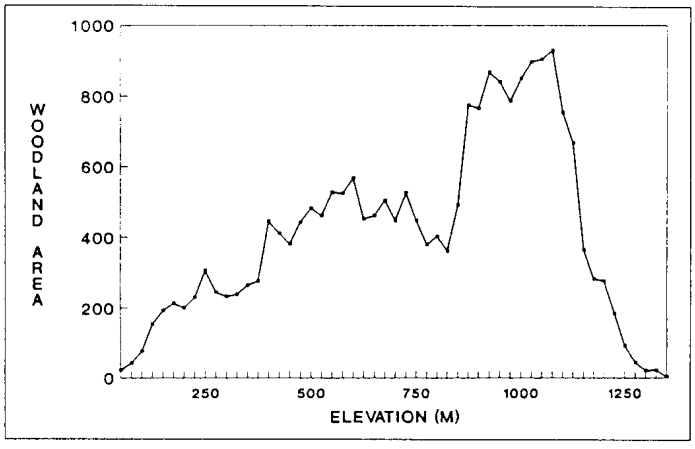


Figure 2—The elevational distribution of Engelmann oak woodland area.

Slope-Aspect

Engelmann oaks occurred throughout slope-aspect categories, but showed a trend towards southwestern aspects (225° to

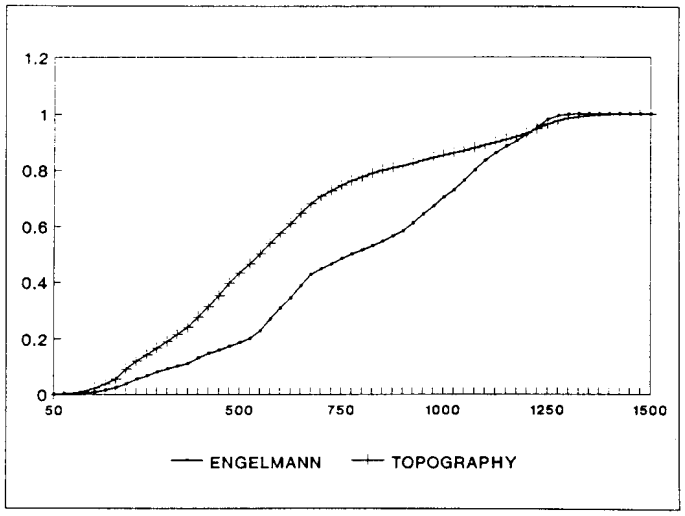


Figure 3—Cumulative frequency (0 to 1.0) of Engelmann oak woodland area (.) and landscape area (+) across elevation (m).

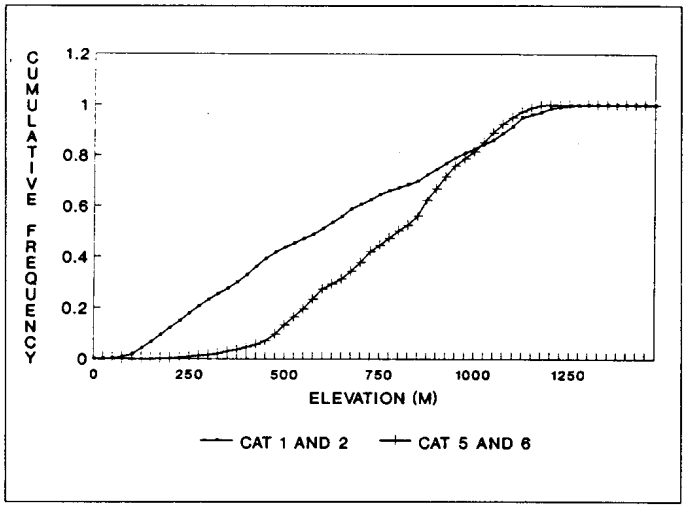


Figure 4—Cumulative frequency (0 to 1.0) of coast live oak (*Quercus agrifolia*) dominated woodland area (category 1 and 2) and Engelmann oak (*Quercus engelmannii*) dominated woodland area (category 5 and 6) across elevation (m).

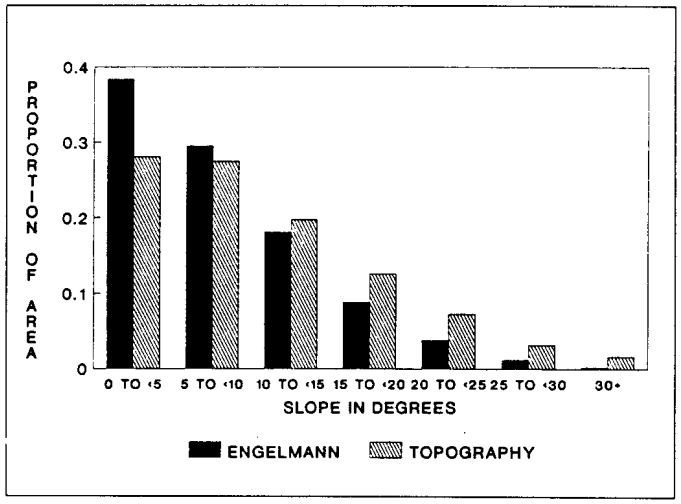


Figure 5—The proportion of Engelmann oak woodlands area (ENGELMANN) and landscape area (TOPOGRAPHY) among 5º slope categories.

315° azimuth) (figure 6). The distribution of Engelmann oak woodlands among slope-aspect categories deviated from what would be predicted by random distribution across the nine quadrangles (Chi-square test for contingency; $P_{est} < 0.05$, 5 d.f). Even though the difference was consistent in direction, Engelmann oak woodland area varied no more than 6 pct from the area that would be predicted by distribution of slope-aspects in the sample nine quadrangles. The distribution of woodland categories is equivocal and suggests no pattern between Engelmann oak dominated and live oak dominated woodlands (figure 7).

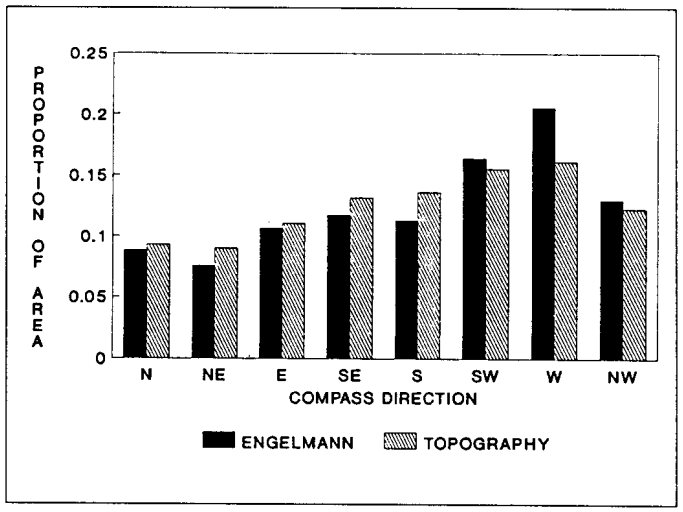


Figure 6—The proportion of Engelmann oak woodland area (ENGELMANN) and landscape area (TOPOGRAPHY) among 45° compass divisions.

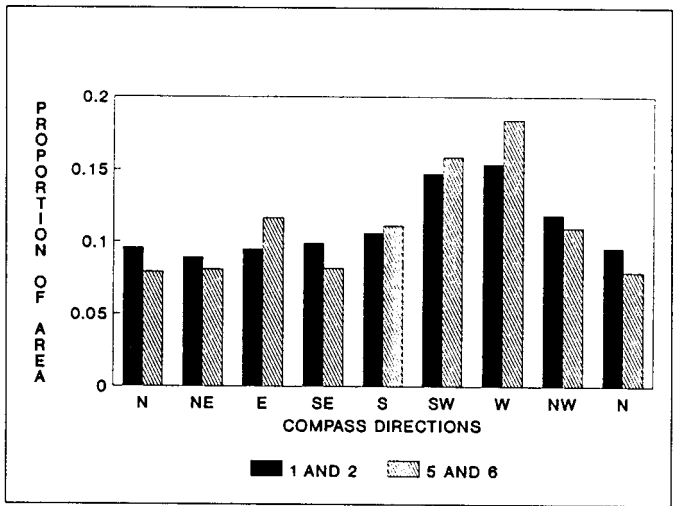


Figure 7—The proportion of coast live oak (*Quercus agrifolia*) dominated woodland area (category 1 and 2) and Engelmann oak (*Quercus engelmannii*) dominated woodland area (Category 5 and 6) among 45° compass divisions.

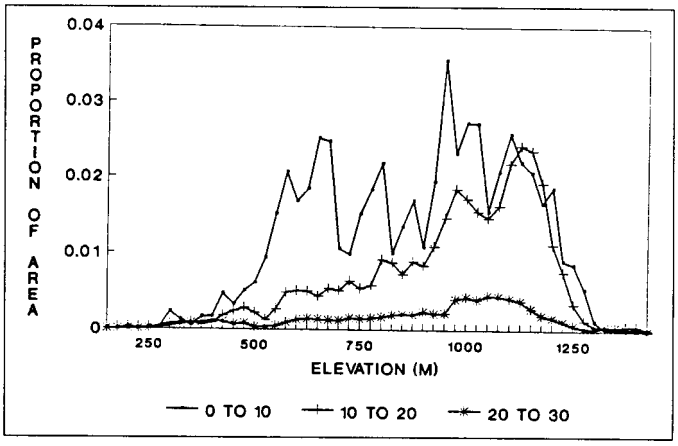


Figure 8—The elevational distribution of landscape area among slope categories: 0 to ≤10° (.); > 10° to ≤20° (+); and > 20° to ≤30° (*). intervals and elevation.

Confounding Effect of Slope on Elevational and Aspect Data

The area within specific slope categories was not evenly distributed across elevational categories. A recalculation of elevation distribution, corrected for slope area within each elevation category (figure 8), suggests that variable pattern in elevation may be attributable in part to the availability of 0° to 10° slopes (figure 9). No differences were found when the aspect analysis was run on data grouped by slope category: aspect distributions were not significantly different among 10° slope intervals (0° to ≤10°; 10° to ≤ 20°; and 20° to ≤ 30°).

Aspect and Elevation

The distribution of woodlands among aspect categories showed no gradients across topographic elevation. Instead, the tendency of woodlands to occur on south facing slopes was relatively uniform from 50 m to 1250 m of elevation (figure 10), and did not vary significantly from what would be predicted by the elevational distribution of aspects in the landscape. This relationship did not change when the data was re-analyzed using only slopes greater than 10°.

Distribution Among Counties and Ownerships

Approximately 93.5 pct of Engelmann oak woodland areas occur in San Diego; approximately 6.0 pct occur in Riverside County and 0.4 pct occur in Orange County. The extant woodland areas in Los Angeles County account for less than 0.1 pct of the species distribution. Less than 0.5 pct of Engelmann oak woodland areas occur in any incorporated cities (only Poway and Escondido).

The Cleveland National Forest controls the largest area of Engelmann oak woodlands (table 1). However, the largest proportion (57 pct) of the species distribution falls under the administration and land-use planning of the County of San Diego as private lands (including land grants). Approximately 60.5 pct of the Engelmann oak dominated woodlands (categories four, five, and six) are administered by the County, while the National Forest administers approximately 25.7 pct. The remaining lands are administered primarily by Native Americans (7.7 pct; Indian Reservations) and the U.S. Marine Corps (6.4 pct; Camp Pendleton).

The largest polygon areas occurred in category five woodlands on the National Forest (31.6 ±139 ha) and category four woodlands on Land Grants (32 ± 99 ha). Category four woodlands were larger, on average, than category five woodlands in all land-use types except for the National Forest lands. Pure stands had the largest average area (12.9 ± 26 ha) on Land Grants.

DISCUSSION

Geographic Distribution

The area covered by Engelmann oaks is the smallest reported for any species of oak tree in California. The estimate of 15,000 ha (36,900 ac) is relatively close to Bolsinger's (1987) estimate of 39,000 ac of Engelmann oak woodlands; the 9 pct

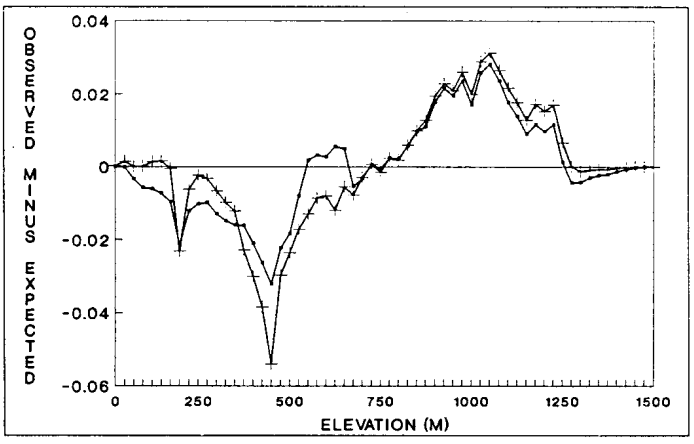


Figure 9—The difference between the distribution of Engelmann oak (*Quercus engelmannii*) woodlands and the distribution expected if these woodlands were randomly distributed across the landscape. The points (.) denote the distribution differences at 25 m elevation intervals; the crosses (+) denote the differences when the expected distribution is adjusted to include only areas with slopes < 10°.

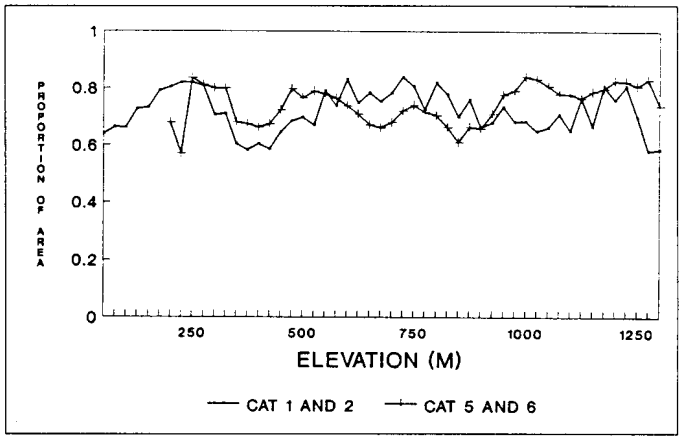


Figure 10—The proportion of oak woodland area on south facing (90º to 270° azimuth): coast live oak *(Quercus agrifolia)* dominated woodland area (category 1 and 2)(.); and Engelmann oak (*Quercus engelmannii*) dominated woodland area (Category 5 and 6) (+).

difference is attributable to methods used to divide Engelmann and live oak woodlands and to methods of mapping. The results of this study do not significantly alter his conclusions, but indicate a greater intergradation of Engelmann oak and live oak than could be detected at the statewide scale that Bolsinger was required to use.

Engelmann oak woodlands occupy a small portion of the overall range of the species; in general, stands are widely scattered and often small in area. The only regions where they contribute over 10 pct to vegetation cover-types are the Santa Rosa Plateau in Riverside County, and mountain region of San Diego County from Palomar Mountain to Cuyamaca Peak. A quarter of Engelmann oak woodland area occurs as linear or interdigitated woodlands. These areas, found on the western edge of the species distribution, are typically dominated by live oaks. The small average size of Engelmann oak woodlands, their scattered distribution, and the linearity of woodland polygons suggests that these stands are strongly effected by adjacent conditions and human activities, perhaps more so than the larger tracts of oak woodlands in western Sierra Nevada Mountains and central Coast Ranges.

Topographic Distribution

Engelmann oaks are most concentrated on low angle slopes, on southwestern aspects, and between elevations of 700 m and 1,250 m. While these data provide a general model of Engelmann oak occurrence, the variance in woodland distribution across elevation and aspect suggest other factors strongly influence the species distribution.

Engelmann oak woodlands occurred primarily in areas of less than 10° slope. Although Engelmann dominated woodlands tend to occur on steeper slopes than live oak dominated woodlands, the majority of both types of woodlands occur on slopes of less than 10°.

The upper elevational limit of Engelmann oak woodlands was far more abrupt than would have been predicted by the landscape. Temperature decreases (both average annual and daily minimum) and rainfall increases (annual precipitation) are the primary climatic condition associated with elevational increase in southern California mountains (Major 1988); it appears that 1275 m of altitude produces low enough temperatures to severely reduce Engelmann oak establishment and persistence.

The lower elevational limit of Engelmann oak distribution is far less abrupt, but appears to be tied to precipitation. A comparison of woodland occurrence to estimates of rainfall distribution (California Department of Water Resources, 1980) suggests that Engelmann oaks are concentrated in areas with over 45 cm (18 in) of annual precipitation and are nearly absent from areas with less than 35 cm (14 in). Rainfall in the region is controlled in part by orographic conditions (unpublished data[3]). It appears that the elevations where rainfall typically exceeds 35 cm (350 m) approximate the elevations where Engelmann oak concentrations occur (400 m). The two depressions located in the lower elevations of figure 9 represent large areas of valley where rain shadows may alter precipitation more than elevation (Major 1988).

Engelmann oak woodlands showed a slight tendency to occur on south facing slopes through its elevational range, in part reflecting the slightly southern orientation of aspects across the landscape. The data indicates that Engelmann oak woodlands were not concentrated on either south-facing slopes at high elevations or on north-facing slopes at lower elevations. It appears that either (1) the species tends to occur on south facing slopes; however, light and temperature are contributing rather than critical elevation factors in the species distribution; or (2) the low angle slopes do not provide sufficiently different light and temperature conditions to change the aspect distribution of Engelmann oak stands at high and low elevations.

Distribution of Woodlands Among Land-Use Types

The U.S. Forest Service has the largest tracts of Engelmann oak woodlands under one management, and provides the best opportunity for comprehensive planning for the conservation and management of the species. Land Grants, particularly those which have not been divided into subunits, provide the next largest group of undivided woodland areas. In some cases, these large tracts of lands will remain as buffers, separating Forest Service lands from urbanizing areas. In other cases, the pressures and incentives to develop large tracts of private lands suggests that some Engelmann oak woodlands may have to be protected through land purchase and donation to conservation agencies.

At present, very little of the distribution of the Engelmann oak is protected in parks or preserves. Cuyamaca Rancho State Park has approximately 0.1 pct of the species distribution. The Nature Conservancy and the County of Riverside are attempting to acquire the Santa Rosa Plateau, which contains approximately 5 pct of all Engelmann oak woodlands. U.S. Marine Corps and Native American lands provide de facto nature preserves because of their low levels of land development. However, these areas should not be considered as preserves because their charters and management goals do not necessarily protect woodlands.

The greatest challenge in Engelmann oak conservation occurs in the small parcels which share 36 pct of all Engelmann oak woodlands. Maintenance of community woodlands through the management actions of individual landowners will require a combination of education and creative policies by the counties of San Diego and Riverside. Most woodlands occur on slopes of less than 10°, and are likely to be developed as the population of southern California expands into foothill areas.

[3]Unpublished data on file, Geography Research Library, Department of Earth Sciences, University of California, Riverside, CA 92521.

ACKNOWLEDGMENTS

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Germination Characteristics of Engelmann Oak, and Coast Live Oak from the Santa Rosa Plateau, Riverside County, California[1]

Gerald E. Snow[2]

Abstract: Over 2,000 acorns of *Quercus agrifolia* (coast live oak) and over 500 acorns of *Q. engelmannii* (Engelmann oak) were collected in the Jim Knight pasture area of the Santa Rosa Plateau. These were used to test for temperature and moisture conditions on germination of viable acorns in the laboratory under controlled environmental conditions. At 24°C *Q. engelmannii* had almost 90 percent germination after 6 days, while *Q. agrifolia* had about 20 percent (96 percent after 20 days). At 14°C completeness and speed of germination of *Q. engelmannii* was reduced to about 80 percent after 36 days, while *Q. agrifolia* had over 90 percent at 30 days. At 4°C *Q. engelmannii* had about 60 percent germination at 72 days, while *Q. agrifolia* had over 90 percent at 72 days. At varying degrees of moisture stress from field capacity to -100 bar atmosphere (at 20°C) *Q. engelmannii* had at least 70 percent germination of viable acorns after 36 days, while *Q. agrifolia* did not germinate in a-100 bar atmosphere, reached complete germination in a -10 bar PEG-vermiculite mixture after 60 days and took 132 days for complete germination under 100 percent relative humidity conditions. Drying (20°C, 45 percent RH) acorns for up to 3 weeks with 24 percent moisture loss had no effect on *Q. engelmannii* but *Q. agrifolia* lost 42,58 and 75 percent of their initial moisture after 1, 2 and 3 weeks drying and all the seeds were dead after 2 weeks. The "self-rooting" of *Q. engelmannii is* also discussed. These germination characteristics are related to the distribution of these two oak species in the field.

The two major oak species in southern oak woodlands are Engelmann oak (*Quercus engelmannii* Greene) and coast live oak (*Q. agrifolia* Née), the former often growing in open savannas called the "Engelmann oak phase" and the latter growing in denser more widespread woodlands termed the "coast live oak phase" (Griffin 1977). Some of the factors influencing the establishment and distribution of these two species on the Santa Rosa plateau in the Santa Ana Mountains were the greater fire resistance of Engelmann oak seedlings compared to coast live oak (Snow 1980), the inhibition of seedling establishment by cattle in open areas and the concentration of coast live oak around rock outcrops (especially in cracks and the north side) due to ground squirrel transport and the apparently higher moisture requirements for germination (Snow 1973).

The only study as extensive as this one on oak germination was Korstian's (1927) study on germination and early survival in certain eastern white oaks (subgenus *Lepidobalanus*) and black or red oaks (subgenus *Erythobalanus*). Although *Q. engelmannii* is in the white oak group and *Q. agrifolia* in the black oak group, only general comparisons can be made due to the markedly different conditions under which these western "Mediterranean" climatic type oaks have developed. Also *Q. agrifolia* acorns mature in one season and have no dormancy (U.S. Forest Service, Woody-Plant Seed Manual, 1948) which are characteristics typical of white oaks rather than black oaks. In spite of these differences these two western white and black oaks show many of the same differences Korstian found in the eastern white and black oaks.

This paper focuses on the germination response to temperature and moisture conditions of these two southern oak woodland species. The temperature and moisture conditions used are assumed to cover the full range for these conditions found in the field.

METHODS

Over 2,000 acorns of *Q. agrifolia* and over 500 acorns of *Q. engelmannii* were collected from the ground under trees in the Jim Knight pasture area of the Santa Rosa plateau and air shipped to Corvallis, Oregon. After arrival the acorns were stored at 4°C and 95 ± 5 percent RH for three weeks before germination tests were begun.

For temperature germination tests wooden flats filled with wet vermiculite were maintained at 4, 14 and 24 ± 1°C in constant temperature chambers. Sixty *Q. agrifolia* and 50 *Q engelmannii* were randomly assigned to each of the temperature chambers. Acorns were planted at least 2 cm deep and maintained at field capacity with distilled water. Germination (2 mm of radicle extending beyond the pericarp) was checked one and two days after planting and then every two days for 90 days or until germination was complete. All ungerminated acorns were tested for viability by removing the pericarp and planting the seed in wet vermiculite at 20°C for up to 30 days. A germination value which varies directly and proportionally with the speed of germination, total germination or both (Czabator 1962) was calculated for each germination curve.

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In preliminary experiments, *Q. agrifolia* showed little or no germination under limited moisture conditions while *Q. engelmannii* did not appear to be affected by these conditions. In order to determine more precisely the germination-moisture response, the following moisture conditions for germination at 20 ± 1 °C were used: (I) vermiculite maintained at field capacity with distilled water; (II) 100 percent RH atmosphere; (III) vermiculite saturated with a -10 bar polyethylene glycol solution; (IV) -100 bar atmosphere. For moisture conditions I and III, the acorns were packed in vermiculite inside a vertically placed glass tube (7 cm diameter and 60 cm long) with vented rubber stoppers top and bottom. For moisture condition II an approximately 100 percent RH atmosphere was obtained by placing vermiculite saturated in distilled water over the bottom of a flat, round, clear plastic, six-liter germination chamber sealed with stopcock grease. Acorns were supported above the bottom in open glass petri dishes. For treatment III a -10 bar osmotic potential polyethylene glycol solution was added daily to the vermiculite to maintain this osmotic potential. The solution was made fresh each week and the vermiculite changed to avoid possible inhibitory effects reported for stored solutions (Greenway and others 1968). For moisture condition IV, a -100 bar atmosphere was maintained by using one liter of a saturated sodium sulfate solution (O'Brien, 1948) in a two-liter glass dish, 10 by 20 by 10 cm. Acorns were supported above the saturated salt solution in open glass petri dishes.

The use of the -10 bar polyethylene glycol osmotic solution with vermiculite may not exactly simulate the same matric potential in soil, even though identical in free energy status (Bonner and Farmer 1966). But the work of Parmar and Moore (1968) suggested that polyethylene glycol may simulate the soil rather closely in terms of the effects of water stress on total germination. Kaufmann and Ross (1970), in comparing soil and solute systems, found that for studying total germination polyethylene glycol may be satisfactory but when germination rate is important the solute system does not adequately represent the more normal soil conditions because germination in the soil system is much slower.

Thirty acorns of each species were assigned to each of the four moisture conditions. All the acorns were surface sterilized by being placed in a 2.6 percent solution of sodium hypochlorite for one minute. Germination was checked every two days for 90 days or until germination was complete, except for *Q. agrifolia* in the 100 percent RH test which continued for 132 days until germination was complete. All ungerminated acorns were tested for viability as described before.

The percent moisture on a dry weight basis of subsamples from stored and germinated acorns of the temperature and moisture tests were determined. Acorns were weighed to the nearest 0.01 g with and without the pericarp (shell), then oven dried at 95°C for 48 hours and weighed again

The relationship between germination, water uptake and moisture content was determined more specifically using 20 *Q. agrifolia* and 10 *Q. engelmannii* randomly selected acorns, half of which had their pericarps removed. All were planted together in a single vermiculite flat as described before and maintained at field capacity for 30 days. At 12, 24 and subsequently every 24 hours, each seed and acorn was weighed to the nearest 0.01 g. After germination dry weights were obtained as described before and the percent moisture determined for the various time intervals.

The effects of drying acorns for different lengths of time on their subsequent germination were also determined for a few sound, unmarred acorns selected from a single tree of each species. Fifteen *Q. agrifolia* acorns were divided into three groups of equal size and weight to be dried at 20 ± 1 ºC and 45 ±5 percent RH for one, two and three weeks. Ten *Q. engelmannii* acorns were divided into two groups of equal size and weight to be dried under the same conditions for one and three weeks. Each group was weighed as a unit every 24 hours. Following the drying period for each group, they were planted in vermiculite as described before and maintained at field capacity for 30 days to test for germination. After germination or 30 days, the dry weights were obtained as described before and the percent moisture determined for the various time intervals.

After five months under the storage conditions described before, 20 *Q. agrifolia* were tested for viability. Since this test indicated 100 percent viability, 50 acorns were randomly selected and divided into two groups to determine the percent moisture which would kill approximately 50 percent of the seeds. This was done by drying one group for three and one-half days and the other for seven days at 20 ± 1 °C and 50 ± 5 percent RH and then testing them for viability. A subsample of five acorns from each group was individually weighed and dry weights determined after each drying period.

The phenology of shoot development from mid-germination until the first leaves were expanded at 14 and 24°C was determined for both species by observations recorded for the acorns in the 14 and 24°C germination test. A 14-hour photo period at 2000 foot candles was used at each temperature.

An index of the self-rooting ability of each species was obtained. The distance to the base of the shoot from the radicle emergence point on the acorn after the leaves expanded was measured for seedlings grown at 14 and 24°C from acorns used in germination tests at these temperatures. Twenty acorns of *Q. agrifolia* and 15 of *Q. engelmannii* at each temperature were measured.

RESULTS

The results of the germination of the two species at 4, 14, and 24°C in vermiculite at field capacity are presented in figure 1. *Quercus engelmannii* had a germination value (26.8) about five times larger than *Q. agrifolia* (5.4) at 24°C. At 14°C their germination values were about the same (3.8 and 4.4 in the same order). At 4°C *Q. engelmannii* (0.9) was almost half that of *Q. agrifolia* (1.6). *Quercus engelmannii* showed a marked reduction in both speed and completeness of germination with decreasing temperatures while *Q. agrifolia* showed only a reduc-

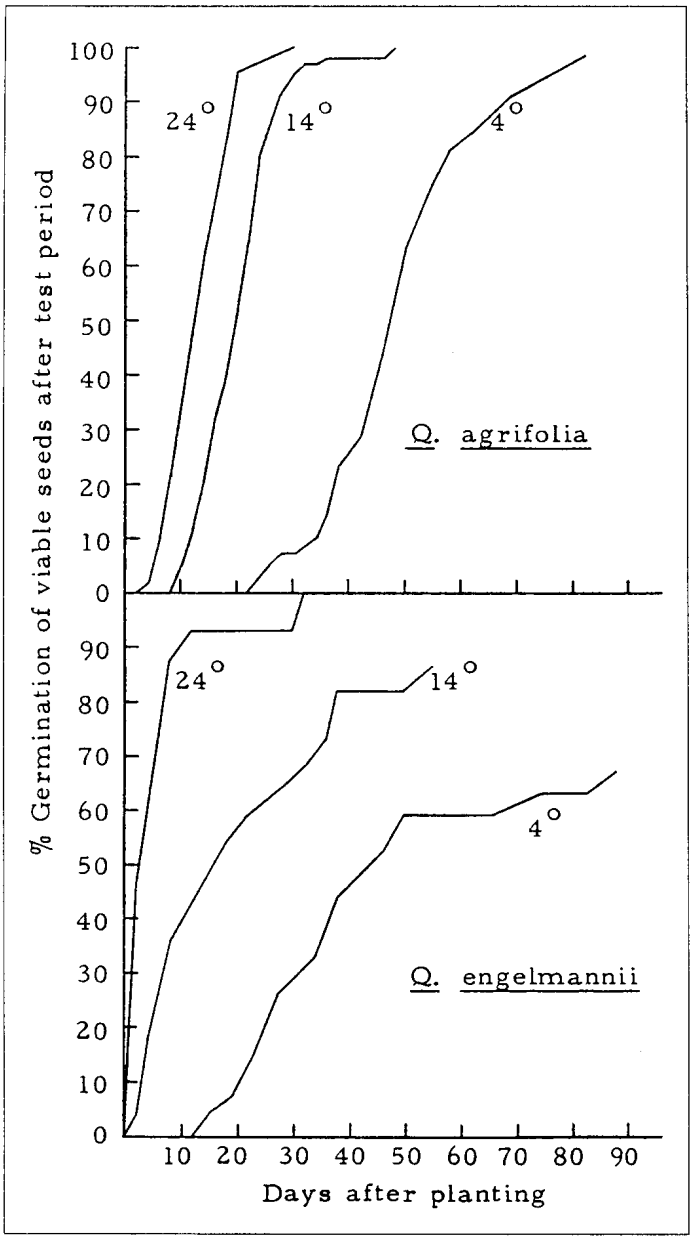


Figure 1—Germination of Q. *agrifolia* and *Q. engelmannii* at 4, 14, and 24°C. Sixty acorns of *Q. agrifolia* were planted for each temperature and 50 of *Q. engelmannii for* each temperature.

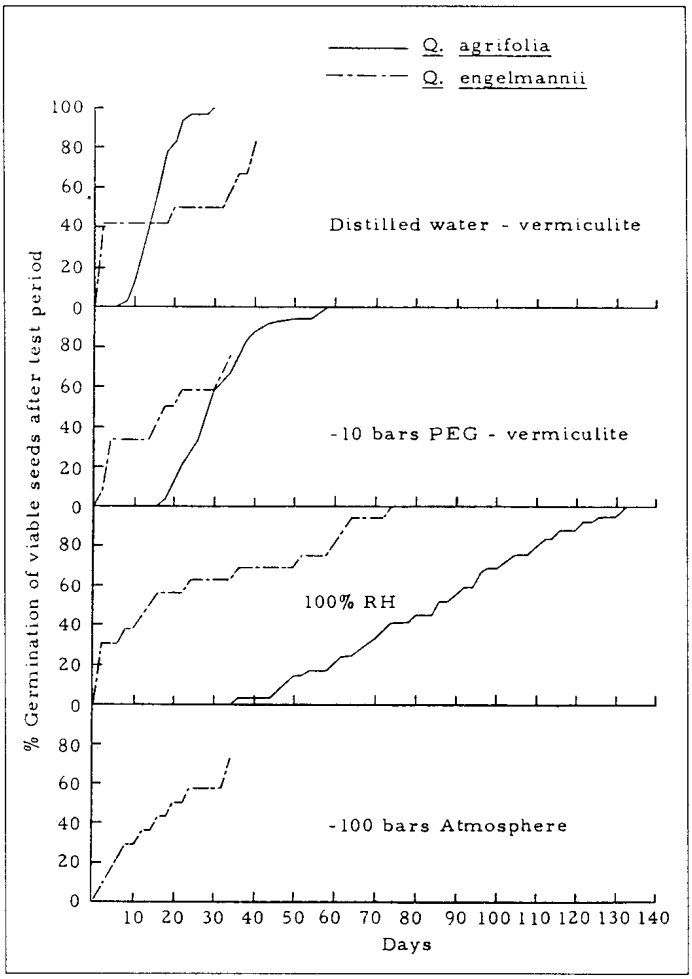


Figure 2—Germination of *Q. agrifolia* and *Q. engelmannii* under increasing degrees of moisture stress at 20°C. Thirty acorns of each species were used in each of the four moisture levels.

tion in its speed of germination.

The results of the germination of the two species under increasing degrees of moisture stress are presented in figure 2. *Quercus engelmannii* showed little influence from any of the moisture treatments with its germination values ranging between 1.9 and 2.4. After 36 days the percent germination for *Q. engelmannii* ranged between 67 and 75 percent for all four treatments. *Quercus agrifolia* showed a marked depression in germination by the increasing moisture stress. Germination values for the vermiculite at field capacity, the -10 bars polyethylene glycol (PEG) solution and vermiculite, the 100 percent RH atmosphere and the -100 bars atmosphere respectively are: 4.8, 2.5, 0.4 and 0.0. After 36 days the percent germination for *Q. agrifolia* in the same series was 100, 76, 3 and 0 percent.

The moisture content (percent of dry weight) of the seeds of the two oak species from the field and various germination conditions is summarized in table 1. The percent moisture content of *Q. engelmannii* seeds field collected and stored for nine days was 10 to 15 percent higher than *Q. agrifolia.* The range of percent moisture content for germinated seed under various conditions was very broad for *Q. engelmannii* (54-120 percent moisture) but much narrower for *Q. agrifolia* (57-78 percent moisture). Another difference between the two species indicated in the table is the ability of *Q. engelmannii* to germinate in the -100 bars atmosphere at the same moisture content as the field collected and stored seeds and lack of germination in *Q. agrifolia* under these same conditions. Apparently *Q. engelmannii* can germinate without any additional water uptake from the field and storage conditions while *Q. agrifolia* requires additional uptake for germination.

Drying for one and three weeks had no effect on subsequent germination in *Q. engelmannii.* After losing 15 percent of their initial moisture content after one week and 24 percent after three weeks of drying, all the acorns germinated from both periods.

Table 1— *The percent moisture (dry weight) of* Q. agrifolia *and* Q. engelmannii *seeds from the field and various germination conditions.*

Condition	*Q. agrifolia*[a]		*Q. engelmannii*[b]	
	No. sampled	Pct moisture and range	No. sampled	Pct moisture and range
Field collected and stored for 9 days at 4°C and 95 pct RH	10	51(40-58)	10	61 (55-66)
Germinated at mean temperature of 14 °C	30	67(60-75)	10	79(63-120)
Germinated in wet vermiculite at 20°C	28	69(61-77)	7	77(64-118)
Germinated at 100 pct RH atmosphere at 20°C	28	65(57-71)	5	68(56-78)
Germinated in vermiculite at -10 bars and 20°C	18	68(62-78)	0	
Germinated in -100 bars atmosphere at 20°C	5[c]	51(47-57)	5	58(54-62)

[a]Acorns are 2 pct less than the values for seeds.
[b]Acoms are about 10 pct less than the values for seeds.
[c]None of these germinated.

The *Q. agrifolia* lost 42, 58 and 75 percent of their initial moisture content after the one, two and three week drying periods. After one week of drying it had 40 percent germination but after two and three weeks of drying all the seeds were dead.

Based on the above experiment and the experiment to determine the percent moisture content which would kill 50 percent of the *Q. agrifolia* seeds, it was found that a moisture content of seeds between 26 and 34 percent (for whole acorns between 25 and 31 percent) or about 30 percent less than the field and storage conditions would kill about 50 percent of the seeds. Any acorns with a moisture content of 20 percent or less were dead. This point was not determined for *Q. engelmannii* due to lack of acorns.

As expected, both species took longer to develop shoots and leaves at the cooler temperature. *Quercus engelmannii* required almost twice as much time as *Q. agrifolia.* At 24°C Q. *agrifolia* took 35 days from mid germination until the first leaves were expanded while *Q. engelmannii* took 56 days. At 14°C *Q. agrifolia* took 59 days and *Q. engelmannii* took 103 days.

An illustration of the more rapid shoot development in *Q. agrifolia* and the self-rooting mechanism of *Q. engelmannii* is seen in figure 3. The *Q. agrifolia* on the left had been growing for 13 days after germination and had a shoot more than twice as long (1.5 cm) as the *Q. engelmannii* on the right which has been growing for 16 days (its shoot is 0.7 cm). Also note that the petioles of the cotyledons of the *Q. engelmannii* have elongated downward so that the shoot base is about 2.5 cm below the radicle emergence point on the acorn. There is no downward elongation of the petioles of the cotyledons in the *Q. agrifolia* so that its shoot arises from the same point at which the radicle emerged from the acorn. The distance from the shoot base to the radicle emergence point on the acorn for Q. *engelmannii* showed no significant difference between 14 and 24°C. The mean distance for 30 acorns measured was 1.4 cm and ranged from 0.5 to 2.5 cm.

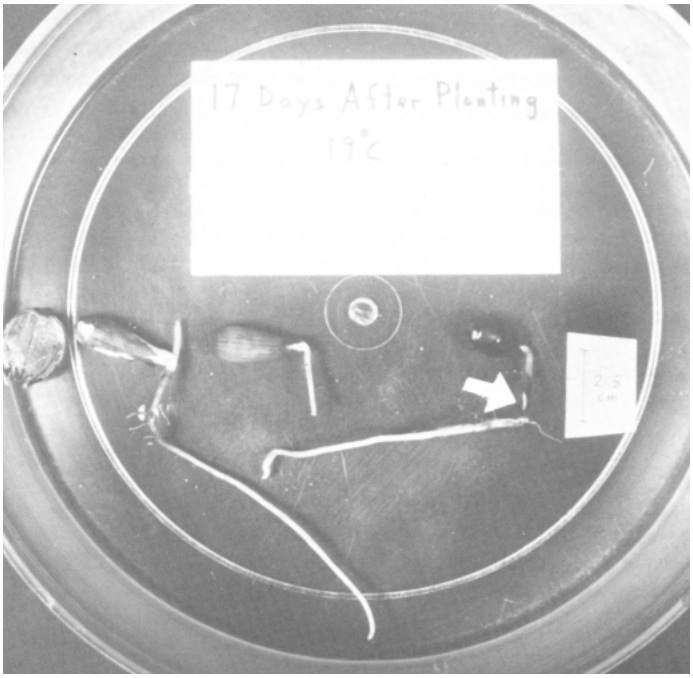


Figure 3—An illustration showing the degree of development and shoot origin in the two oak species 17 days after planting at 19°C. From left to right are the following: a *Q. agrifolia* 13 days after germination with its pericarp removed, an intact *Q. agrifolia* three days after germination, and an intact *Q. engelmannii* 16 days after germination. The arrow points to the cotyledonary node. The cotyledonary node is at the tip of the acorn in *Q. agrifolia.*

DISCUSSION

These two western white and black oaks show many of the same differences Korstian (1927) found in the eastern white and black oaks. For example, the white oaks have a higher initial moisture content than the black oaks and their acorns often germinate as soon as they are shed while the black oaks germinate later. Thirty percent of the field collected *Q. engelmannii* collected for this study had already germinated while less than 5 percent of the *Q. agrifolia* had done so and I have found *Q. engelmannii* cached in a hollow tree trunk germinating in the fall before any rains had come.

The general characteristics of the germination curves in figure 1 at 24°C for *Q. engelmannii* and *Q. agrifolia* are very similar to the warmer temperatures tested for the eastern white and black oaks (Korstian, 1927). Both *Q. engelmannii* and the eastern white oaks show very rapid initial germination rates while *Q. agrifolia* and the eastern black oaks show an initial delay in germination and sigmoid germination curves. This delay in *Q. agrifolia is* mainly due to the time required for water uptake in order to bring the seed to the moisture content required for germination.

At 4°C *Q. engelmannii* shows a marked depression in speed and completeness of germination while *Q. agrifolia* mainly shows a greater delay in the onset of germination probably mainly due to slower water uptake at this low temperature. Field temperatures may get this low, especially overnight in winter months. The eastern white and black oaks showed little or no germination at 4°C (Korstian, 1927).

Matsuda and McBride (1987) planted three species of California white oaks and three species of California black oaks, including *Q. agrifolia,* at three elevations in the Sierra Nevada and the Santa Lucia ranges. Two of the white oaks, including *Q. douglasii* germinated soon after planting at all elevations, while the black oaks germinated 1 to 3 months later. *Q. agrifolia* germinated up to 2 months later than the faster germinating white oaks.

The lack of or poor germination of *Q. agrifolia* under low moisture conditions and the insensitivity of *Q. engelmannii* to these conditions again reflects on their initial moisture content. *Q. engelmannii* requires little or no increase in moisture content and begins germination within the first day or two, whereas *Q. agrifolia* requires an increase in moisture content to effect germination by exposure to moist conditions for from one to five weeks (table 1 and figure 2). Korstian (1927) found the eastern white oaks tested had better germination in drier soil than the black oaks he tested but both had poor germination in soil a little drier than the wilting coefficient. Bonner (1968) reported little germination for stresses greater than 10 atm using a sucrose osmotic solution for the eastern black oak, *Q. palustris* Muenchh.

The eastern white oak whole acorns in Korstian's (1927) study showed more rapid and greater water uptake than the black oak acorns which also appears true for the two western species studied here (figure 4). Both species in this study showed a more rapid water uptake with the pericarps removed which was also true for four eastern black oak species studied by Bonner (1968).

Since *Q. agrifolia* has a tougher, thicker pericarp enclosing the seed much more tightly than *Q. engelmannii,* the additional water uptake by *Q. agrifolia* might be required in order to crack the pericarp and allow the radicle to grow out. The results of the relationship between water uptake, moisture content and germi-

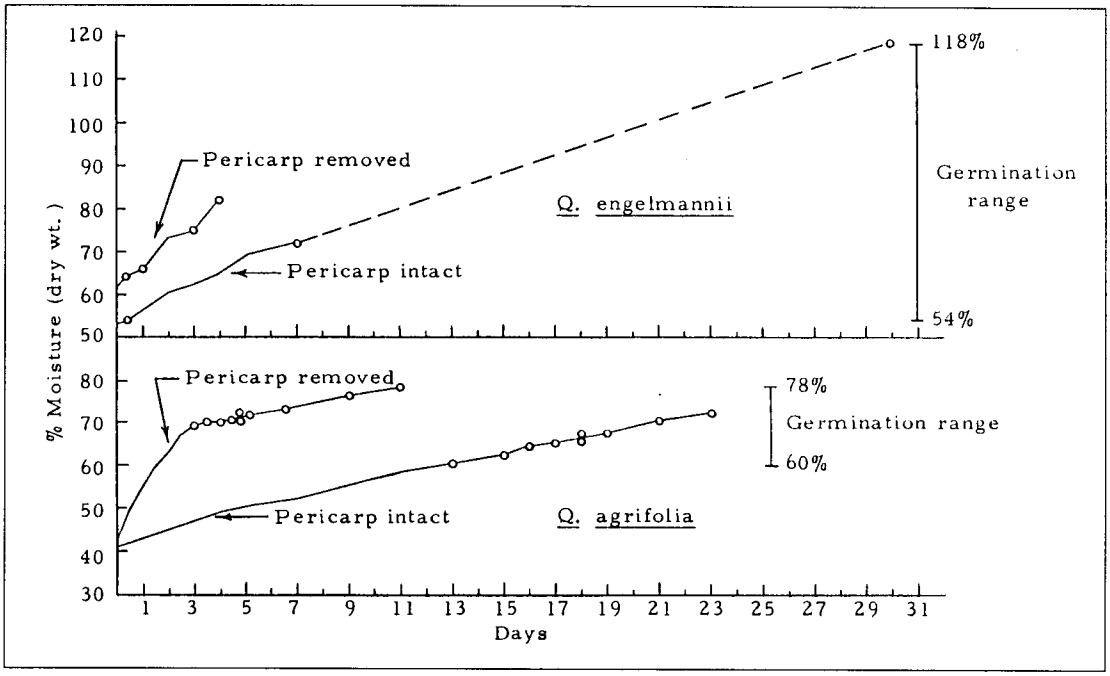


Figure 4—Water uptake and germination of *Q. agrifolia* and *Q. engelmannii* at 20°C. Circles indicate germination of individual acorns.

nation of seeds with and without the pericarp presented in figure 3 do not support that view. Even with the pericarp removed, *Q. agrifolia* seeds required a substantial increase in moisture content (from 45 percent to almost 70 percent moisture) before germination began (figure 3). Again it can be seen that *Q. engelmannii* can begin germination with little or no increase in moisture content. The typical delay in the beginning of germination in *Q. agrifolia* seen in figures 1, 2, 3 and 4 is at least in part due to the reduced rate of water uptake (figure 3) when the pericarp surrounds the seed in the typical acorn.

Krajicek (1968) found that *Q. falcata* var. *pagodaefolia* Ell. (an eastern black oak) lost moisture and viability very rapidly on air drying at room temperature. *Q. agrifolia* did not lose moisture or viability as fast as this species but it did lose moisture more rapidly than *Q. engelmannii.* Griffin (1971) air-dried in an unheated room acorns of two species of central California white oaks for 60 days with no gross effect on viability. Some of the acorns germinated during this storage.

The 50 percent loss of viability on drying for *Q. agrifolia* falls in about the same range as for the eastern black oaks in Korstian's (1927) study (moisture content between 21 and 33 percent). The eastern white oaks' 50 percent loss of viability occurred between a moisture content of 32 and 50 percent which may be similar to *Q. engelmannii* but none of them in this study got very far into this critical range.

Matsuda and McBride (1986) found that *Q. agrifolia* began to develop shoots significantly sooner after germination than the central California white oak, *Q. douglasii,* grown under the same conditions. Similar results were found in this study with much longer delays in shoot development in *Q. engelmannii* as compared to *Q. agrifolia.* This may allow *Q. engelmannii* more time for root development before moisture stresses are imposed by transpiring leaf surfaces. It would seem that this mechanism might have an adaptive advantage in establishment in more open exposed habitats where *Q. engelmannii* is normally found.

The self-rooting mechanism seen in *Q. engelmannii* in the elongation of the cotyledonary petioles carrying the radicle and plumule out of the acorn and down into the soil has also been described for the genus *Marah* (Cucurbitaceae) especially *Marah oreganus* (Torrey and Gray) Howell (Schlising 1969). Engelmann (1880) and Coker (1912) have noted this phenomenon in other oaks, especially white oaks. This pattern of germination and seedling establishment for these and a few other dicotyledonous plants occurs mainly in areas of hot and dry habitat that are generally referred to as having Mediterranean climate (Schlising 1969).

This study has shown that *Q. engelmannii* may be better adapted for establishment in more open exposed habitats than *Q. agrifolia* because it is less sensitive to moisture loss on air drying, will germinate with little or no additional water uptake, is self-rooting and has delayed shoot development. *Quercus agrifolia* may need more protected, moist habitats for initial establishment like the north side of rocks or in cracks in rock outcrops (where it is usually found on the Santa Rosa plateau) because of its greater sensitivity to moisture loss on air drying, its requirement for water uptake for from one to five weeks to effect germination (depending on temperature and moisture conditions), its lack of a self-rooting mechanism and its more rapid shoot development after germination.

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Influence of Fire on Oak Seedlings and Saplings in Southern Oak Woodland on the Santa Rosa Plateau Preserve, Riverside County, California[1]

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Abstract: One wildfire and two prescription burns were monitored at 15 oak seedling/sapling regeneration sites and at four non-burned comparison sites to study the effect of fire on seedlings and saplings of *Quercus engelmannii* (Engelmann oak) and *Q. agrifolia* (coast live oak). The number of initial top-killed seedlings and saplings, initial survivors, postburn resprouts and total survivors at the end of the study were compared between fire study sites and the non-burned comparison sites. The initial top-kill rate was higher in the burn sites than in comparison sites. Although top-killed seedlings and saplings in burned sites resprouted at a higher rate than top-killed seedlings and saplings in unburned sites, the differences were not statistically significant. Total overall survival of test seedlings and saplings at the end of the study was slightly higher in burned sites than in non-burned sites. Resprouting after fires may compensate for the high initial top-kill rate of fire in oak woodlands and contribute to the early recovery and total survivorship of the young oak population following fires.

This study reports the influence of three burn experiments monitored in 1988 and 1989—one wildfire and two planned prescription burns on seedlings of *Quercus engelmannii* Greene (Engelmann oak). *Q. agrifolia* Née (coast live oak) occurs as a co-dominant with *Q. engelmannii* in the "Engelmann oak phase" of southern oak woodland (Griffin 1977). Of the total seedling and sapling oak samples (N=791) in the 15 bum test sites, 699 were *Q. engelmannii,* the focus of this study, and 92 were *Q. agrifolia*. Snow (1980) reported on the differential response of *Q. engelmannii* and *Q. agrifolia* seedlings to prescription fires. He states that buds of *Q. engelmannii* are better protected and/or more resistant to fire and heat than those of *Q. agrifolia.* The few *Q. agrifolia* oak samples in our burn sites were included in the total analysis.

Wildfires can be very destructive to the mature oak trees, depending on the season, climatic conditions and fuel properties. Wildfires may burn at high intensity (104-132 °F) and may kill surface or subsurface perniating buds (Lathrop and Martin 1982b). However, prescription burns are typically light-intensity (98 °F) mosaic fires initiated when fuel moisture, humidity, and wind velocity make the fires controllable. Studies have shown that burning initially involves a major disturbance to vegetation, but tends to generate new and fresh plant growth (Sugihara and Reed 1987, Lathrop and Martin 1982a,b). Sugihara and Reed state that periodic low intensity burning can result in long-term preservation of one of California's threatened oak woodland types. The vulnerability of above ground parts of shrubs or saplings to fire is due to the thin bark (surrounding their trunks) and damage to the cambium. Low or light-intensity fires cause little apparent injury to trees, except where heavy fuel has built up directly under or adjacent to canopies. Seedlings and saplings less than 5 cm diameter breast height (DBH) will be top-killed by most fires, including light intensity mosaic burns (Plumb 1980).

This paper reports on the number of oak seedlings and saplings at field test sites which survived or were top-killed as a direct result of the three fires studied, subsequent resprouting of destroyed above ground parts, and total survivors at the end of the study period.

STUDY AREA

The 1255 hectare (ha) Santa Rosa Plateau Preserve (SRPP), located on the Santa Rosa Plateau in the southeastern part of the Santa Ana Mountains of the Peninsular Ranges (Lathrop and Thorne 1978,1985a, 1985b) is a complex mosaic of vegetation communities: southern California grassland; riparian woodland; southern oak woodland; chaparral; and vernal pool ephemeral. Among management objectives of the prescribed burns on the SRPP, conducted by the California Division of Forestry (CDF) in cooperation with the California Nature Conservancy, were to: 1) reduce mulch layer 50-75 pct; 2) remove non-native grasses; 3) reduce shrub fuel load below the canopy and adjacent to *Quercus engelmannii* by 50-75 pct; and 4) reduce chaparral shrub canopy by 75 pct. This was part of an effort to restore native plants to the SRPP, and to increase species richness. The prescribed burns also reduce fire hazard, improve wildlife habitat, and increase water runoff (without running the risk of erosion) to enhance stream flow.

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METHODS

Prior to the burns, 15 study sites were selected at given *Quercus engelmannii* trees which had naturally occurring oak seedlings (basal stem diameter <1 cm) and saplings (basal stem diameter ≥1 cm - <10 cm dbh) under the canopy and in the immediate vicinity surrounding the tree. Three of these sites were fortuitously set up in an area subsequently burned by wildfire. The sample number (N) was determined as the number of live (with green stems and leaves) sample seedlings and saplings at all study sites prior to the wildfire and prescription burns. Each oak seedling or sapling was flagged and tagged with 3/4 inch numbered metal tags at each study site. Seedlings and saplings at sites within the prescription burns and the wildfire were counted prior to and within a short time after the fires to determine the number of survivors (S) and those which were top-killed (Tk) by the fire. Survivorship rate was determined as a function of the initial number of live oak samples (N) which survived the fire. Resprouts (Rs) were those seedlings and saplings which were initially top-killed by fire but subsequently produced new above ground growth. Total survivorship (TS) was determined as the number survivors at the last interval plus resprouts (Rs) minus secondary top-killed (STk) specimens. Desiccation (Des) and browsing (Brw) by small rodents (i.e: *Peromyscus* sp. [deer mouse], *Spermophilus beecheyi* [California ground squirrel], *Perognathus californicus* [jumping mouse], and *Thomomys bottae* [California pocket gopher]) were the usual cause of secondary top-kill following fire. Oak samples were considered to have sustained top-kill if there were blackened remains, above-ground parts completely destroyed by contact with flames, or if leaves and stems were brown from being heat-killed. It is well known that most oak species vigorously resprout (Rs) from root crowns and at the below-ground bud zone (Plumb 1980). The *Quercus engelmannii* and *Q. agrifolia* seedlings that were top-killed by fire or heat may still have remained alive at their roots, below-ground buds, and stem buds and thus, may have retained the ability to resprout from these buds.

Burnt wire flag markers were replaced with new flags and the metal specimen number tags were left in place for each seedling/sapling sample in the test population at the first postfire monitoring. We conducted postburn measurements at all test sites each fall and spring seasons, usually in November and May because these times of the year correspond to the greatest periods of regrowth and mortality. Postburn data collected were: 1) number of secondary top-killed (STk) seedling and saplings; 2) resprouts (Rs) of original fire damaged samples; and 3) number of total survivors (TS). Following fire, renewal of seedlings and saplings may take place by resprouting. However, many resprouted seedlings die-back and resprout several times. The frequency of resprouting of *Quercus engelmannii* seedlings, however, tends to diminish with age and may cease altogether before reaching the more stable sapling stage.

The wildfire of August 31, 1988 burned over grassland and oak woodland, mainly on the north slope and top of Mesa de Colorado on the SRPP (table 1). The two prescription fires burned through valleys and gentle slopes on November 16, 1988 (four sites) and June 13, 1989 (eight sites), respectively (table 1). Four comparison sites, containing a total N of 703 seedlings and 38 saplings of *Quercus engelmannii* and 14 *Q. agrifolia* seedlings in adjacent non-burned oak woodland on the SRPP, were monitored over approximately the same seasons as the burn sites to compare recovery and frequency of resprouting between burn and non-bum sample seedlings and saplings (table 2).

Table 1—*Description of fire conditions and area of burns in hectares (ha) of one wildfire and two prescription burns on the Santa Rosa Plateau Preserve. S= number of study sites; N= total number of preburn seedlings (sdl) and saplings (spl). W spd.= wind speed; RH= relative humidity; high intensity fire= 104-132°F; low intensity fire= 98°F.*

Fires	N Sdl	N Spl	Conditions	Type
WILDFIRE				
August 1988			Temp. 85°F	Moderately high intensity
121 ha, 3 sites			W spd. 15/mi/hr	Fire carried by
Q. agrifolia	2	1	RH semi-dry	ground/shrub cover
Q. engelmannii	79	43		
PRESCRIPTION BURN 1				
November 1988			Temp. 68°F	Medium intensity
109 ha, 4 sites			W spd. 1-2/mi/hr	Fire carried by
Q. agrifolia	62	5	RH 45 pct	ground cover
Q. engelmannii	132	9		
PRESCRIPTION BURN 2				
June 1989			Temp. 70°F	Low intensity
170 ha, 8 sites			W spd. 3-5/mi/hr	Fire carried by
Q. agrifolia	22	0	RH 27 pct	ground cover
Q. engelmannii	436	0		

Table 2—*Overall breakdown of total number (N), total number initial top-killed (Tk), total initial survivors (S), total resprouts (Rs), total secondary top-killed (STk), and total survivors (TS) of seedlings (A) and saplings (B) at each of the 15 burn sites and jour comparison sites from Fall 1988 - Spring 1990 on the Santa Rosa Plateau Preserve.*

	Wildfire			Prescribed 1				Prescribed 2								Comparison			
Sites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
A. SEEDLINGS										NUMBER									
N	25	38	18	113	2	19	60	69	38	142	30	26	54	50	49	47	123	335	212
Tk	15	35	18	88	2	14	50	69	35	136	30	24	54	50	49	8	14	48	70
S	10	3	0	25	0	5	10	0	3	6	0	2	0	0	0	39	109	287	142
Rs	13	24	4	75	0	8	29	48	26	96	19	11	29	14	15	0	10	15	51
STk	6	4	1	10	0	3	5	5	1	6	0	0	0	2	3	5	67	122	78
TS	17	23	3	90	0	10	34	43	28	96	19	13	29	12	12	34	52	180	115
B. SAPLINGS																			
N	14	30	0	0	7	0	7	0	0	0	0	0	0	0	0	0	0	5	3
Tk	11	30	-	-	0	-	7	-	-	-	-	-	-	-	-	-	-	0	0
S	3	0	-	-	7	-	0	-	-	-	-	-	-	-	-	-	-	35	3
Rs	7	28	-	-	0	-	7	-	-	-	-	-	-	-	-	-	-	0	0
STk	0	0	-	-	0	-	0	-	-	-	-	-	-	-	-	-	-	7	0
TS	10	28	-	-	7	-	7	-	-	-	-	-	-	-	-	-	-	28	3

The chi-square goodness of fit test (Zar 1984) was used to test the null hypotheses that initial top-kill, resprouts, and long term survival rates do not differ between comparison and burn sites and between *Quercus agrifolia* and *Q. engelmannii.*

RESULTS

The initial top-kill for the wildfire (table 1) was 109 individuals out of 125 (tables 2, 3). Of this number, 11 *Quercus engelmannii* seedlings and five *Q. engelmannii* saplings survived. All three of the *Q. agrifolia* samples (two seedlings and one sapling) were top-killed. Sixty-eight *Q. engelmannii* seedlings out of 81 (83.9 pct) sustained top-kill, as did 40 *Q. engelmannii* saplings out of 45 (88.9 pct; table 3). However, 72 individuals (66 pct of top-killed specimens) resprouted by may 1989 (10 months postburn), plus three surviving stems (three stems perished) make 68 pct of the original preburn N of 125 (table 3). Only six resprouts died in the next year. Thus the seedling and sapling population at the wildfire test sites remained at or near 81 through the monitoring period (tables 2, 3).

The second fire examined was a prescription burn of November 1988 (table 1). One hundred sixty-one of the 208 preburn sample seedlings and saplings (78.3 pct) were top-killed by the fire (tables 2, 4). Sixty seven of the 208 samples specimens were *Quercus agrifolia* (62 seedlings and five saplings). Of the *Q. agrifolia* samples, 59 seedlings (88.0 pct) were top-killed by fire. Ninety-five of the 132 *Q. engelmannii* seedlings and seven of nine saplings did not survive the fire (tables 2, 4). By May 1989 resprouts of *Q. agrifolia* (32) and of *Q. engelmannii* (80) the previous winter season brought the total live stems back to 40 for *Q. agrifolia* and to 116 (including three top-kills by desiccation) for *Q. engelmannii.* Total survivors by the end of the study (May 1990) was 32 samples of *Q. agrifolia* out of the initial N of 67 (47.7 pct) and 110 live stems of *Q. engelmannii* out of the original N of 141(78.0 pct; table 4). This recovery was due in part to continued survival of most of the fire escapees and from resprouting of top-killed seedlings and saplings in the test population.

Table 3—*Response and subsequent recovery of* **Quercus engelmannii** *and* **Q. agrifolia** *seedlings and saplings to wildfire. N= total number of live preburn oak samples at test sites within the burn area; Tk= number top-killed by fire; S= initial fire survivors; Rs= resprouts from fire-killed samples; STk= post burn secondary top-killed samples; TS=survivors of last interval plus resprouts (Rs) minus secondary top-killed (STk); Des= desiccation; Brw= browsing.*

Monitoring date	N	Tk	S	Rs	STk	TS	Pct secondary Tk Des	Pct secondary Tk Brw
WILDFIRE Aug.'88								
Quercus agrifolia	3	3	0	—	—	0	—	—
Quercus engelmannii	122	106	16	—	—	16	—	—
POST BURN								
May 1989								
Quercus agrifolia		—	—	1	0	1	—	—
Quercus engelmannii		—	—	71	3	84	100	—
Sep. 1989								
Quercus agrifolia		—	—	0	0	1	—	—
Quercus engelmannii		—	—	2	8	78	88	12
May 1990								
Quercus agrifolia		—	—	0	0	1	—	—
Quercus engelmannii		—	—	2	0	80	—	—

Table 4—*Response and subsequent recovery of* Quercus engelmannii *and* Q. agrifolia *seedlings and saplings to prescription burning. See legend table 3.*

Monitoring date	N	Tk	S	Rs	STk	TS	Pct secondary Tk Des	Brw
PRESCRIBED BURN 1 Nov. 1988								
Quercus agrifolia	67	59	8	—	—	8	—	—
Quercus engelmannii	141	102	39	—	—	39	—	—
POST BURN May 1989								
Quercus agrifolia		—	—	32	0	40	—	—
Quercus engelmannii		—	—	80	3	116	100	—
Sep. 1989								
Quercus agrifolia		—	—	1	11	30	100	—
Quercus engelmannii		—	—	5	7	114	100	—
May 1990								
Quercus agrifolia		—	—	6	4	32	100	—
Quercus engelmannii		—	—	4	8	110	100	—

Table 5—*Response and subsequent recovery of* Quercus engelmannii *and* Q. agrifolia *seedlings and saplings to prescription burning. See legend table 3.*

Monitoring date	N	Tk	S	Rs	STk	TS	Pct secondary Tk Des	Brw
PRESCRIBED BURN 2 June 1989								
Quercus agrifolia	22	21	1	—	—	1	—	—
Quercus engelmannii	436	426	10	—	—	10	—	—
POST BURN Sep. 1989								
Quercus agrifolia		—	—	1	0	2	—	—
Quercus engelmannii		—	—	74	6	78	100	—
Apr. 1990								
Quercus agrifolia		—	—	10	0	12	—	—
Quercus engelmannii		—	—	173	11	240	73	27

The fire at the second prescription burn of June 1989 (table 1) top-killed 97.6 pct of the total test seedlings (n=458; tables 2, 5). There were no saplings in any of the eight test sites. Twenty one *Q. agrifolia* seedlings out of 22 were top-killed by the burn (table 5). Only 10 *Q. engelmannii* seedling out of the preburn N of 436 were not top-killed by the fire (table 5). By September 1989, there was one resprout of *Q. agrifolia* and 74 resprouts of *Q. engelmannii* seedlings in the test sites, which brought the total live population from 11 after the burn to 80 (tables 2, 5). By April 1990, heavy resprouting of seedlings over the winter, brought the population up to 252, or 55.0 pct of the pre-fire value (tables 2,5).

The non-burn comparison sites (table 2, sites 16-19) were used to measure seedling and sapling recovery from fire as opposed to non-burned seedlings and saplings. The initial top-kill rate was higher in burn sites (90.6 pct, N= 791) than in comparison sites (18.5 pct, N= 755) where X^2= 809.96, df= 1, and P= <0.001. Although the resprout rate was higher in burn sites (63.2 pct, N= 717) than in comparison sites (54.3 pct, N= 140), it was not statistically significant (X^2= 3.55, df= 1, P= 0.059). Likewise, burn sites showed a higher long term survival rate (60.8 pct) than comparison sites (54.6 pct; X^2= 5.91, df= 1, P= 0.015).

The initial top-kill rates from fire were the same for both *Quercus agrifolia* (90.2 pct, N= 92) and *Q. engelmannii* (90.7 pct, N= 699; X^2=0.0, df= 1, P= 1.0), and there were no significant differences in the resprout rates during the study period for *Q. agrifolia* (55.4 pct, N= 92) and *Q. engelmannii* (59.8 pct, N= 699; X2=0.47, df= 1, P= 0.49). However, the long term survival rate during the study period was greater for *Q. engelmannii* (61.5 pct, N=699) than for *Q. agrifolia* (48.9 pct, N=92; X^2=4.87, df= 1, P= 0.027).

DISCUSSION

Our data show that resprouting may occur several years following the initial demise of a particular seedling. Although there is an upsurge of top-kill to seedlings and saplings with fire, strong resprouting was noted to occur in all burns. Chi-square tests indicate significant differences in both initial top-kill rates and long term survival rates between burn and comparison sites. However, there were no significant differences in subsequent resprout rates between burn and non-burn sites.

Comparison of preburn and postburn data demonstrate the effect of the fire on the young oak seedlings and saplings (tables 2-5). Although the initial top-kill rates were essentially the same for both *Quercus agrifolia* and *Q. engelmannii,* long term survival from the fire was generally less for *Q. agrifolia* compared to *Q. engelmannii.* The mature *Q. engelmannii* and *Q. agrifolia* trees at the burn sites were not noticeably affected by the fires. However, each of the three fires studied destroyed several large and small trees where fuel build up was high beneath their canopies; for the most part only the lower canopy leaves and twigs were fire-scorched. New bud growth for twigs and leaves of partially burned trees were evident within a few months after the fires. Stump sprouts of destroyed saplings were noticed within weeks or days, particularly following the wildfire. Most oak seedlings in the path of the fire were top-killed directly by the fire or indirectly by the heat. Fire causes higher initial top-kills to oak seedlings and saplings, but ultimately enhances long term survival and recovery of the reproductive population.

MANAGEMENT RECOMMENDATIONS

Top-killed seedlings and saplings in burned sites apparently fared better than those top-killed by desiccation and browsing. The eventual success of the increased resprouting frequency following any fire may be influenced by the season of the burn. For example, the initial upsurge of resprouting of *Quercus engelmannii* and *Q. agrifolia* seedlings and saplings after fire will have a better chance of surviving their first season if burns occur in late summer or fall. This permits the newly regenerated oaks to avoid the summer drought. Regenerated oak seedlings, following our late summer and fall prescription burns, had relatively good survival during the ensuing winter months (tables 3, 4). Our study indicates that prescription burns intended to enhance regeneration in oak woodland might be better if conducted in late summer or early fall to permit better survival of fresh resprouts, without first having to withstand the summer drought, as a spring burn would entail.

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Size Class Distribution of *Quercus engelmannii* (Engelmann Oak) on the Santa Rosa Plateau, Riverside County, California[1]

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Abstract: Size class distribution of *Quercus engelmannii* (Engelmann oak) on the Santa Rosa Plateau was studied to understand whether current recruitment of young oaks is sufficient to maintain the population in spite of high natural mortality and impacts of development in some portions of the plateau woodland. Sapling-size oaks (1-10 cm dbh) made up 5.56 pct, 4.17 pct and 6.58 pct of total trees sampled at hill (N=252), mesa (N=216) and valley (N=228) sites respectively where cattle were removed in 1986. Approximately 22.5 pct out of 200 trees sampled in an adjacent oak woodland (estimated to have been non-grazed for 20 years) were of sapling size. Peak abundance of *Quercus engelmannii* was in the 46-50 and 51-55 cm dbh size classes on hill, valley and mesa sites and in the 36-40 and 46-50 cm dbh size classes in an adjacent oak woodland. Trees in size classes larger than the 46-50 cm dbh increment declined in abundance at all four sites. Only 17.1 pct of total trees (N=896) were in sizes classes beyond 66-70 cm dbh and only two trees in size class 131-135 cm dbh. Despite the high numbers of young oaks at one of the four sites sampled, current stand size structure of *Quercus engelmannii* on the Santa Rosa Plateau indicates that reproduction is insufficient to maintain the present occurence and abundance of older age classes in the future.

Quercus engelmannii Greene (Engelmann oak) and *Q. agrifolia* Née (coast live oak) are characteristic of the southern oak woodland (Thorne 1976). Griffin (1977) divides the southern oak woodland of California into two phases: 1) the coast live oak phase, which occurs between Orange and Santa Barbara counties where *Juglans california* S. Wats (California walnut) is often co-dominant with *Quercus agrifolia;* and 2) the Engelmann oak phase, which mostly occurs in Riverside and San Diego counties, completes the southern oak woodland. *Quercus engelmannii* has a small total range compared to *Q. agrifolia* (Plumb and Gomez 1983) and occurs only in the southern part of the woodland range where it dominates on drier slopes and savanna-type habitats. It ranges, in dense to scattered stands, south from Los Angeles County to Riverside and San Diego counties and northern Baja California. The purpose of this study was to conduct additional field measurements of size structure of Engelmann oak stands on the Santa Rosa Plateau to extend previous work (Snow 1972, Lathrop and Zuill 1984, Lathrop and Wong 1986, Lathrop and Arct 1987) and to compare stand structure with two grazing situations—four years removed from cattle grazing and twenty years removed. In an effort to determine the gap between the recruitment of *Quercus engelmannii* and the current stand size structure on the Santa Rosa Plateau, four additional sites were measured for size class distribution. The Santa Rosa Plateau, although a relatively small area of the total range of the Engelmann oak phase of southern oak woodland, is considered to be a good representative sample of this type of woodland.

Regeneration Deficiency

While coast live oak is reported to be reproducing normally—enough to replace the present old trees when they die, current establishment of Engelmann oak appears insufficient to maintain current stand size structure on the Santa Rosa Plateau. Bartolome and others (1987) indicate that, regardless of specific causes, current establishment appears insufficient to maintain current stand structure for some sites, although all major species (of California oaks) are reproducing. Previous stand structure studies of southern oak woodland on the Santa Rosa Plateau have shown a relatively sparse density of young Engelmann oaks less than 32 cm diameter breast high [dbh].

Factors Affecting Regeneration

The problems of natural regeneration of California hardwoods were identified by Sudworth (1908), Jepson (1910) and Bartolome, and others (1987). Some California oaks are subject to factors which have serious impacts on their ability to recruit trees into adult age classes. Suggested causes for this lack of regeneration include: 1) anthropogenic disturbances, such as young oak destruction by grazing (Burcham 1956); 2) fires and fire prevention policies (Dodge 1975); 3) introduced exotic plant and animal species (Griffin 1980); and 4) predation upon seedlings and saplings by various endemic insects and vertebrates (Knudsen 1987; White 1966; Griffin 1971, 1976, 1980).

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STUDY AREA

The Santa Rosa Plateau (SRP) is a topographic unit in the southern part of the Santa Ana Mountains of the Peninsular Ranges (Lathrop and Thorne 1978). This 18,218 hectare (ha) Plateau consists essentially of mesas (ca 610 m elevation), canyons, and rolling hills. Vegetation is primarily grassland-oak woodland dissected by scattered chaparral on slopes of mesas and hills. Prior to recent development of single family homes and ranches, the entire plateau was a cattle range, with a long history of ranch use.

METHODS

Engelmann oak trees and saplings (size class increments 1-5 and 6-10 cm diameter breast height [dbh]), were sampled for abundance (no/ha) and basal area (m^2/ha) at 224 points along a series of transect lines in southern oak woodland on the SRP using the quarter method (Brower and Zar 1984) for both trees and saplings. No seedlings were included in the study. This method is applicable to measuring broad size classes in single species stands (Mensing 1977). Data were gathered during the fall of 1988 and spring and summer of 1989 for a total of 896 individual Engelmann oak trees and saplings (N), representing four topographic units—hill (N=252), valley (N=228) and mesa (N=216) on the Santa Rosa Plateau Preserve (SRPP), a 1,255 ha preserve on the plateau, and a saddle (located between two mesas) on Santa Rosa Springs, an oak woodland savanna adjacent to the SRPP (N=200; owned by RANPAC Engineering Corporation, Temecula, California). The hill, valley and mesa sites on the SRPP had been ungrazed by cattle for four years at the time of this study. Stand size structure of Engelmann oak for the three preserve sites was compared to the saddle site on RANPAC land; which had not been grazed for approximately 20 years. This permitted a comparison of impact of grazing on regeneration in the two grazing situations.

The point quarter sampling for each of the four topographic units (sites) was begun with a random point within an oak woodland stand to be measured. A compass direction was then selected which would accommodate the configuration of the long, narrow woodland patterns to permit the maximum distance for sampling. Points along this compass line were located at random, using a random numbers table to pick numbers between 35 m (minimum distance between points to avoid sampling any one tree or sapling twice) and 55 m. The distance between points varied, depending on the random numbers selected. Likewise, distance of the compass line transects varied, depending on the size of the stand. Openings in the oak woodland greater than 46 m were considered grassland intrusions (White 1966) and were not measured—a new line transect was then established at a random point in an adjacent woodland stand. This procedure was repeated until a minimum of 50 quarter points (200 trees or saplings) were measured at each of the four sites. At each point, distances were measured to the nearest Engelmann oak trunk in each of four quadrants, whether the tree was single or multiple trunked; all trunks below breast height were measured and included in its basal area.

Trees and saplings were grouped by 5 cm dbh increments and total abundance (no/ha) and total basal area (m^2/ha) were determined for each topographic site using methods as outlined for point-quarter sampling in Brower and Zar (1984). Abundance (no/ha) of *Quercus engelmannii* saplings and trees are plotted onto 5 cm dbh size class increments for each of four topographic units to observe size structure. However, no attempt is made to estimated age of our size class increments due to the inability to assume any relation between the size of trees and their age (McClaran 1986). However, we do include a regression of age and DBH from our ring counts on cores (N=55) and slabs (N=74) of *Quercus engelmannii* specimens collected over the past few years—using tree-ring analysis with standard guidelines and procedures as outlined by Baillie (1982).

RESULTS

Size class distribution of Engelmann oaks at hill, valley and mesa sites on the Santa Rosa Plateau Preserve (SRPP) are presented in figures 1, 2, and 3 respectively and for the saddle site in an adjacent oak woodland (fig. 4). Peak abundances of *Quercus engelmannii* trees were in the 46-50 and 51-55 cm dbh size classes for each of the three sites on the SRPP (figs. 1-3) and in the 36-40 and 46-50 cm dbh size classes in the saddle site (fig. 4). Saplings (size classes 1-5 and 6-10 cm dbh) made up 5.56 pct, 4.17 pct and 6.58 pct of total trees at hill (N=252), mesa (N=216) and valley (N=228) sites respectively (figs. 1-3). The saddle site (estimated to have been ungrazed for 20 years) had 22.5 pct saplings out of 200 trees sampled (fig. 4). Trees beyond the standard deviation of abundance in the size-class increments declined in number at all four sites. Only 17.1 pct of total trees (N=896) were in size classes beyond 66-70 cm dbh and only two trees in size class 131-135 cm dbh (figs. 1-4).

Abundance values for total *Quercus engelmannii* samples were 30.3/ha, 35.7/ha, and 51.6/ha for hill (N=252), valley (N=228) and mesa (N=216) sites respectively; with basal areas 9.32 m^2/ha, 8.16 m^2/ha and 8.71 m^2/ha for hill, valley and mesa sites respectively (figs. 1-3). The abundance value of *Q. engelmannii* trees and saplings, measured at the saddle site adjacent to the SRPP (N=200), was 51.8/ha; and basal area of 8.17 m^2/ha (fig. 4).

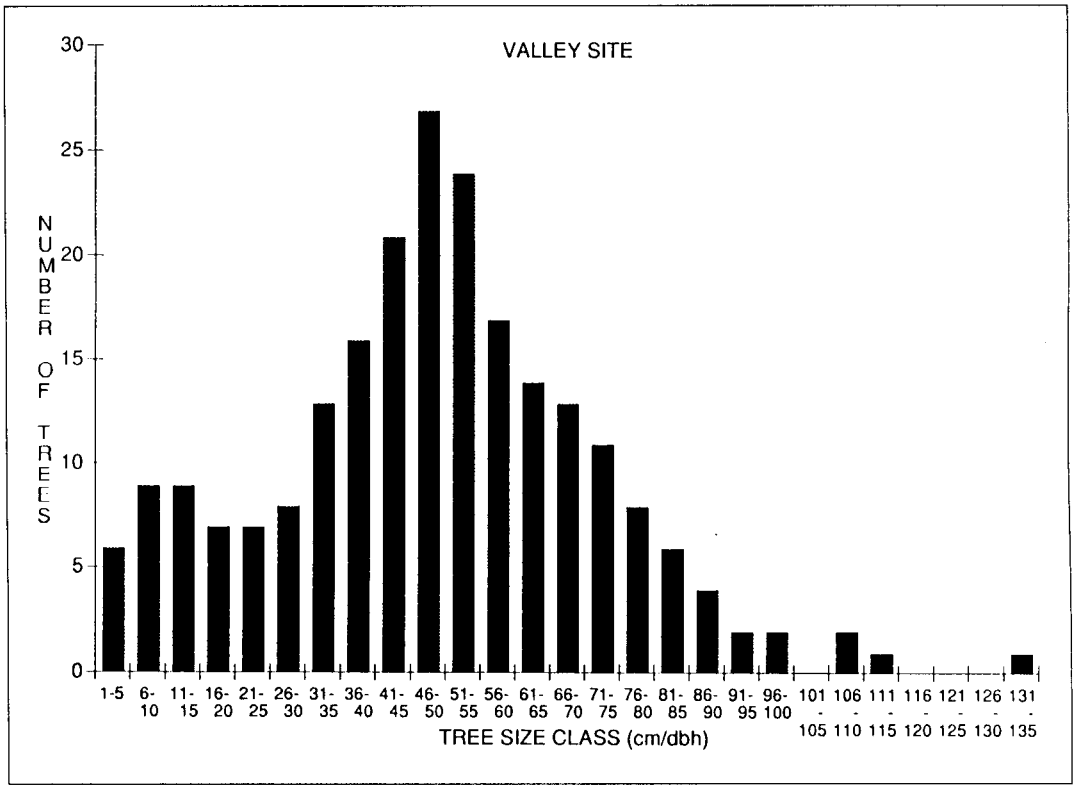


Figure 1—Size class distribution of *Quercus engelmanni* in valley Savanna of the Santa Rosa Plateau Preserve. Number of trees sampled: N = 252; basal area = 9.23 m^2/ha; abundance (no/ha) = 30.3.

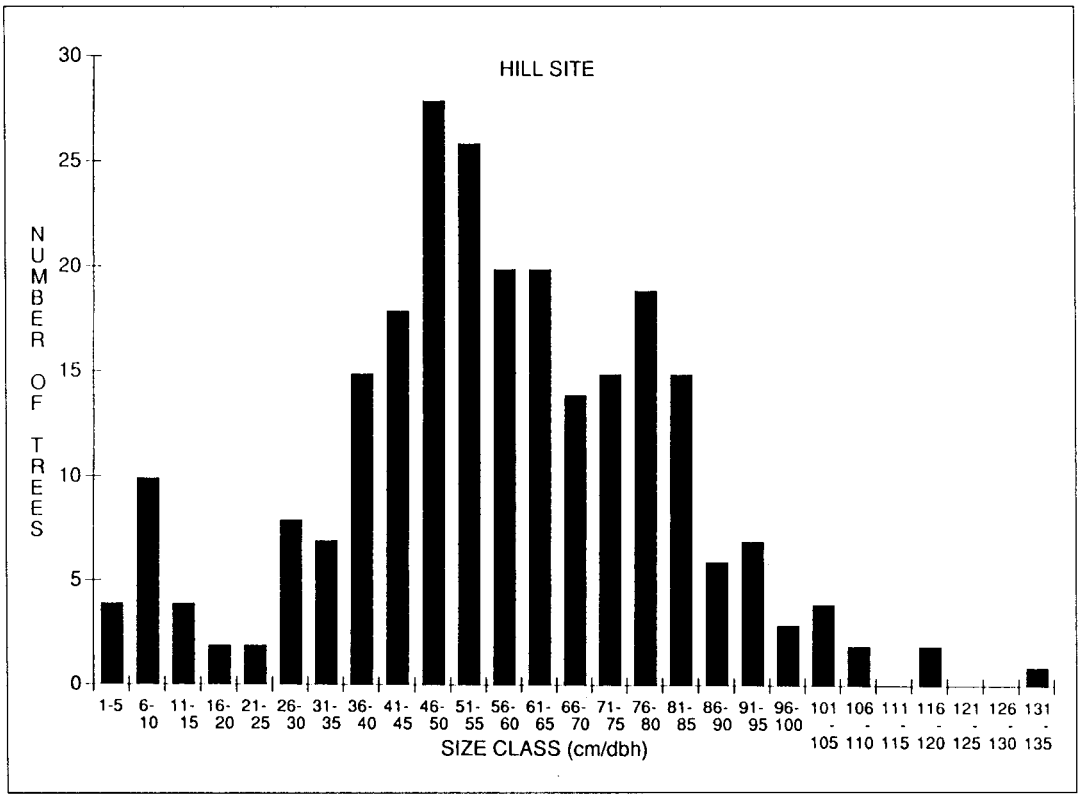


Figure 2—Size class distribution of *Quercus engelmanni* in hill Savanna of the Santa Rosa Plateau Preserve. N = 252; basal area = 9.32 m^2/ha; abundance (no/ha) = 35.7.

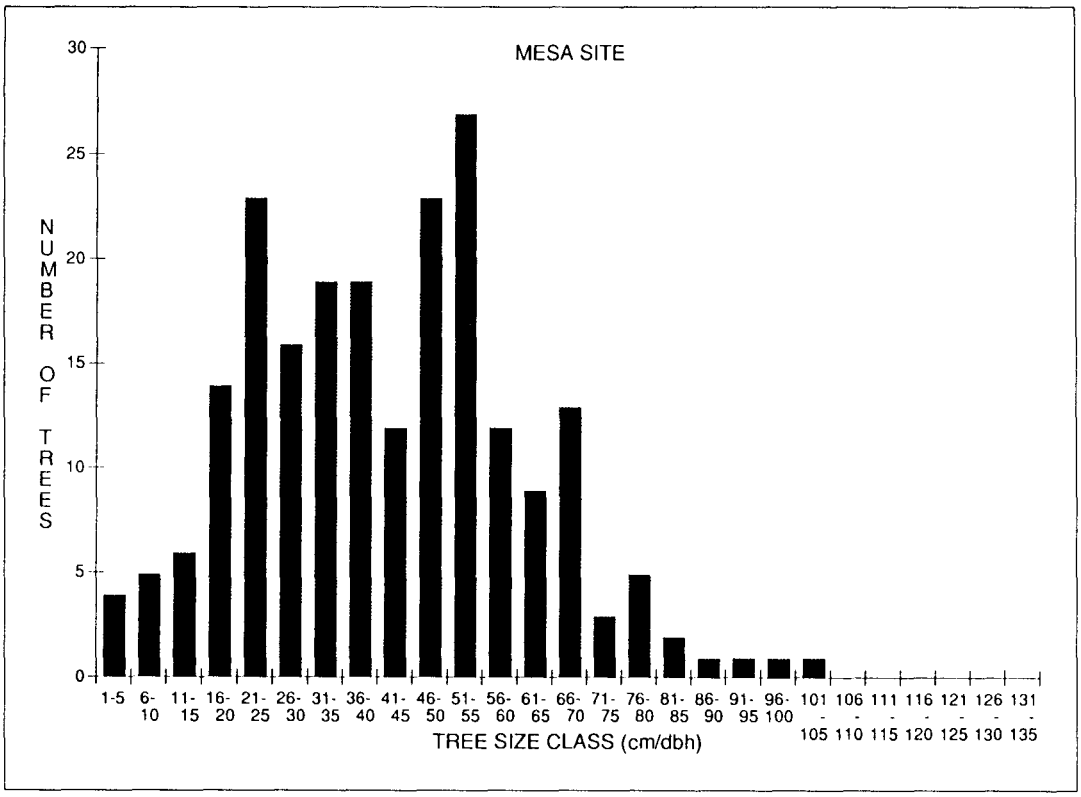


Figure 3—Size class distribution of *Quercus engelmanni* in mesa Savanna of the Santa Rosa Plateau Preserve. N = 216; basal area = 8.71 m^2/ha; abundance (no/ha) = 51.6.

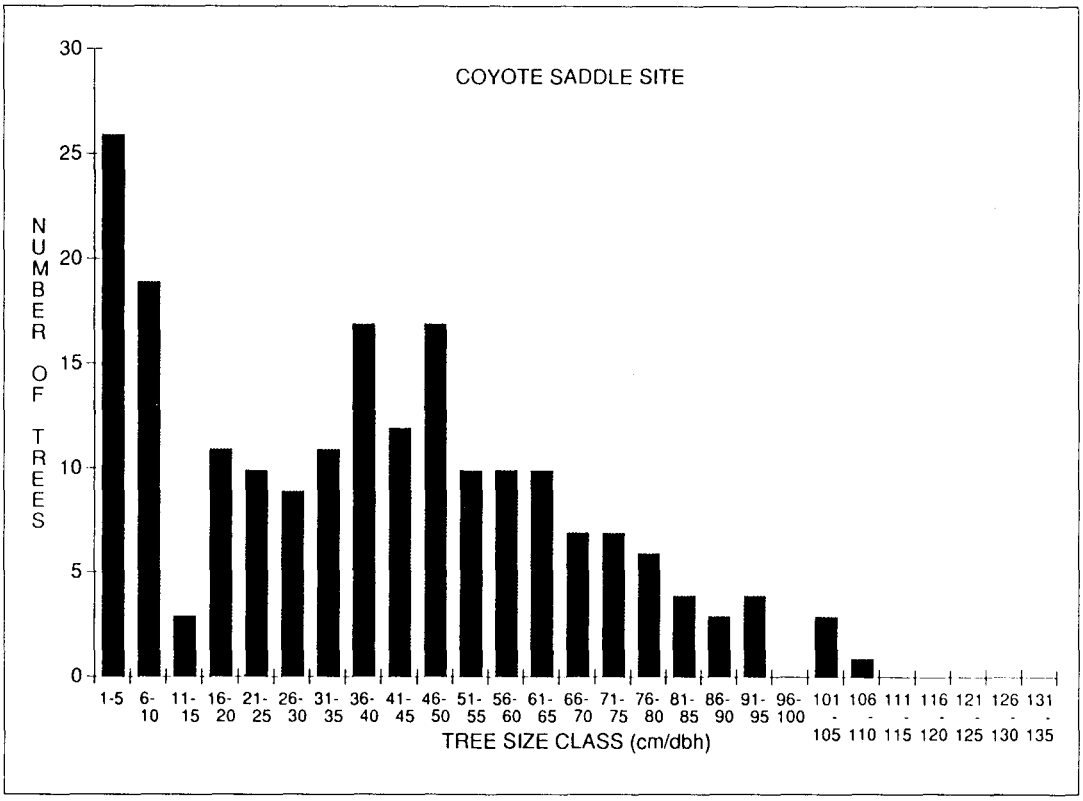


Figure 4—Size class distribution of *Quercus engelmanni* in saddle site adjacent to the Santa Rosa Plateau Preserve. N = 200; basal area=8.17 m^2/ha; abundance (no/ha) = 51.8.

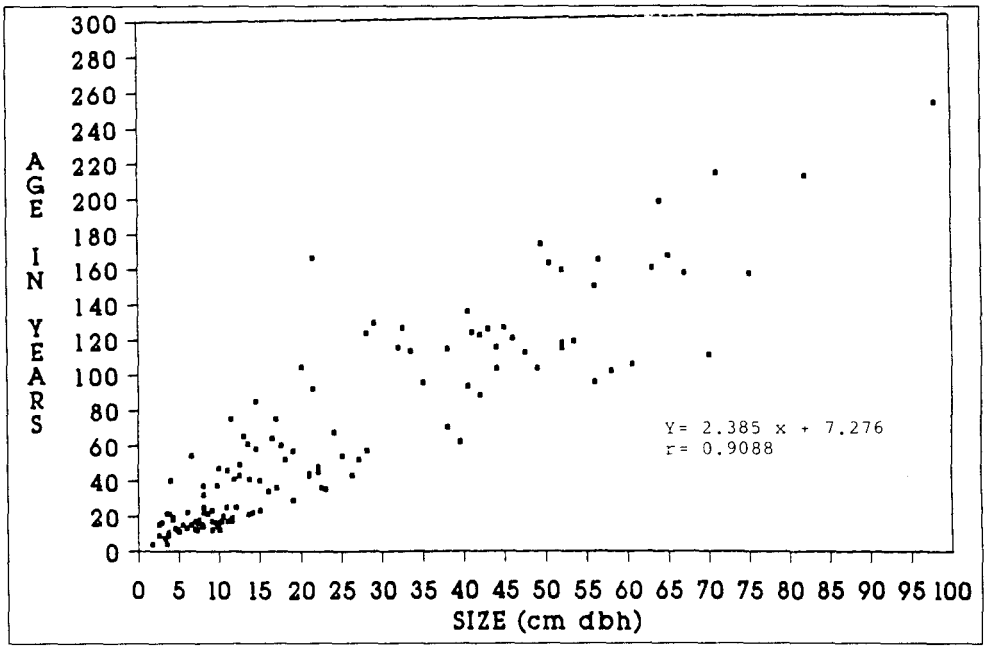


Figure 5—Scatter diagram of regression of age (yrs.) onto size (cm/dbh) of *Quercus engelmannii* ring counts. Number of trees sampled: N = 129; Y intercept = 7.276; slope of line = 2.385; r = 0.9088.

Data from regression analysis of age (yrs) onto size category (cm dbh), using annual ring counts (N=129) of *Quercus engelmannii* samples, are plotted on an age-diameter scatter diagram (Fig. 5; y= 2.385 x + 7.276; r= 0.9088). Although the linear relationship between age and size is highly significant, the 95 pct confidence level spans several decades for the larger trees, hence size cannot be used as a reliable predictor of age of our samples. McClaran (1986) indicates that even if there is a positive relationship between tree diameter and age, it is too weak to use as a predictor of age when trees are similar in size.

DISCUSSION

There was apparently adequate recruitment of *Quercus engelmannii* when the current stand size classes from 31-35 through 61-65 became established (figs. 1-4). However, stand size structure at all four sites indicate a lack of both young and very old oaks, exhibiting standard bell-shaped curves. The saddle site (fig. 4) is a possible exception for lack of young oaks, in that the two smallest size classes (1-5 and 6-10 cm dbh) represent 22.5 pct of total trees (N=200). The 1-5 and 6-10 size classes in the three sites on the SRPP (figs. 1-3) are only 5.4 pct of total trees (N=696). There is a noticeable drop in number for At 11-15 cm dbh size class in the saddle site (fig. 4) before it picks up again, but the relatively high numbers in the first two classes at this site, as opposed to to the other three could possibly reflect the cattle grazing history. The three sites on the SRPP were ungrazed for four years at the time of this study whereas the saddle site is estimated to have been non-grazed by cattle for 20 years. There are no fences around Santa Rosa Springs oak woodland region, where the saddle site is located, but isolation and rugged topography may have kept cattle on adjacent land (SRPP) away from it. Comparing this region with the SRPP sites, leads us to postulate that removing cattle for approximately 20 years has permitted more saplings (increments 1-5 and 6-10, fig. 4) to survive than the number surviving at the other three sites (figs. 1-3) which were only four years removed from cattle grazing.

Outside of cattle grazing, the present low abundance of smaller size classes cannot be taken as proof that the stands are in decline. This depends on a number of factors besides the number of trees. The present sparse density of trees less than approximately 30 cm dbh could be due to lack of seedlings, poor seedbed, or early mortality due to desiccation, disease, or insect and rodent browsing. We conclude that the few older, larger trees above around 65 cm dbh were also the result of natural mortality just as it was in size classes below 30 cm dbh (Lathrop 1989). The Engelmann oak woodland on the Santa Rosa Plateau has evidently been influenced by anthropogenic factors in the past, due to the plateau being nearly continuously grazed (in most areas) for the last 75 years (Snow 1972).

Seedlings of *Quercus engelmannii* were very rare on the four sites when any sizable number were usually found under the canopy of rare nurse trees. That is, mature oaks which have a favorable combination of good acorn production and ecological conditions for germination and establishment. Seedlings often die back in their first year or two, and may suffer considerable mortality. Current stand structure of *Quercus engelmannii* trees on the Santa Rosa Plateau suggest that reproduction has been insufficient to maintain the present size distribution of the species in the future. This lack of recruitment of young oaks is

also reported in stand structure studies of blue oak (*Quercus douglasii*) and valley oak (*Q. lobata*) in central and northern California (White 1966, Griffin 1971, 1976, Mensing 1977, Bartolome and others 1987, and Thomas 1987).

Continued studies are needed to obtain more baseline ecological information on the natural regeneration of *Quercus engelmannii* in southern oak woodland in order to evaluate the impact of regeneration patterns on future stand development. A historical analysis, including stand age structure studies, as a part in future research on this woodland type would also be warranted. However, developing a good stand age structure for the Engelmann oak woodland is beset with the difficulty of adequately aging trees in a stand; growth rates of annual rings of tree stems vary widely with geographic and topographic locations. Further studies on oaks would contribute research data essential to the development of sound management practices which could foster and enhance natural reproduction of the hardwood range habitat in California.

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