FACTORS AFFECTING BLUE OAK SAPLING RECRUITMENT AND REGENERATION

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EXECUTIVE SUMMARY

Blue oak (*Quercus douglasii*) is an endemic California oak that occurs throughout the foothills of the Coast Ranges and the western slope of the Sierra Nevada. There is a widespread belief that blue oak may not be regenerating well over much of its extensive range. Past research projects have demonstrated that a number of factors can affect the growth and survival of blue oak seedlings and saplings, but have not led to a consensus about the overall status of blue oak regeneration.

This study was undertaken to assess the status of blue oak regeneration at the stand level and to determine how environmental and management factors influence blue oak sapling recruitment. A major objective of this research was to determine how management practices (such as grazing and clearing), stand characteristics (such as tree canopy and understory vegetation), and site factors (such as slope, aspect, soil type, and precipitation) affect the likelihood of blue oak sapling recruitment. This information might then be used to help develop management methods that would favor natural regeneration by blue oak.

We assessed blue oak sapling recruitment, tree mortality, and site variables in plots located at 15 study locations distributed throughout the range of blue oak. Study locations were selected on the basis of having blue oak as the dominant canopy species, and having available information on the history of grazing, fire, clearing, and other management practices over the preceding 30 years. The selection of locations and plots was conducted without prior knowledge of the amount of sapling recruitment present. A random-origin systematic grid was used to locate 100 sample plots at each location over an area of about 61 ha (150 acres). Circular plots with a 16 m radius (0.08 ha = 0.2 acre) were established at approximately 80 m × 100 m centers. For this study, saplings were defined to have a basal diameter of 1 cm or greater, and a diameter at 1.4 m (dbh) of 3 cm or less. We defined three size subclasses within the sapling size class, and noted the size subclass and position relative to overstory canopy of each sapling.

The effects of history and environmental variables on sapling recruitment were analyzed using logistic regression. Only six locations had high enough frequencies of recruitment to permit us to construct logistic regression models for factors associated with recruitment within locations. Due to inhomogeneity between locations, only summarized location data could be used to construct models to compare the effects of factors between the 15 study locations. All of the logistic regression analyses were complicated by the fact that many of the environmental and management variables were highly correlated with each other. Ecological observations recorded at each location were used to help interpret the results of the statistical models.

Overall, 15.3% of the plots contained saplings. We found moderate numbers of saplings at four locations, no saplings at all at another four locations, and few to very few saplings at the remaining seven locations. The majority of all saplings were shorter than browse line (1.4 m). Most of the saplings we observed arose from seedlings rather than as sprouts from cut stumps, but sprout-origin saplings outnumbered seedling-origin saplings at one location. All locations had some sprout origin trees, but the incidence of sprout-origin trees varied widely between locations.

We observed natural mortality of mature blue oak trees at all locations, but estimated mortality rates varied between locations. Based on the balance between tree mortality and sapling recruitment at the plot level, 13 of the 15 study locations appear to be experiencing a net loss in blue oak density and canopy cover. Only two locations had more plots which were

likely to gain blue oak density and canopy cover, due to sapling recruitment, than plots which had lost density and canopy cover due to mortality.

Saplings were more likely to be found in the open than under canopy, but saplings were rarely found in plots lacking blue oak canopy cover. High levels and low levels of tree canopy cover were generally less favorable for sapling recruitment than intermediate levels. Seedling-origin saplings were more likely to be found in plots with recent (30-42 years) tree cutting or other types of canopy gaps than in plots with no recent gaps. However, saplings rarely occurred in old fields and other very old clearings.

We observed that most locations with little or no blue oak sapling recruitment also had little or no regeneration of other woody overstory and understory species. Shrub presence was positively correlated with blue oak sapling recruitment. It appeared that the occurrence of other woody understory plants in plots with blue oak saplings was due to the fact that these are related outcomes which are favored by the same conditions.

Across all locations, intense browsing was negatively associated with sapling recruitment. At locations that had been grazed by livestock, saplings were more likely to occur in areas that were less heavily used by livestock, such as on steep slopes or among rock outcrops. At the one location that had both moderate levels of recruitment and variation in grazing history, sapling recruitment was significantly more likely to be found in a field that had been nongrazed for 20 years than in adjacent grazed fields.

Infrequent fires appear to have either no effect or a slight positive effect on sapling recruitment and growth. At the one study location that had both recruitment and many fires in the past 30 years, portions of the study area which burned repeatedly had fewer saplings than areas which had burned only once or had not burned.

In general, recruitment tended to be more common at more mesic locations. At xeric locations, recruitment tended to occur in more mesic plots. However, at relatively mesic locations, canopy species other than blue oak often dominated the most mesic plots, and blue oak saplings were more likely to occur in somewhat xeric plots.

We believe that most of the blue oak sapling recruitment we observed developed from seedling advance regeneration in the form of small persistent seedlings. Gaps in the overstory tend to favor the recruitment of saplings from seedling advance regeneration. Pioneer colonization of open areas by blue oak is rare under current range conditions, and saplings are seldom recruited under a dense canopy.

Regeneration can be inhibited by factors that deplete the reserve of persistent seedlings in the understory, inhibit the transition from seedling to sapling, or prevent saplings from advancing to the tree stage. Since the process of sapling recruitment can be arrested at different stages, variables related to the recent past history of a site are often better predictors of recruitment than are current site conditions. Sapling recruitment may be constrained by a number of different factors at a location, so that relieving a single constraining factor may have little or no impact on the rate of sapling recruitment.

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1. INTRODUCTION AND PURPOSE

California's blue oak resource

Blue oak (*Quercus douglasii*) is the most widely occurring hardwood in California, covering an estimated 2,911,000 acres (Bolsinger 1988). Blue oak is endemic to the state and is primarily found throughout the foothills of the Sierra Nevada and the Coast Ranges (Figure 2-1). Blue oak is sometimes found on the valley floors, and in the Central Valley, blue oak occurs along Burch Creek (Tehama County) and near Thornton (San Joaquin County). The range of blue oak extends from the Libre Mountains of Los Angeles County to Shasta County, at elevations of up to 460 m (1500 ft) in the north and 1200 m (4000 ft) in the south (Griffin and Critchfield 1976). Blue oak may occur in nearly pure stands, as a dominant in mixed stands that include foothill pine (*Pinus sabiniana*), interior live oak (*Q. wislizenii*), valley oak (*Q. lobata*), and/or coast live oak (*Q. agrifolia*), or as a minor component in mixed stands of oaks and other hardwoods (Allen et al 1989).

Since settlement, mature blue oaks have periodically been cut or cleared over large areas. Blue oak was widely used for fence posts and firewood throughout the latter portion of the 19th century and into the early part of the 20th century. Jepson (1910) noted that blue oak was so heavily drawn upon that "the first-growth has quite disappeared from many sections in the Sierra foothills." Blue oak is still commonly harvested for firewood, although the actual levels of removal are difficult to document. Bolsinger (1988) conservatively estimated that cutting occurred on 336,000 acres of blue oak woodland type between 1980 and 1985.

Blue oak was also cleared extensively as a part of "range improvement" activities that were common from the 1940's through the 1970's. Blue oaks, live oaks, and woody shrubs were considered to be an impediment to forage production, and were cleared over wide acreages through cutting, burning, bulldozing, and herbicide injection (Holland 1976). Bolsinger (1988) estimated that oak woodland acreage was reduced by about 890,000 acres between 1945 and 1973 as a result of rangeland improvement projects. Although rangeland improvement clearing of blue oaks has greatly diminished in the past two decades, blue oaks continue to be removed in large numbers for urban and suburban development (Bolsinger 1988).

Since the early 1970's, both resource professionals and land managers have grown increasingly aware of the value of blue oaks and blue oak woodlands. It is now recognized that blue oak woodlands provide critical habitat to many species of vertebrates and invertebrates. It has also been documented that certain levels of blue oak canopy improve forage production and quality in central California rangeland (Frost et al 1991). Although their contributions are not fully quantified, blue oaks are also valued for reducing soil erosion, absorbing carbon dioxide, and imparting aesthetic qualities to large portions of California.

As appreciation for the value of blue oak woodlands has grown, so have concerns about the sustainability of the state's blue oak resources. Concerns about the ability of blue oak to regenerate have been voiced repeatedly. Most of the state and federal resource professionals responding to a survey in 1988 felt that blue oak regeneration was mostly unsuccessful (Lang 1988).

Survey data from two studies (Bolsinger 1988, Muick and Bartolome 1987) have been interpreted to indicate that blue oak sapling populations are insufficient to maintain current stand densities. Based on hardwood inventory data, Bolsinger (1988) estimated that 50% of the blue oak-type acreage in the state is not stocked with saplings. However, using a randomly-selected subset of the plots established by Bolsinger's group, Muick and Bartolome (1987) found sapling-sized blue oaks on 29 of 41 plots (71%). Bolsinger (1988), reported that seedlings occurred on 37% of the blue oak type acreage, whereas Muick and Bartolome (1987) found blue oak seedlings on slightly more than half of their blue oak plots.

A wide variety of research projects related to natural and artificial regeneration of blue oak has been completed (Standiford and Tinnin 1992), but no clear consensus has developed regarding the factors that limit blue oak regeneration. Muick and Bartolome (1987), noted that blue oak regeneration was highly site specific in their survey, but their analysis was not well suited to factoring out the effects of the environmental and management factors. Other research has indicated that seedling and sapling survival of blue oak and other California oaks may be affected by a variety of factors, including tree canopy (Muick and Bartolome 1987), fire (Haggerty 1991a,b), herbaceous competition (Gordon et al 1989, 1991, Griffin 1971, Davis et al 1991), and herbivory (Swiecki and Bernhardt 1991, Davis et al 1991, Hall and George 1991).

Several studies have looked at historical recruitment patterns in blue oak. Vankat and Major (1978), McClaren and Bartolome (1989), and Mensing (1992) have all reported flushes of blue oak recruitment that coincided with the influx of settlers into California in the period from the 1840's through the 1880's. Differing interpretations for this phenomenon have been offered. However, it is clearly impossible to separate the potential effects of fire, wood cutting, deer hunting, livestock introduction, shifts in understory species composition, and other human-initiated disturbances on recruitment from fragmentary historical accounts. As a result, these studies have not been able to clearly identify factors that favor or inhibit blue oak regeneration.

Study objectives

The basic purpose of our study was to investigate the effects of management and environmental factors on recruitment of blue oaks to the sapling size class. Our objectives in designing this research were to:

1. Determine the frequency of sapling-sized blue oaks at the stand or landscape level at different locations throughout the range of blue oak.

2. Determine whether environmental and management history factors are related to the presence of blue oak saplings in individual plots within locations.

3. Determine whether environmental or history factors are related to differences in sapling recruitment between locations.

4. Determine where blue oak saplings occur relative to existing tree canopy.

5. Assess levels of blue oak regeneration at the stand level by examining the relationship between sapling recruitment and mortality of mature trees.

2. EXPERIMENTAL DESIGN AND METHODS

Sampling design alternatives

In planning this project, we considered the two most applicable study approaches, namely the case-control study and the cross-sectional study. In a case-control study, samples are taken from two known groups, cases (plots with recruitment) and controls (plots without recruitment). This approach therefore requires information about the status of recruitment before experimental units are selected. In the cross-sectional study, the population is sampled at random, so that no prior information about the population is required. For either type of study design, it is necessary to sample a fixed, rather than random number of plots. Random numbers of plots would result from designs where relative levels of recruitment are used to determine the number of plots to be sampled. If the total number of plots is not fixed, it becomes extremely difficult to model the parameters in the data analysis.

The case-control study is typically used in situations where the characteristic of interest occurs at a very low frequency. Since plots are selected on the basis of having or lacking recruitment, half of the plots will have recruitment. However, since the variable of interest is also used as the basis for selecting plots, this design is very subject to bias in the selection of case and control plots. If nonrandom methods are used to select cases and controls, bias is almost unavoidable. Bias can best be avoided in this design by randomly selecting cases and controls from their respective groups.

In order to sample a fixed number of randomly-selected cases and controls, we must be able to identify the plots that have or lack recruitment prior to sampling. Since there was no existing information on the distribution of saplings in the size classes of interest, it would have been necessary to identify plots with recruitment through a preliminary sampling. Aerial photography and other remote sensing methods cannot reliably detect blue oak saplings, so any preliminary sampling would need to be conducted through ground survey. The case-control design therefore requires that any study location be surveyed twice, or that data be taken on many more plots than will be used in the analysis.

Due to the relative inefficiency of the case-control design for the system under study, we selected the cross-sectional study approach. In contrast to the case-control study, no preliminary mapping of recruitment and nonrecruitment sites is needed for a cross-sectional study, since observations on the outcome variable (recruitment) are not needed to select plots. The cross-sectional study is much less subject to sampling bias, and it is relatively easy to ensure that the total number of plots is fixed. Furthermore, data from a cross-sectional study can be used to make unbiased estimates of parameters that describe the blue oak population under study.

The major drawback of the cross-sectional design is that if recruitment is rare, a large number of plots must be sampled in order to get enough recruitment plots for the analysis. Based on the scarce information from previous studies (Bolsinger 1988, Muick and Bartolome 1987, Swiecki et al 1990), we believed that sufficient numbers of plots with recruitment would be found to permit statistical modeling of recruitment within and between study locations. As it turned out, sapling populations were much lower than anticipated at many locations, so that statistical models of recruitment within locations could only be developed for six of our 15 study locations. Although our ability to build statistical models is somewhat limited, the study design we selected was clearly superior to the alternative case-control approach.

Study approach

In designing the study, our working hypothesis was that blue oak sapling recruitment is a multistep process that may require many decades to complete, and may be affected by factors prior to and during this time interval. We realized that no single study could adequately address the impacts of all of these factors over time. Our study design allows us to examine some, but not all, of the environmental and management factors that may affect sapling recruitment. The study design also allows us to make relatively unbiased estimates of sapling populations and rates of regeneration for selected blue oak stands located throughout the range of blue oak.

This study provides the first detailed information about the distribution and frequency of blue oaks at the young sapling stage, and provides information on factors that may favor the transition to this stage of growth. Our study focuses on sapling recruitment for several reasons:

- The reported lack of sapling-sized blue oaks is the major basis for the belief that blue oak regeneration is inadequate.
- Saplings are presumably more persistent than seedlings, and have a higher probability of being recruited to the tree stage than seedlings.
- Saplings are readily visible at all times of the year, and are easy to tally. In contrast, small seedlings are difficult or impossible to detect both early and late in the year.

In most previous blue oak surveys (Bolsinger 1988, Holzman 1993, Muick and Bartolome 1987, Swiecki et al 1990) data has been collected in single plots or clusters of up to five subplots which are widely dispersed. In this study, we utilized a relatively large number of plots (100) spread over a relatively large area (61 ha) at each of 15 study locations. This design allows us to examine the frequency and pattern of recruitment at the stand or landscape level. This sampling scheme was also far more efficient than a dispersed sampling scheme due to the need to compile extensive historical data for each study location. As a consequence of the study design and the characteristics of the data set itself, we are better able to analyze the effects of factors influencing recruitment within study locations than between study locations. However, by distributing our study locations throughout the range of blue oak, we were able to ensure that our observations were not biased by possible regional differences in blue oak recruitment.

Blue oak life stages

In a number of studies on blue oak, the chronological age of seedlings, saplings, or trees has been determined (Griffin 1971, White 1966a, Mensing 1992, Harvey 1989, McClaren and Bartolome 1989, Vankat and Major 1978). In virtually every study, blue oaks of a given size class have been shown to represent a wide range of chronological ages. Conversely, the size diversity of a given age class may be so great that several distinct size classes may be represented.

We believe that size class is a more a useful criterion for classifying blue oak life stages than is chronological age. Limitations to blue oak growth are more clearly related to size than to chronological age. For example, browsing by animals such as cattle and deer can strongly constrain the growth of blue oaks that are shorter than the browse line (about 140 cm), but has little impact on the growth of trees. Small rodents such as mice or voles can chew off or girdle the thin stems of small seedlings, but are unlikely to affect thick woody stems. Furthermore, post-fire blue oak shoot survival has been shown to increase with increasing stem diameter

(Haggerty 1991a). We therefore used size classes alone to define blue oak life stages, as shown in Table 2-1.

The seedling class as defined here includes a small seedling class and a large seedling class (S0). The small seedling class contains both first-year seedlings, which may be rather ephemeral, as well as persistent seedlings which may be many years old (Griffin 1971, Swiecki et al 1990, Allen-Diaz and Bartolome 1992, Phillips 1993). We did not attempt to collect data on small seedlings because they cannot be reliably tallied in a one-time survey. Early in the season, small seedlings are often hidden in herbaceous growth. Late in the season, seedlings may defoliate early or the entire above-ground shoot may die back or be browsed off, but many of these seedlings remain viable. The S0 seedling class consists of seedlings that are typically many years old and are large enough to be visible at any time of the year. We included data on S0 seedlings in the survey because it appeared that seedlings in this size class were likely to be recruited to the sapling size class.

Since browsing of the shoot leader by large vertebrates is one of the most clear limitations to height growth in blue oaks, we subdivided our sapling size class into three stages that reflect transitions associated with browsing. Saplings in the S1 size class are subject to loss of the shoot leader by browsing animals. The tallest shoot tip of saplings in the S2 size class is above the nominal browse line, but the leader is still relatively susceptible to damage that would cause the sapling to revert to the S1 class. Once saplings reach the S3 stage, they are relatively unlikely to have their height growth curtailed by browsing animals and have a high probability of advancing to the small tree stage.

The sapling size class as defined by Muick and Bartolome (1987) and Bolsinger (1988) includes individuals that are included in our small tree size class (Table 2-1). In all locations except 1 and 2, we noted whether trees in the 3 to 13 cm dbh size class were present in the plot, but did not count these small trees as saplings. For all practical purposes, blue oaks of this size have been recruited to the tree stage and are not subject to the same growth limitations as saplings. Inclusion of these larger and generally older oaks in the sapling stage may tend to obscure trends that exist for younger saplings.

Based on previous research of McClaren and Bartolome (1989), we made the assumption that the transition from seedling to young tree (dbh > 3 cm) would be unlikely to occur in less than about 10 to 30 years. To ensure that environmental and management history was relevant to our sapling size class, we compiled data on management and environmental variables extending back at least 30 years for each of our study locations.

TABLE 2-1. Blue oak size class definitions used in this study compared with definitions used in some previous studies.

Size Class	This report	Muick & Bartolome 1987	Bolsinger 1988	Swiecki et al 1990
Seedlings	<1 cm bd*	<1 cm bd	<2.5 cm dbh**, >15 cm tall	<1cm bd
	Subgroups:	*Subgroups:*		
	Small seedlings: < 25 cm tall	1: <10 cm tall		
	S0: ≥25cm tall	2: 10-30 cm tall		
		3: > 30 cm tall		
Saplings	≥ 1 cm bd, ≤ 3 cm dbh	>1 cm bd, <10 cm dbh	2.5 cm, <12.7 cm dbh	≥1cm bd, < 1 cm dbh
	Subgroups:			
	S1: <140 cm tall			
	S2: ≥140 cm tall, dbh <1cm			
	S3: >140 cm tall, dbh 1-3 cm			
Trees	> 3 cm dbh	> 10 cm dbh	≥12.7 cm dbh	≥ 1 cm dbh
	Subgroups:			
	Small trees: >3 cm dbh, ≤ 13 cm dbh			

* bd = basal diameter
** dbh = diameter at 140 cm (4 ft)

Sampling and survey methods

Study locations

We selected 15 study locations which were stratified, to the degree possible, throughout the statewide range of blue oak (Figure 2-1, Table 2-2). We restricted the total number of locations in order to avoid spending an excessive proportion of project resources on locating, traveling to, and compiling site histories for different locations. Furthermore, sampling a relatively large number of plots at each location helped to ensure that many of the predictor variables evaluated would indeed vary within the study location. This allowed us to examine the effects of these variables on recruitment within locations, and provided a better picture of how recruitment is distributed at the stand or landscape level.

In order to be considered as a potential study location, locations needed to have at least 61 ha (150 acres) of more or less contiguous woodland dominated by blue oak within an area 1520 m by 900 m (136.8 ha=338 acres). The sampled areas typically included the cover types described within the blue oak rangeland cover series of Allen et al (1989). In addition, we also needed to have management history data for the 30 years prior to 1992, which was generally provided by the landowner or land manager. Many of our study locations were located on land owned by public agencies, because records on past management history were generally available and the managing agencies were interested in cooperating on the project. To avoid sampling bias, we selected study locations without regard to the presence of recruitment or the occurrence of predictor variables.

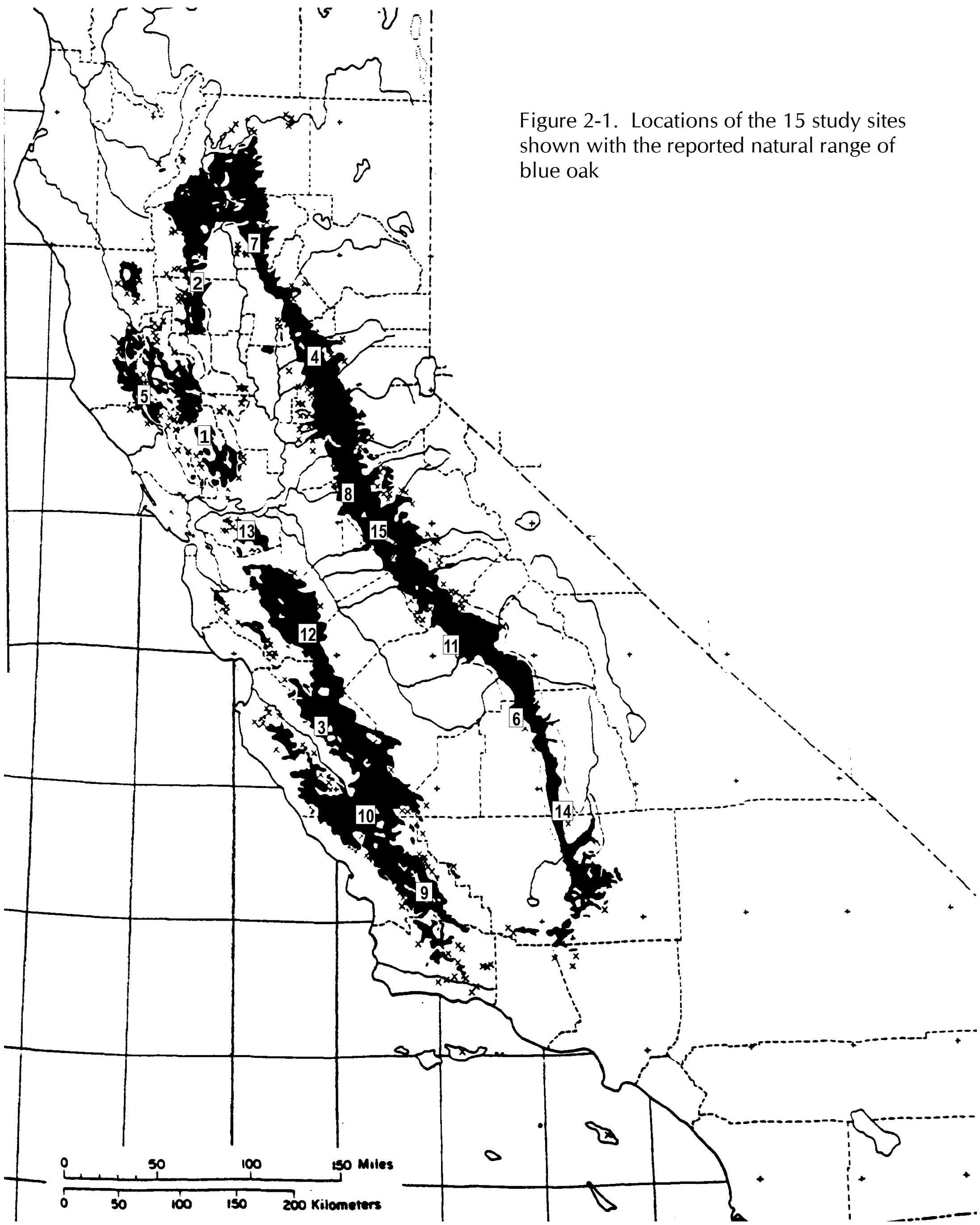


Figure 2-1. Locations of the 15 study sites shown with the reported natural range of blue oak

Distribution from Griffin and Critchfield 1976

TABLE 2-2. Geographic and ownership data for study locations.

Location number	Location name	Current ownership and/or management	County	UTM zone	Average UTM easting (m)	Average UTM northing (m)
1	Wantrup Wildlife Sanctuary	Napa County Land Trust	Napa	10	554735	4271282
2	Black Butte Lake	U.S. Army Corps of Engineers	Glenn	10	553292	4404768
3	Pinnacles National Monument	National Park Service	San Benito	10	662932	4039382
4	Sierra Foothills Research and Extension Center	University of California	Yuba	10	647587	4350115
5	Hopland Field Station	University of California	Mendocino	10	494389	4317874
6	Sequoia-Kings Canyon National Park	National Park Service	Tulare	11	334333	4039574
7	Dye Creek Preserve	The Nature Conservancy	Tehama	10	582836	4441652
8	Pardee Reservoir	East Bay Municipal Utility District	Amador	10	688662	4238956
9	Pozo	Private ranch	San Luis Obispo	10	753536	3901888
10	Lake San Antonio	Monterey County Parks Department	Monterey	10	685169	3965153
11	Hensley Lake	U.S. Army Corps of Engineers / Private ranch (2 parcels)	Madera	11	244071	4114370
12	Henry W. Coe State Park	California Dept. of Parks and Recreation	Santa Clara	10	631037	4115335
13	Mt. Diablo State Park	California Dept. of Parks and Recreation	Contra Costa	10	594691	4196788
14	California Hot Springs	Private ranch	Tulare	11	346852	3972446
15	Jamestown	Private ranch	Tuolumne	10	728713	4198291

Plot selection

The selection of individual plots was based on a random-origin systematic sample. Within each study location, we used aerial photography, vegetation cover maps, and topographic maps to determine which portions of the location had sufficient amounts of blue oak cover type. We selected a random point from within the eligible portion of each study location, and superimposed a sampling grid over a map of the location beginning at the random origin coordinates. A predetermined set of rules (Appendix 1) was used to position the sampling grid. These rules ensured that the grid was positioned in such a way that at least 100 eligible plots could be located in an area approximately 1520 m by 900 m. We subsequently photocopied the position of the grid onto a topographic map of the location and calculated the UTM coordinates of the starting point.

Circular 16 m radius (0.08 ha=0.2 acre) fixed-area plots were located at 80 m intervals along parallel transects spaced 100 m apart. This pattern provides for a minimum interplot spacing of 48 m and an approximate sampling density of one plot per 0.8 ha (2 acres). We conducted a preliminary survey to determine an appropriate plot spacing, and selected this sampling density in order to minimize the possibility that recruitment in one plot would directly affect the likelihood of recruitment in an adjacent plot.

We established an additional set of rules for determining the eligibility of individual plots in the field (Appendix 1). Plots were considered ineligible for sampling if they were more than 80 m from the nearest blue oak. This rule was used to minimize sampling in areas that were beyond the blue oak stand. We attempted to sample all 100 plots in a contiguous block containing five transects of 20 plots each (1520 m × 400 m = 61 ha). If ineligible or inaccessible plots were encountered in this portion of the grid, plots in additional transects were sampled. Deviations from the target sample size occurred only at locations 3 (99 plots) and 4 (101 plots). In the field, we navigated between plots using a compass and an optical rangefinder, and ground positions were verified through the use of topographic maps, aerial photos, and a portable Global Positioning System (GPS) receiver operating in autonomous mode (without differential correction).

Outcome variables

Each blue oak sapling within each sampled plot was counted and classified by each of the following criteria:

- sapling size class - S1, S2, or S3 (Table 2-1);
- position relative to the overstory canopy - open (beyond influence of canopy shade), edge (slightly inside or outside of the canopy edge and subject to partial shading), or canopy (directly beneath canopy);
- origin category - seedling-origin or sprout-origin.

Since basal resprouting may occur repeatedly during seedling and sapling stages (McClaren and Bartolome 1989, Swiecki et al 1990), we defined the stump sprout category as saplings arising from stumps or topkilled trees with a basal diameter of at least 8 cm.

We recorded the presence and abundance of S0 seedlings (Table 2-1), using a count class scale (1-10, 11-20, 21-30, 31-40) rather than direct counts.

Predictor variables

We recorded data on soil, vegetation, vertebrate impacts, and topography in each plot and made further observations to supplement management history information. A complete list of the predictor variables assessed within each plot, and other compiled and calculated variables is shown in Appendix 2. Plot data assessments were normally based on characteristics and factors found within each plot. However, in the case of browsing variables, the rating was occasionally based on vegetation located adjacent to the plot if there was no woody vegetation within the plot.

Clear day potential solar radiation (insolation) was calculated from slope, aspect, altitude, and latitude data using a program provided by Dr. Tom Rumsey (Department of Biological and Agricultural Engineering, University of California, Davis) based on the Hottel estimation model in Duffie and Beckman (1991). Information on soil types and depths were obtained from published soil survey data for most locations. Unpublished soil survey data were obtained for locations 6 and 9. Field observations on soil depth, texture, and rockiness were used in conjunction with soil survey data to estimate the total soil available water-holding capacity for each plot, as described in Appendix 2.

Site environmental variables were gathered from a number of sources. Rainfall data were compiled from the nearest official or unofficial weather station(s). Reference evapotranspiration (ETo) was calculated from published data (Pruitt et al 1987).

We obtained management and fire history for each study location from the current and sometimes former landowner or manager. The quality of this data varied from location to location, as land ownership and management had changed in some instances. Additionally, only a few of the locations had written records of past management practices. We gathered management history on grazing practices, clearing, and range improvement, although range improvement history was sketchy at most locations. Fire history was based on fire maps in some locations, and on the recollections of the landowner or manager in others. Fire histories were cross-checked against records in the California Department of Forestry and Fire Protection Historical Fire Database and fire reports. In some cases, we used historical aerial photographs to verify clearing history data. Although we had intended to standardize all of our history data to cover the 30 years prior to 1992, it was necessary to extend our clearing history interval back to 1950, due to uncertainty about the date of tree cutting at location 1.

Variables such as slope, altitude, and rainfall were scored as continuous variables, i.e., variables that may take any value within a range. Topographic position, browsing intensity and a number of other factors were scored as categorical variables, which can only assume a limited number of discrete values. For a few factors, only the presence or absence of the factor within the plot was noted, for example, whether fire scars were present. These are referred to as binary variables, which are essentially categorical variables with only two levels.

Ecological observations

Miscellaneous plot observations were noted on the data sheets. In addition, we recorded our overall observations in a written narrative after completing data collection at each location. These notes and narratives are the source of the observations presented below in Section 3.

Statistical analyses

Our original plot data set included over 90 variables, including 20 possible outcome variables. We initially constructed contingency tables to help identify those predictor variables which might be related to the outcome variables and reduce the high number of predictor variables to a practical level. We also screened predictor variables to identify and eliminate variables which were highly correlated with each other, and those which did not vary sufficiently to be included in the analysis. Outcome variables were screened similarly, and only selected outcomes were included in statistical analyses.

The effects of history and environmental variables on recruitment were analyzed via logistic regression, using several software packages. For the binary outcome variables (yes/no outcome), we fit the data to a logistic regression model. The parameters obtained from this type of model are odds ratios.

The odds ratio is the odds of an outcome given one level of a factor divided by the odds of an outcome given another level of that factor. Mathematically, this can be expressed as follows:

$$\text{odds ratio} = \frac{\text{odds}(\text{success}|x_1)}{\text{odds}(\text{success}|x_2)}$$

where x_1 and x_2 are two different levels of the factor x. The odds of success given x is the probability of success given x divided by the probability of failure given x, that is:

$$\text{odds (success}|x) = \frac{P(\text{success}|x)}{1 - P(\text{success}|x)}$$

If the odds ratio is **greater than one**, an outcome is **more likely** at level x_1 than at level x_2 of the factor x. If the odds ratio is **less than one**, an outcome is **less likely** at x_1 than at x_2. An odds ratio of one would indicate the levels of the factor being compared have no effect on the outcome variable. In our analyses of **categorical** variables, the lowest level of a factor is used as the basis of comparison to each of the higher levels. For instance, effects of canopy cover class are based on comparisons between the lowest canopy cover class and each of the higher classes. For continuous variables, the odds ratio is based on each increment of the continuous variable, for example, per foot increase in elevation. In this example, the odds ratio for n feet of elevational change would be the per foot odds ratio raised to the power n. Since **binary** predictor variables have only two levels, (e.g. a plot either has or hasn't been burned in the past 30 years), the odds ratio indicates whether a factor has any effect on an outcome.

An odds ratio much higher than one indicates that a factor has a strong positive effect on an outcome. An odds ratio much smaller than one (i.e., the reciprocal is a large number) indicates that a factor has a strong negative effect on a factor. Confidence intervals are calculated and shown for all odds ratios reported from our analyses. The interpretation of the parameters associated with the regression models is explained in greater detail in the Section 5.

For outcome variables that consist of counts, such as the number of saplings per plot, data were fitted to a Poisson model. In this type of model, the parameters can be interpreted as rate ratios. The rate ratio is the probability of an outcome given one level of a factor over the probability of an outcome given a second level of the factor, that is:

$$\text{rate ratio} = \frac{P(\text{success}|x_1)}{P(\text{success}|x_2)}$$

The interpretation of rate ratios is similar to that of odds ratios, and if an outcome is rare, the odds ratio and rate ratio are approximately equal. For binary variables, a rate ratio greater than one indicates that the outcome is more likely in the presence of a factor than in its absence. For example, a rate ratio of 2 for the binary factor x would indicate that the outcome is twice as likely to occur when x is present than when it is absent. A rate ratio equal to one results when the outcome and the factor under study are unrelated. The rate ratio is less than one if the outcome is less likely in the presence of a factor. For **categorical** variables, the rate ratio is calculated to indicate whether an outcome is more or less likely at the lowest level of the factor compared to each other level of the factor. For **continuous** variables, the rate ratio indicates the change in probability per unit increase (e.g. per foot of altitude).

All models were constructed using a stepwise procedure. Factors were generally considered for entry into the multivariate models if odds ratios or rate ratios from single variable models were significant at $P \leq 0.10$, but some variables which were nonsignificant in the single variable models were also tested in multivariate models. The reported significance level of each factor is dependent upon the other factors which are in included the model. Therefore, the significance level of each factor reported in the final models should be interpreted as if it were the last factor added to the model.

The ratio of the model deviance to the total model degrees of freedom was used to evaluate overall model fit, where a ratio of one indicates a good overall fit. In addition, for the final models with the ALLRECR outcome at locations 1, 3, 4, and 15, we computed the probability of recruitment for each plot predicted by the model. The probability is calculated from the following formula:

$$P(\text{ALLRECR}|\text{model}) = \frac{e^{\mu}}{1 + e^{\mu}}$$

where:

$$\mu = \beta_0 + \sum x_i \beta_i$$

and:

β_0 is the coefficient for the general mean or intercept,
x_i is the level of the predictor variable i within the plot, and
β_i is the coefficient for variable i, which is equal to the natural logarithm of the odds ratio.

Comparisons of predicted and observed recruitment are tabulated and presented graphically on location maps. For these comparisons, we designated that recruitment was predicted by the model if the calculated probability of recruitment was ≥ 0.5.

3. SITE CONDITIONS AND RECRUITMENT AT THE STUDY LOCATIONS

Descriptions of the site conditions and the status of sapling recruitment at each of the study locations are presented below. These descriptions are based on plot data, information compiled from other sources, and our recorded field observations.

The location descriptions are presented in the chronological order in which we surveyed the locations. Except as otherwise noted, site histories are for the 30 year period from 1962 to 1992. Authors for scientific names of trees and shrubs are listed in Appendix 2. A listing of the soil series mapped at each location is presented in Appendix 3. Numbers presented for grazing intensity are approximations of stocking levels based on average stocking rates. Cow-calf pairs are counted as 1.5 animals for these calculations. To the extent possible, hardwood cover types were assigned to each location using the descriptions in Allen et al (1989).

1. Wantrup Wildlife Sanctuary (Napa County)

Survey dates: 7/17, 7/19, 7/21, and 7/24/92

The study area is located within the Wantrup Wildlife Sanctuary at the southern end of the Pope Valley. The northern portion of the study area is part of the 1842 Locoallomi land grant to the Pope family, which originally settled the area. The land grant was later divided and homesteaded until about the turn of the century. Over the past century, the hillside land where the study plots were located has been used for sheep and cattle grazing, and as a source of wood. The property was acquired in about 1961 and held as a private ranch by one owner. In 1982, the land was deeded to the Napa County Land Trust and has since been managed as a wildlife sanctuary.

Since this was our first study location, we made some slight adjustments to our sampling design and data collection procedures during the initial phase of data collection at this location. This resulted in a more irregular plot distribution at this location (Figure 5-1) than at subsequent locations.

Physical environment: The study area was located on the northeast-facing slopes of the hills that rise above the southwest side of the valley. The study area transects ran from just above the floor of the valley to almost the top of the slope, encompassing an elevational difference of almost 300 m (Table 3-1). Most plot aspects were to the north and northeast, and most slopes were moderate to steep. There were 28 plots with slopes greater than 30%. Insolation values for the plots are normally distributed around a relatively low average (Appendix 4, Table 3-1). Average precipitation is relatively high and ETo is somewhat reduced by a moderate coastal influence, resulting in a low overall ET deficit (Table 3-2). Soils at this location are moderately deep silt loams and silty clay loams, and most plots had moderate to high available water-holding capacities (AWHC) (Table 3-2, Appendix 3).

Fire: No wildfires have occurred in the last 30 years or more. Fire scars were seen on trees in nine plots, and are probably related to burning of brush following clearing, and possibly earlier fires.

Clearing: Wood cutting at the ranch has been intermittent. In 37 plots, no trees have been cut for at least the past 30 to 40 years. Fourteen plots were cleared sometime between 1970 and 1979, and 49 plots were cleared prior to 1970 and possibly as early as 1950, but the exact date or dates is unknown. There were several older clearings within the study area, as well as some dense areas of small diameter trees that may have been recruited following earlier cutting.

TABLE 3-1. Characteristics of the physical environment of plots at the study locations.

Location	Average altitude (m)	Altitude range (m)	Average December average day insolation (MJ/m^2)	Average total annual insolation (MJ/m^2)
1	302	293	6.99	6354
2	165	61	7.51	6487
3	502	342	9.40	6857
4	457	152	7.77	6698
5	521	207	10.22	7332
6	569	244	10.71	7391
7	327	91	7.62	6636
8	233	85	8.75	6870
9	604	85	10.70	7310
10	311	103	9.82	7096
11	221	110	9.53	6999
12	648	439	8.60	6788
13	242	122	7.58	6348
14	855	268	12.36	7809
15	423	88	8.52	6883

TABLE 3-2. Selected precipitation, evapotranspiration, and soil available water holding capacity (AWHC) data for the study locations.

Location	Average precipitation 1962-1992 (cm)	Minimum 2-year rainfall total, 1962-1992 (cm)	Estimated ETo (cm)	ET deficit (cm)	Estimated plot soil AWHC ≥10 cm (% of plots)
1	82.85	76.78	116.9	34.05	65%
2	51.69	66.34	127	75.31	52%
3	42.34	65.74	120.47	78.13	0%
4	70.25	75.16	128.78	58.53	64%
5	93.17	109.63	103.3	10.13	47%
6	65.95	85.55	123.48	57.53	8%
7	56.61	74.68	129.38	72.77	9%
8	55.74	58.9	126.64	70.9	14%
9	52.91	68.45	124.29	71.38	84%
10	37.49	46.36	120.82	83.33	83%
11	27.06	39.83	129.71	102.65	60%
12	65.02	80.52	115.88	53.22	71%
13	45.84	48.49	119.17	73.33	51%
14	69.47	101.3	119.64	50.17	56%
15	79.25	99.97	122.5	43.25	78%

Range improvement: Some cleared areas were seeded with Harding grass (*Phalaris aquatica* L.) between 1962 and 1982.

Grazing: In the past 30 years, the study area was grazed during two discrete periods. From 1968 through 1971 cattle were grazed year-round at 1.7 animal-months/acre/year. From spring 1982 to spring 1985 horses were grazed year round at 0.4 animal-months/acre/year.

Herbivores: Evidence of small burrowing animals (gophers and possibly moles) was present throughout the study area wherever blue oak/grass was the predominant cover type, but was generally lacking in areas with heavy canopy and leaf litter. Ground squirrels occurred at the lowest elevations of the study area. Deer were plentiful in the area and wild pigs have recently moved into the area.

Vegetation type: The floor of Pope Valley just north of our study area was dotted with valley oaks (*Q. lobata*). Blue oak predominated at the lower elevations above the valley floor. Blue oak density was fairly high overall (Table 4-12), and several rather dense patches were present in the study area. At higher elevations, foothill pine (*Pinus sabiniana*), black oak (*Q. kelloggi*), California buckeye (*Aesculus californica*), coast live oak (*Q. agrifolia*), and California bay (*Umbellularia californica*) were common. California bay was most common along drainages. In 24 of the plots, blue oak was the only tree species (Table 3-3); 67 plots had two or more tree species, and five plots had six tree species present. The full range of canopy cover was represented, from open (3 plots) to closed canopy (6 plots), but average canopy cover was relatively high (Table 4-12). Canopy cover was greater than 50% in 46 plots. The cover type at the lowest elevation is blue oak/grass, but at upper elevations the vegetation does not correspond well to any of the Allen hardwood range cover types.

Fifty two percent of the plots contained shrubs, but shrub cover was greater than 20% in only one plot. The most common shrubs were poison oak (*Toxicodendron diversilobum*) and manzanita (*Arctostaphylos manzanita)* (Table 3-4), and few plots had more than two shrub species. The herbaceous layer was generally fairly dense, and residual dry matter levels were high. Annual grasses predominated in many of the more open areas, with dense stands of Harding grass, wild oat (*Avena fatua* L.), and medusa head (*Taeniatherum caput-medusae* (L.) Nevski) dominating in different areas. Native bunchgrasses, including California fescue (*Festuca californica* L.) and purple needlegrass (*Nassella* (=*Stipa*) *pulchra* (A. Hitchc.) Barkworth) were common throughout the study area (Table 3-4), and attained fairly high cover values in a few plots.

TABLE 3-3. Occurrence of common canopy tree species at each location.

	Percent of plots with tree species								
Location	*Quercus douglasii only*	*Q. douglasii*	*Q. agrifolia*	*Q. wislizenii*	*Q. lobata*	*Q. kelloggii*	*Pinus sabiniana*	*Umbellularia californica*	*Aesculus californica*
1	24%	82%	21%		9%	36%	36%	20%	39%
2	85%	85%							
3	35%	78%	5%				47%		5%
4	6%	88%		76%	1%	8%	68%		2%
5	30%	76%	39%	6%	13%	7%		9%	12%
6	29%	99%		50%					34%
7	80%	86%		1%					5%
8	58%	80%		11%			18%		4%
9	61%	83%	22%		4%				
10	35%	86%	11%		7%				
11	65%	66%		3%					
12	4%	81%	44%		35%	58%	41%	33%	9%
13	35%	82%	13%	2%	17%		19%	1%	26%
14	31%	94%		50%	4%		1%	3%	49%
15	19%	67%		52%	5%		15%		

TABLE 3-4. Overall occurrence of shrubs and occurrence of common shrub species and native bunchgrasses at each location.

	Percent of plots with species						
Location	Any shrub species	*Arctostaphylos* spp.	*Rhamnus ilicifolia*	*Toxicodendron diversilobum*	*Ceanothus cuneatus*	*Heteromeles arbutifolia*	Native bunchgrass species
1	52%	38%		19%		11%	58%
2	2%		2%				1%
3	85%		23%	5%	21%	3%	62%
4	83%	7%	18%	73%	18%	6%	51%
5	23%	15%		3%		5%	61%
6	79%	50%	52%	8%	19%		2%
7	16%	1%	5%	4%	9%		5%
8	12%	1%	1%	7%	2%	1%	1%
9	23%	6%	5%	13%			49%
10	77%	6%	42%	2%	8%	24%	60%
11	3%						1%
12	80%	58%	8%	18%		1%	89%
13	44%	6%	27%	15%		12%	13%
14	44%		12%		29%		32%
15	50%	14%	10%	37%	9%	4%	1%

Regeneration: This location had the highest total number of blue oak saplings (Figure 4-2) and the greatest density of blue oak saplings per plot, due to high numbers of saplings in a number of plots. One single plot had over 30 S0 seedlings, 199 S1 saplings, one S2 sapling, and seven S3 saplings. Among seedling-origin saplings, only 1.7% (13/751) of the S1 class were dead, and none in the S2 or S3 classes were dead. In contrast, of the 15 sprout origin saplings tallied, six (40%) were dead.

Saplings occurred almost exclusively in plots in which trees had been cut, but not all previously cut plots contained saplings (Table 3-5). No recruitment was observed in an area in the mid-elevation portion of the study area that had been cleared and seeded to Harding grass, or in several other small clearings. Dense sapling recruitment was mostly limited to the lowest elevation portions of the study area, at altitudes that were only 70 to 100 m above the adjacent floor of Pope Valley. Recruitment at higher elevations generally consisted of one to a few saplings per plot. Almost all sapling recruitment was of seedling origin (Figure 4-2), even though it was found in areas that had been cut. Most blue oak stumps were cut low to the ground and were typically rotted.

We observed several dense patches of apparently even-aged, small diameter blue oak trees that appeared to have regenerated following a much earlier cutting. One such area was at a low elevation, close to the area of dense sapling recruitment. Another dense patch of small diameter trees was located at a higher elevation, adjacent to a clearing seeded with Harding grass.

Because sapling distribution was highly clumped, there were fewer plots with increases in blue oak density due to recruitment than there were plots which lost density due to mortality (Figure 4-7). The level of natural mortality at this location was relatively low (Table 4-12), but mortality may have been underestimated because of past cutting and removal of dead trees.

Wood decay and canker rot symptoms are common in mature trees throughout the site, and we observed a fruiting body of *Inonotus dryophilus* (Berk.) Murr. We also observed one likely root disease center.

We did not observe many small seedlings overall. We had established two blue oak seedling study plots within the study area in 1988 (Swiecki et al 1990), one at a low elevation, in the area where recruitment was common, and one at a higher elevation where recruitment was sparse. In June 1993, five years after natural seedlings were tagged, seedling survival was 83% at the low elevation plot and 72% at the upper elevation plot. Most seedlings at both plots had not grown appreciably, and most were less than 15 cm tall. Two seedlings at the lower plot, one at canopy edge and the other in the open, were large enough to be classified as S0 seedlings.

Since this was our first site, we recorded few observations about regeneration by other species. However, we did note the occurrence of seedling and young manzanita at the lowest elevation in the same area where blue oak saplings occurred, and some valley oak and blue oak saplings are present in the field north of the study area. Sapling-sized regeneration of foothill pine, toyon (*Heteromeles arbutifolia*) and California bay was also seen, especially at higher elevations.

TABLE 3-5. Distribution of saplings among previously cleared and uncleared plots at Location 1.

Year(s) when trees were cut	Number of plots	Live seedling-origin S1-S3 saplings (% of plots)	Live seedling-origin recruitment (S0-S3) (% of plots)
None or prior to 1950	37	3%	5%
Between 1970-1979	14	36%	57%
Between 1950-1970	49	51%	57%

2. Black Butte Lake (Glenn County)

Survey dates: 7/29-7/31/92

In the 1850's two pioneer families settled near the study area and built up large herds of sheep and cattle. The area was primarily used as sheep range at least until the 1950's. The study area is located on land managed by the Army Corps of Engineers, which operates Black Butte Lake. All plots are located within the wildlife area on the western shore of the lake, south of the Burris Creek arm. The reservoir was formed after a dam was built on Stony Creek west of Orland. Construction of the dam was initiated in 1960 and water storage commenced in October 1963.

Physical environment: The study area was in a rolling hilly upland area dissected with steep drainages, but with little overall elevation change (Table 3-1). Plot slopes ranged from nearly level to moderately steep. Thirty-two plots had slopes of less than 15%, but an equal number had slopes greater than 30%. Plot insolation values are low to moderate overall, but slightly skewed toward higher values (Appendix 4). Site soils are gravelly loams which are moderately deep, but rooting depth may be inhibited in areas by claypans that may be present at a depth of only 20 to 50 cm. Estimated soil AWHC in the plots was low to moderate, ranging from 6 to 15 cm.

Fire: No fires have occurred in the last 30 years or more. We saw no fire scars on any of the trees.

Clearing: No known tree cutting has occurred within at least the past 30 years in most of the plots. Trees were cut in 3 plots in 1962 near the high pool level of the lake. There was also clearing of trees in one plot in 1978 associated with the construction of an earthen dam to form a cattle pond.

Range improvement: There have been various unrecorded range improvement efforts. Subterranean clovers are now widely established, and an introduced alien bunchgrass was found in some areas.

Grazing: The study area was reportedly used primarily for sheep grazing until some time in the 1950's, and was subsequently used for cattle grazing. No official grazing was conducted between 1960 and 1964 during the development of the reservoir, although some trespass grazing may have occurred during this interval. From 1965 to 1981, the area was grazed by cattle from October to May at an intensity of about 0.8 animal-months/acre/year. From 1982 to 1989, the area was grazed from November to the end of March at an intensity of about 0.4 animal-months/acre/year. Grazing was terminated in May 1989, when the area was designated as a wildlife area, and the area has not been grazed since.

Herbivores: According to W. Thornton, the area has a moderate summer resident deer population and a low winter migratory deer population. Rodent populations are relatively high in the area. Ground squirrels and jackrabbits were abundant throughout the area, and were especially common on the lower portions of slopes.

Vegetation: With the exception of one valley oak, the only tree species within the study area was blue oak. The cover type was uniformly blue oak/grass. Total canopy cover was relatively low. There were 53 plots with 20% canopy cover or less, and only 11 plots with more than 50% canopy cover. Stand density varied with topography. Average stand density on ridges and upper slopes (about 60 trees/ha) was less than half of that found along lower slopes and drainages (about 160 trees/ha).

The only shrubs seen in the study area were a couple of large, rather decadent manzanitas and two old and equally decadent redberry (*Rhamnus ilicifolia*). Only the latter occurred within plots. According to W. Thornton, shrub cover in the area was more extensive as late as the early 1960's, and included large stands of buck brush (*Ceanothus cuneatus* var. *cuneatus*), which have since died out. There is no record of recent efforts to specifically eliminate shrubs from the understory, and the loss of shrub cover appears to be a consequence of management practices, particularly grazing.

From the aerial photographs it appeared the canopies of existing oaks have grown in the last 40 years. Canopies are touching now that were separated in a 1953 aerial photo.

Regeneration: We saw no saplings of blue oak or any other woody species anywhere in the entire study area. No blue oak sapling recruitment resulted following clearing that occurred in 1962-63 along the lake shore at the high pool level. There was apparently earlier clearing, perhaps near the turn of the century, which did give rise to a flush of recruitment, visible today as pole sized trees and a few sprout-origin trees (Table 4-4). The dead stump was still evident at the base of some of these sprout origin trees. For the most part, this earlier episode of recruitment was confined to northerly aspects and lower slope positions. In some cases, this earlier regeneration appears to have arisen under the canopy or at the canopy edge of the few residual trees that were left at the time of clearing.

Based on counts of dead trees, natural mortality appears to be relatively low (Table 4-12), and due to a lack of recent fires or wood removal, this estimate is considered to be fairly reliable. This is further verified by a comparison between recent (1988) and 1953 aerial photos, which show very little tree loss. We observed the canker rot fungus *Inonotus andersonii* (Ellis & Everh.) Cerny within the study area, and we have also observed the root rot fungus *Ganoderma lucidum* (W.Curt.:Fr.) Karst. on blue oak near the study area.

A blue oak seedling observation plot was established just outside the study area in 1988 (Swiecki et al 1990), but was destroyed by ground squirrels before permanent markers could be installed. A second seedling plot located about 3 km south of the study area was resurveyed in July 1993, at which time only 6.5% of the seedlings tagged five years earlier were still surviving.

3. Pinnacles National Monument (San Benito County)

Survey dates: 8/12-8/14/92

The study area is located within Pinnacles National Monument, which was established in 1908. The study area is located east of the Pinnacle Rocks and north of Bear Gulch. Portions of the study area were added to the park between 1908 and 1930. La Soledad mission was established in 1791, at what is now Soledad, 15 km to the southwest. One homestead was located in the vicinity of the study area from around 1917 to around 1930. With the exception of human-initiated fires, the stand has been relatively undisturbed for the past 62 years.

Physical environment: Terrain at this location is very rugged. Most of the plots were located on south-facing slopes and a small plateau area, but some plots had northerly aspects. There were many plots with high insolation values, but also a fair number of plots with moderate to low insolation values (Appendix 4), so that the overall insolation averages for this location were moderate (Table 3-1). This is one of the most xeric study locations due to low rainfall and high ETo (Table 3-2). Soils at this location were typically very rocky, shallow, and coarse textured, resulting in low calculated AWHC values. All of the plots had estimated soil AWHC of 10 cm or less (Table 3-2), and 80 of the plots had AWHC of 5 cm or less. However, trees may obtain water from roots that penetrate fissures in the fractured granite bedrock.

Fire: There were more recent fires here than at any of the other locations. Most wildfires in the study area originated near park roads or trails. Thirteen plots have burned three times in the past 30 years, in 1977, 1979, and 1982. Thirty-four plots burned in 1979, three plots burned in 1981, one plot burned in 1982, two plots burned in both 1977 and 1979, and 24 plots burned in both 1979 and 1982. Twenty-two plots have not burned since at least 1931. Fire scars were seen on trees in 54 plots.

Clearing: No substantial wood cutting has occurred since the park was established. Frequent fires in the study area would have obliterated old stumps from any earlier clearing that may have occurred. Some trees have evidently been cut near the roads, trails, buildings, and under a power line. There were a few sprout-origin blue oaks near the main road.

Range improvement: None since the park was established.

Grazing: There has been no livestock grazing since the park was formed. Grazing history before that is unknown, but some seasonal grazing may have occurred.

Herbivores: Deer are common in the area. Browsing damage was generally moderate to high. Although the browse line was fairly strong, unbrowsed growth below the browse line could sometimes be seen. Saplings (S1) were clearly being browsed down, more severely in some areas than in others. Rodent populations were relatively low overall, but some areas had high levels of rodent activity. Ground squirrels, gophers, and mice appeared to be the most common rodents.

Vegetation: The study area was a mosaic of different vegetation types. In many areas the blue oak woodland comes to the fringe of chamise (*Adenostoma fasiculatum*) chaparral, mixed chaparral, or open grasslands. Some areas that are now grassland could previously have been blue oak stands. The boundaries between the chaparral and blue oak woodland were generally quite distinct, although trees were occasionally found at the edge of the chaparral or intermingled in sparse to moderately dense chaparral. In 35% of the plots, blue oak was the only tree species, and foothill pine was the most common tree associate (Table 3-3). Blue oak density was lower than at many of the other locations (Table 4-12). Total canopy cover was less than 20% in 26 plots, and only eight plots had more than 50% canopy cover. The predominant cover type is blue oak—foothill pine/grass.

Eighty-five percent of the plots contained shrubs (Table 3-4) and 27 plots had shrub cover ranging from 20% to 80%. Many different shrub species were present, with up to eight species tallied in a single plot. In addition to those shown in Table 3-4, shrubs found at this location included chamise, California sagebrush (*Artemesia californica*), birch-leaf mountain-mahogany (*Cercocarpus betuloides* var. *betuloides*), yerba santa (*Eriodictyon tomentosum)*, California buckwheat (*Eriogonum fasiculatum*), California juniper (*Juniperus californica*), and black sage (*Salvia mellifera)*.

Wild oat (*Avena barbata* Link, *A. fatua*) was a major component throughout the grasslands. There was very little medusa head or ripgut brome (*Bromus diandrus* Roth). Various bunchgrass species were common, but usually had relatively low cover values.

Regeneration: Although the blue oak stand at this location is rather limited in extent, it appears to be viable due to at least moderate levels of regeneration. All of the saplings were of seedling origin, and this location had the highest proportion of plots with seedling-origin saplings (Table 4-1). Sapling mortality among these seedling-origin saplings was higher than at location 1: 7.8% (14/153) of the S1 saplings and 12.5% (3/24) of the S2 and S3 saplings within plots were dead. Other woody species, including foothill pine, also appeared to be successfully regenerating at this location.

Recent repeated fires had clearly influenced regeneration of blue oak and other woody species. Based on field observations and aerial photographs, it appeared that fires have eliminated some patches of chamise and other chaparral shrubs. Fire also seems to have suppressed the transition of blue oak saplings from S1 to S2 or S3. In areas that burned more often, S0 seedlings and S1 saplings were fairly common, but S2 and S3 saplings were rare (Table 3-6). Browsing by deer is also a factor here, and its effects may interact with fire effects. Browsing by deer may significantly slow regrowth following fire, and browse-stunted saplings may be more susceptible to topkill by fire. In addition, growth rates are likely to be slow at this location due to the xeric conditions, except in areas along drainages that obtain additional water from runoff.

TABLE 3-6. Occurrence of seedling-origin recruitment in plots at Location 3 which have been burned various numbers of times between 1977 and 1982.*

Number of fires	Number of plots	Percent of plots with live seedlings or saplings				
		S0	S1	S2	S3	S0-S3
0	22	41%	32%	9%	4%	50%
1	38	42%	50%	10%	16%	71%
2	26	12%	27%	0	0	31%
3	13	15%	31%	0	8%	46%

* Prior to these fires, plots had last burned in 1931.

Saplings were commonly found in gaps formed through tree mortality (Table 3-7). Several clear examples were seen where a dead mature tree was surrounded by S1 saplings around the former canopy edge. Some recent gaps were probably not detected, because fires may have consumed dead trees. On occasion, saplings were also seen under the canopy of foothill pine. Some of this may represent colonization of new sites due to acorn dispersal by birds, such as scrub jays, or rodents.

TABLE 3-7. Occurrence of saplings in plots with or without gaps at location 3.

Recent (30 year) gap present in plot	Number of plots	Live seedling-origin S1-S3 saplings (% of plots)
No	61	34%
Yes	38	50%

More plots showed an increase in blue oak density than a decrease (Figure 4-7). Mortality of young and mature blue oak trees was only slightly higher than at the two previous locations, at 5.1% (Table 4-12). Estimated mortality is probably low for this location, due to the likely destruction of dead trees by fire in many areas. Much of the blue oak mortality is also probably associated with fire, although disease and drought probably interact with fire. Typical canker rot symptoms were not common on blue oak, but evidence of wood decay was common, and trees in some areas appeared to be affected by root-decay fungi.

4. Sierra Foothills Research and Extension Center (Yuba County)

Survey dates: 8/17-8/18, 8/20-8/21/92

The area was apparently settled around the time of the gold rush and homesteaded through the early 1900's. By the 1940's or 1950's, separate parcels had been consolidated under one owner. An old stagecoach route passed through the area, and we found a long rock wall, a couple of small excavations, and various old clearings within our study area. The University of California acquired the land and established the experiment station in 1960. Our study area was located in parts of several fields in the northwestern portion of the station.

Physical environment: Much of the study area was located on moderate west- and north-facing slopes. Two relatively flat plateaus were also found within the study area. There were very few plots with strong southern exposures. Most plots had rather moderate insolation values, resulting in moderately low average insolation values (Table 3-1). Although ETo is relatively high, rainfall is higher than at many of our other Sierran foothill locations (Table 3-2). A number of intermingled soil types are present in the study area but the majority of all plots were rated as having low to moderate soil AWHC. The soils are mainly well-drained loams, but vary in depth and rockiness (Appendix 3).

Fire: There have been no wildfires in the area for more than 30 years, but 33 plots had fire-scarred trees.

Clearing: Four different clearing histories were identified. Eighty five plots have not been cleared since before 1960 at least. Trees less than 30 cm dbh were felled in eight plots in 1989. Three plots were in an area along a fence line that was cleared with a tractor in 1965, and five plots were located in an area where ponderosa pine was logged in about 1960.

Range improvement: Subclovers have apparently been seeded in many areas, but the exact timing and location of specific range improvement activities is unknown.

Grazing: The area has been grazed by cattle for an extended period. Prior to 1953 and back into the 1940's at least, the area was used for winter grazing (October through May) and managed as a unit. Between 1953 and 1958, summer grazing (June-August) was added to the winter grazing regime. Beginning in 1958, the October through May grazing regime was resumed, at an average stocking rate of one animal per 10 to 13 acres (about 0.6 to 0.8 animal-months/acre/year). Since the station was established, stockers have generally been grazed in the study area. The most recent grazing regimes within the study area are summarized in Table 3-8.

TABLE 3-8. Recent grazing histories at location 4 (Sierra Field Station).

Grazing regime	Number of plots	Cumulative grazing score*	Grazing history	
1 (Natural area)	23	90	1960-1971 June-August light stocking rate	1972-1992 no grazing
2	60	326	1958-1977 0ct-May 0.7 animal-months/acre/year	1978-1992 June-August 0.13 animal-months/acre/year
3	18	340	1958-1977 0ct-May 0.7 animal-months/acre/year	1978-1992 0ct-June 0.4 animal-months/acre/year

* This is calculated as shown for the variable CUMGRAZE in Table 5-1.

Herbivores: The deer population has reportedly dropped over the time that the station has been in existence, and is reported to be low now. Browsing evidence, particularly in the nongrazed area, supports this observation. Both deer and cattle browsing now are generally moderate to light in most areas, with only a few areas showing heavy current use. Stubby saplings in some plots attest to periods of heavier browsing in the past. Interior live oak (*Q. wislizenii*) saplings generally appeared to be less heavily browsed than the blue oak saplings, suggesting that cattle and/or deer may prefer blue oak over live oak.

Vegetation type: Much of the study area would be classified blue oak−interior live oak/grass cover type, but a number of cover types were represented in the study area. Only 6% of the plots contained blue oak as the only tree species. Live oak and foothill pine were common associates in many areas, and some areas were dominated by nearly-impassable thickets of sprout-origin interior live oak. Ponderosa pine (*Pinus ponderosa*) was a major component on the north face of one hill in the study area, and black oak was common on some north-facing slopes. Valley oak was rarely observed (Table 3-3).

Shrubs were found in 83% of the plots (Table 3-4). Shrub cover was greater than 20% in only 10 plots. Shrub species diversity was moderate, and 16 plots had three or more species present. Poison oak, coffeeberry (*Rhamnus californica)*, redberry, and buck brush were common. Poison oak had become especially dense in the areas that had been cut in 1989 and 1960. Native bunchgrasses, including *Elymus glaucus* Buckley are common in some areas, but introduced annual grasses predominate in the herbaceous layer. Herbaceous vegetation was variable, and the composition in the nongrazed area differed from that in the currently-grazed fields (Table 3-9).

TABLE 3-9. Seedling-origin recruitment and other characteristics of plots within different grazing regimes at location 4.

Grazing regime*	Number of plots	Live seedling-origin S1-S3 saplings (% of plots)	S0 seedlings (% of plots)	Native bunchgrass (% of plots)	Average blue oak canopy class	Average total canopy class
1	23	61%	35%	83%	3paradox.17	3.91
2	60	30%	22%	53%	2.28	3.52
3	18	39%	11%	6%	2.28	2.94

* See Table 3-8.

Regeneration: The total amount of sapling recruitment at this location was similar to that at location 3 (Tables 4-1, 4-6; Figures 4-1, 4-2). However, in contrast to location 3, about a quarter of the saplings at this location originated as stump sprouts (Figure 4-2, Table 4-4). All of these were found in the area in which small to moderate diameter (<30 cm) blue oaks were cut in 1989 (Table 3-10). About 7% (3/43) of these young sprout-origin saplings were dead. Mortality was higher among seedling-origin saplings, most of which were likely to be much older than the sprout saplings. Twenty percent (26/127) of the S1 and 14% (3/21) of the S2 and S3 seedling-origin saplings counted were dead.

TABLE 3-10. Occurrence of saplings in plots with different histories of tree cutting at location 4.

Year(s) when trees were cut and type of clearing	Number of plots	Live sprout-origin S1-S3 saplings (% of plots)	Live seedling-origin S1-S3 saplings (% of plots)	Live seedling-origin recruitment (S0-S3) (% of plots)
None or prior to 1960	85	0%	36%	42%
1960 (ponderosa pine harvest)	5	0%	80%	80%
1965 (fence line clearing)	3	0%	33%	67%
1989 (blue oak harvest)	8	88%	38%	38%

Seedlings and saplings were more common in the ungrazed natural area than in the grazed pastures (Table 3-9). Both seedling- and sprout-origin saplings were commonly associated with cutting (Table 3-10). There were a few instances where blue oak saplings were clearly coming up in gaps created by the death or removal of a mature blue oak, but saplings were also found in situations where such dynamics were not obvious. As noted at location 3, blue oak saplings were sometimes found beneath foothill pine canopy, or in gaps created by foothill pine mortality.

A few blue oak saplings were also found in the area where ponderosa pine had been logged around 1960. The lack of overstory blue oak in this area suggests that blue oak may be invading this area after the disturbance. The ponderosa pine had not regenerated well in this area, which had become dominated by tall shrubs. We saw regeneration of many of the other woody species throughout the study area.

The stand showed evidence of past episodes of regeneration, at least some of which were apparently associated with clearing. Some old clearings (pre-1960) were still treeless or had only scattered trees, which may have been left during clearing or regenerated after clearing. Other areas had dense "doghair" stands, some of which had a few very large old residual trees. In these dense stands, many of the small suppressed trees in the understory were in poor condition, and appeared to be in decline.

Almost half of the plots at this location had sprout-origin blue oak trees, which made up 12% of all blue oak trees (Table 4-4). Multitrunked sprout-origin interior live oak trees were especially common throughout the study area. Many live oak branches had broken due an atypical snowfall in 1990.

As at Location 3, more plots showed a net increase in blue oak density than a decrease (Figure 4-7). Mortality was not especially high at this location (Table 4-12), possibly because the stand is relatively young overall and/or because site conditions are relatively mesic. Some of the oldest blue oak trees were in varying stages of decline. Some wood decay pathogens are present and active in the area. We noted *I. andersonii* in one plot, and *Laetiporus sulphureus* (Bull:Fr.) Boud. & Sing. and *G. lucidum* have previously been found at the station.

5. Hopland Field Station (Mendocino County)

Survey dates: 8/27/92-8/29/92

This area is historically a sheep grazing region. The area was originally homesteaded before the turn of the century, and the parcels were subsequently consolidated beginning around the 1930's. The field station was established by the University of California in 1951 primarily for sheep range research. The study area is located on the east side of the station, and includes portions of several pastures and the nongrazed Riley Ridge Biological Area.

Physical environment: The study area is located on the lower to middle slopes of the Mayacmas Mountains, east of the valley of the Russian River. Slopes were generally moderate, with the exception of some highly eroded drainages and the eastern end of the study area, which was located on Riley Ridge. The entire study area slopes to the south and west. Most plots had relatively high insolation values (Table 3-1, Appendix 4) due to the generally southerly exposures and moderate slopes. Although this was the location with the greatest annual precipitation and lowest annual ET deficit, many of the soils at this site are rather sandy and rocky and have low available water-holding capacities (Table 3-2).

Fire: Seventy-two plots have not burned at least since 1951. Twenty-three plots were located in an area which burned in a wildfire in November, 1959. Small controlled burns for range improvement were conducted in July, 1960 (3 plots) and September, 1979 (2 plots). We saw fire scars on trees in 26 plots, 15 of which were in the area that burned in 1959.

Clearing: Ninety-seven plots have not been cleared within memory. Most of the trees in one plot had been killed by herbicide injection in the 1950's and were subsequently cut down.

Two plots were in areas cut in 1989 for a study examining blue oak stump sprouting (McCreary et al 1991b).

Range improvement: Some portions of the grazed pastures have been seeded with subclovers and fertilized with phosphorus and sulfur in alternate years. The controlled burns were conducted to control medusa head.

Grazing: The study area has a history of sheep grazing extending back to at least the 1930's and probably to the turn of the century. Thirty of our plots fell within the Riley Ridge Biological Area, which has been excluded from grazing since 1957. The remaining plots were located in several different grazed pastures. Since 1951, when the ranch was acquired by the University, sheep have been rotated in and out of the pastures all year long, for periods of several weeks to several months at a time. On average, an individual pasture is typically grazed four months of each year. Stocking rates are usually moderate but are sometimes heavy, and average about 2.4 animal-months/acre/year.

Grazing intensity was generally rated as high throughout the grazed pastures, based on the degree to which woody vegetation had been browsed and the abundance of sheep droppings. However, except in parts of one pasture, herbaceous growth was not very closely cropped.

Herbivores: Deer populations are reported to be rather high at this location. This is consistent with the amount of browsing damage seen in the Riley Ridge Biological Area, which has been excluded from grazing since 1957. Browsing of all woody vegetation was intense in both the grazed pastures and the nongrazed Biological Area. Rodent populations were generally low, but signs of gopher, mouse, and/or vole activity were noted in over a third of the plots. Wild turkey was introduced into the area in 1970.

Vegetation type: The tree species present at this location are mostly the same as at location 1, except that foothill pine was absent at this location (Table 3-3). Madrone (*Arbutus menzesii*) occurred in the study area, but did not occur in any of our plots. In 30% of the plots, blue oak was the only tree species, and 50% of the plots had two to five canopy species. Although they did not match completely with the published descriptions, the cover types represented at this location were closest to blue oak/grass, blue oak—coast live oak/grass, and blue oak—valley oak—coast live oak/grass. Total canopy cover was highly variable; 32 plots had less than 20% canopy cover, and 47 plots had more than 50% canopy cover.

Twenty three plots contained shrubs, but only three had more than 20% shrub cover. Several species of manzanita (*A. manzanita, A. standfordiana*, and *A. glandulosa*) were the most common shrub species (Table 3-4). Poison oak was quite rare, and the few patches present were heavily browsed. In much of the grazed pastures, herbaceous cover was sparse, due to grazing and exposed rock at the soil surface. Herbaceous cover was much denser and taller in the Riley Ridge Biological Area, and wild oat and bunchgrasses were more common in this area than in the grazed pastures.

Regeneration: We did not see any blue oak saplings within the entire study area, including both the grazed and non-grazed areas. We did observe a few seedlings within the study area, and we did see some blue oak saplings along roadsides near the station. We saw almost no sapling-sized regeneration of any woody species in the grazed pastures. The only exception was one or two coast live oak saplings adjacent to a steep ravine, and these were protected by fallen tree branches. In the Riley Ridge Biological Area we saw some live oak, madrone, and scrub oak (*Q. berberidifolia)* saplings. The scrub oak saplings were heavily browsed.

Based on the presence of sprout-origin trees and some dense even-sized groups of trees, we infer that some of the existing blue oak stand may have regenerated after clearing. It appeared that the last such episode of regeneration had occurred some time ago, perhaps 60 or more years ago. There were relatively few small-diameter trees at this location (Figure 4-4).

Lack of recruitment was not related to a lack of need for regeneration, since 22 plots showed a loss in blue oak canopy cover due to tree mortality within the past 30 years. Seven percent of the blue oaks were dead (Table 4-12). Some of the dead trees were quite large, and probably represent oaks that were left standing after the first period of clearing. The largest blue oak we saw at any of the 15 locations was observed here. Mortality associated with wood decay fungi was present throughout the site. We saw at least two species of wood decay fungi fruiting on some of the stumps in plots cut for the 1989 stump sprouting study.

6. Sequoia National Park (Tulare County)

Survey dates: 9/3/92-9/5/92

The study area is located within Sequoia National Park, north of State Route 198 and the Kaweah River near the Ash Mountain Park Headquarters. The area has been within the park since 1890, but was probably not fenced off to exclude open range livestock until the 1920's. Virtually the entire study area fell within the Administrative Pasture, which has been grazed by horses and mules for at least the last 50 years. McClaran (1986) had four 0.05 ha study plots located within one portion of our study area.

Physical environment: The plots were located in an area of mostly south-facing foothills. Several low peaks were present within the study area, which is also traversed by several large seasonal creeks which drain toward the Kaweah River to the south. Most plots had southerly aspects and moderate slopes, so plot insolation values were generally high, as was the average insolation for the location (Appendix 4, Table 3-1). High insolation values interact with low soil available water holding capacity and high evapotranspiration rate (Table 3-2) to make this a rather xeric site.

Fire: Seventy five plots have not burned since at least 1940. Wildfires burned one plot in 1960, 13 plots in 1970, three plots in 1979, and five plots in 1980. Three plots have burned twice in the past 30 years (1960 and 1969; 1967 and 1979; 1968 and 1980). Fifty-nine plots had fire-scarred trees.

Clearing: A number of old, decorticated, eroded stumps were found in the center portion of the study area. Most of these stumps were cut at heights of about 50 cm or more, and were mostly over 40 cm in diameter at the height of the cut. Park Service sources indicate that most of these probably date to the 1930's, when a CCC camp existed in the area. In 1981, McClaran (1986) cut down approximately five saplings in four plots that were in the same general location as several of our plots. It is unlikely, but possible, that one or more of our plots could have overlapped one or more of his plots.

Range improvement: None is reported.

Grazing: Cattle were initially introduced into the area in the 1860's and would have grazed the area until it was fenced in the 1920's. Sheep may also have used the area in the same period, and McClaran (1986) reported that the U.S. Cavalry pastured riding stock in the area between 1891 and 1913. Since at least the 1940's, the area has been used as winter pasture for the horses and mules which are used in the park's montane backcountry in the summer.

Typically, the area was used to pasture 80 to 90 animals in the winter months (mid-October to mid-June), and a small number (4-10 animals) over the summer. For the past 15 to 20 years, except in drought years, winter stocking has been reduced to 15-20 animals between November and May, when most of the stock is moved to another location. Although the entire pasture encompasses 810 ha (2,000 acres), the study area included most of the most heavily used portions of the pasture, including an approximately 8 ha (20 acre) pasture which is used as a holding area to accumulate animals before they are transported.

Certain flats and feeding areas showed evidence of very heavy use by livestock, whereas livestock use was minimal in steep or especially rocky areas, and in the more densely vegetated areas along the creeks. Two plots fell outside the main pasture fence, in an area which is only grazed occasionally. Approximate stocking rates and grazing seasons within the study area are shown in the following table (Table 3-11).

Table 3-11. Recent grazing histories at location 6 (Sequoia).

Grazing regime	Number of plots	Grazing history	
1 (Main pasture)	83	1950-1976 year round 2.6 animal-months/acre/year	1977-1991 year round 0.9 animal-months/acre/year
2 (Holding area)	15	1950-1976 year round 2.6 animal-months/acre/year	1977-1991 May-October 5 animal-months/acre/year
3 (Outside of main pasture fence)	2	1962-1991 light occasional grazing, season variable	

Herbivores: Deer populations are high in the area from October through April, and the study area was littered with deer antlers. Rodents were common throughout the area, but were not uniformly distributed. Ground squirrels were abundant in a few areas.

Vegetation type: Blue oak was the dominant tree species over most of the study area, but 71 plots had more than one canopy species. Interior live oak and buckeye were the most common tree species associated with blue oak within plots, and foothill pine was absent (Table 3-3). Sycamore (*Platanus racemosa*) and California ash (*Fraxinus dipetala*) were also present along the creeks. The average density of blue oaks was high, and similar overall to locations 1 and 4 (Table 4-12). At the time of our survey in early September, blue oaks at this location were already 50% to 80% defoliated, presumably due to drought stress. The main cover types present are closest to blue oak−interior live oak/grass and blue oak−wedgeleaf ceanothus/grass.

The vegetation exhibited clear effects of browsing by horses, mules, and deer. Although 79% of the plots contained shrubs (Table 3-4), shrub cover was generally sparse, except near creeks, some rock outcrops, and where plots were located at the edge of the chaparral. Only 15 plots had more than 20% shrub cover, and 60 had no more than 2.5% shrub cover. Redberry was present in about half the plots, but was severely browsed. It was often located at the base of blue oaks and was usually less than 45 cm tall. *Arctostaphylos viscida* was very common, and some large arborescent specimens were tall enough to be part of the tree canopy layer.

Grass cover was generally present in areas where soil was present, even under interior live oak and manzanita cover, but the herbaceous layer was rather thin overall and the total amount of residual dry matter was low. Thirty-three plots had less than 50% herbaceous cover. Low herbaceous cover was found in plots with larger amounts of surface rock and in some areas where livestock had eaten or trampled all herbaceous matter. Bunchgrasses were very rare within plots (Table 3-4).

Regeneration: Current recruitment was sparse (Table 4-6, Figure 4-2). A single sprout origin S1 was tallied, and all other saplings were of seed origin. Most saplings and S0 seedlings were found in areas that were relatively inaccessible to livestock, such as steep slopes, very rocky areas, and along portions of the creeks where access was restricted by brush. Only a few S0 seedlings or saplings were found in areas where browsing was heavy (Table 3-12), and these were always severely browsed. Blue oak saplings are present in the general vicinity of the study area along roadsides and near park buildings. No manzanita seedlings or saplings were noted, but sycamore saplings were seen in the creekways.

Almost the entire stand appeared to be second growth, and very large diameter trees were generally lacking. An earlier episode of recruitment was apparently associated with the old 1930's stumps in some places, but generally not in the more open and flat areas that are heavily used by livestock. Although many plots had small-diameter trees (Figure 4-4), these generally appeared to be fairly old. These observations are supported by McClaran's (1986) stand age distribution data.

Current levels of recruitment are insufficient to offset current mortality (Figure 4-7). Nearly half of the plots contained dead trees (Table 4-12). Due to the likely destruction of dead trees by recent fires in a quarter of the plots, it is likely that the estimated mortality rate is somewhat lower than the actual rate. Canker rot symptoms were common in the area, and we observed *I. andersonii* fruiting on a blue oak in the study area.

TABLE 3-12. Seedling origin recruitment in plots with different levels of chronic vertebrate browsing at location 6.

Chronic vertebrate browsing rating	Number of plots	Live seedling-origin S1-S3 saplings (% of plots)	Live seedling-origin recruitment (S0-S3) (% of plots)
1 (low)	9	22%	56%
2 (moderate)	35	26%	34%
3 (high)	56	4%	9%

7. Dye Creek Preserve (Tehama County)

Survey dates: 9/10-9/11/92

Our study area was located north of Dye Creek, and was centered over the northeast end of Juniper Gulch. The area was originally settled in the mid 1800's, and the area may have been grazed by sheep in the late 1800's. A long rock wall built in the 1800's cuts across the study area. The area was homesteaded into smaller parcels from about 1900 to the 1920's. These parcels were subsequently consolidated into a single 15,200 ha (37,540 acre) property that was managed as a cattle ranch. The property became a preserve in 1988 and is managed by The Nature Conservancy, but cattle ranching has continued on the property. Organized hunting of deer and pigs on the property was initiated in 1966 and has continued to the present.

Physical environment: The landscape within the study area consists of flat-topped volcanic tablelands cut by moderately steep ravines or gulches. The tablelands slope very gradually towards the west between the gulches. The overall range in plot elevations at this location is relatively low (Table 3-1). Plot slope was 10% or less in 49 plots. Consequently, most plot insolation values fell in a fairly narrow range and average insolation values are relatively low (Appendix 4, Table 3-1).

Soils are loamy in texture but are very rocky and shallow. Within the study area, the deepest soil was found on both north and south slopes of ravines in a band just below the top of the plateau. Soil depth is generally shallow on the flat tablelands, but deeper bands and patches of soil are found where fissures exist in the underlying volcanic rock. These areas of deep soil range from bands 30 to 60 cm wide to patches of many square meters, and are readily apparent because they support taller and thicker grass growth. The shallow soils on the plateau are apparently subject to ponding during wet weather.

Fire: In June 1976, a wildfire burned the 31 plots north of the rock wall. In the plot area, the fire was a low intensity ground fire, owing to the sparse herbaceous cover and wide tree spacing. The remaining 69 plots have not burned since sometime prior to 1962. Only 20 plots contained fire-scarred trees, and 9 of these were south of the rock wall.

Clearing: Two plots fell in a small area in which trees were cut in 1970. There has been no other recent clearing in the study area. Based on the presence of occasional sprout-origin trees (Table 4-4) and some clumps of even-sized small diameter trees, we infer that some cutting probably occurred in the past, possibly during the homesteading period after the turn of the century.

Range improvement: There are no records of range improvement activities, although it appeared that rose clover (*Trifolium hirtum* All.) and alien perennial grasses had been introduced in some areas.

Grazing: The area has been grazed by cattle since at least the turn of the century. Cattle were present year-round until about the late 1940's, when a winter grazing regime was adopted. Since about 1950, cattle have been grazed from the beginning of December to mid-April or early May at an average stocking rate of one cow or cow-calf pair per 20 acres over the entire ranch (approximately 0.3 to 0.45 animal-months/acre/year).

On the flat tablelands, the browse line was very strong, and we observed a few dead S1 saplings that were severely stunted and heavily browsed. Oaks were much less browsed in areas where access to livestock was limited, such as steep slopes and especially rocky areas, indicating that much of the browsing damage was likely due to cattle.

Herbivores: Domestic pigs were introduced into the area between about 1900 and 1920 and have naturalized in the area. Pig dung and other signs of pig activity were common in some areas, but we saw little evidence of deer presence. According to R. Barrett, deer populations in the area probably peaked around 1960 and have since declined to moderate levels.

Evidence of rodent activity was plentiful. There were many large ground squirrel burrows under rocks and sometimes stumps or dead trees. Gopher mounds were also plentiful, particularly in the deeper soil areas.

Vegetation: Blue oak occurred as the only tree species in 80% of the plots (Table 3-3), and only 8 plots had two or more canopy species. Interior live oak, California juniper, and buckeye were most commonly found in the gulches, but occasionally occurred on the plateau. The blue oak trees appeared stunted compared to other study locations, and there were many small-diameter trees (Figure 4-4) which appeared to be quite old. Average stand density was moderate (Table 4-12) but only seven plots had more than 50% canopy cover. Blue oak density was greatest on the sides of the gulches, especially the north facing slopes, and in the band of deeper soil just below the plateau. Tree density and canopy cover was much lower on the plateaus (Table 3-13). The overall cover type is blue oak/grass.

Shrub cover was sparse. Only 16 plots had shrubs (Table 3-4), and 13 of these had only a single shrub species present. The highest shrub cover class represented was 2.5 to 20%, and this level of shrub cover was observed in only four plots. Shrub cover was greatest in the same areas that blue oak cover was greatest.

Native bunchgrasses were rare (Table 3-4). Even annual grasses were sparse on most shallow soils of the plateaus, which were dominated by annual forbs. Annual grasses tended to predominate in the deep soil patches and bands on the plateaus.

Regeneration: Blue oak saplings were uncommon (Figure 4-2, Table 4-6), and we saw few blue oak seedlings. Live seedling-origin saplings were primarily located in the gulches (Table 3-13). As noted above, these areas typically have deeper soils and less livestock browsing than the plateaus, as well as lower insolation values in the case of north-facing slopes.

TABLE 3-13. Seedling origin recruitment and other stand characteristics of plots in different topographic positions at location 7.

Topographic position	Number of plots	Average total canopy rating	Blue oak density (live trees/ha)	Dead blue oak trees (% of total)	Live seedling-origin recruitment (S0-S3) (% of plots)
hilltop	55	1.65	62	7.5%	5%
upper 1/3 hill	26	2.31	168	6.1%	23%
lower 2/3 hill and low flats	19	2.89	188	5.9%	37%

We encountered one dense stand of stump-sprouts that arose from trees cut in 1970. This clump was located on a north-facing slope in the deep soil band below the plateau. Some of the resprouts are now small trees 10-12 cm diameter, but two resprouts in one plot were still in the sapling stage (S1 and S3). The low-cut stumps in this area were small, mostly about 15 cm in diameter. Most sprouted stumps gave rise to multitrunked trees, but not all of the stumps produced sprouts. Several seedling-origin saplings were also found in these plots. We did not note any regeneration of other woody species at this location.

Certain areas of the stand, such as the area where the stump sprouts were, appear to have regenerated following earlier clearings. In some cases, a few old declining trees were found in the vicinity of cohorts of small-diameter trees, and it appeared that these older trees might represent trees that were left during past clearings. Based on stand morphology, most past regeneration is found in the same topographic positions where most of the current regeneration is located (Table 3-13).

The observed level of mortality was moderate (Table 4-12), although some dead trees may have been destroyed by the one known fire or removed for firewood. Apparent mortality was also slightly greater on the plateaus than along the gulches (Table 3-13). Sapling recruitment was inadequate to maintain current stand densities (Figure 4-7), particularly on the plateaus. Under current conditions, stand densities on the plateaus will probably continue to thin.

8. Pardee Reservoir (Amador County)

Survey dates: 9/17-9/18/92

The study area is located in the lower elevations of the Sierra Nevada foothills, on a portion of land between the north and channel arms of Pardee Reservoir. The land was acquired by the East Bay Municipal Utility District in 1927 and Pardee Dam was built in 1929. This area was settled at the time of the Gold Rush. Several old mines and prospects are located within two miles of the study area, and we saw at least one old prospect in the study area. Old sections of rock wall which were found within the study area were presumably associated with a homestead that predated the dam.

Physical environment: The terrain in the study area ranges from nearly level to moderately steep. The study area is a rolling upland, which is dissected by a number of moderately steep gulches that drain toward the reservoir in several different directions. There is relatively little overall change in altitude within the study area (Table 3-1). Half of the plots had slopes of 15% or less, and plot insolation values were moderate overall and normally distributed around the mean (Table 3-1, Appendix 4).

The soils at this location have a silt loam surface texture (Appendix 3), and soil depth is variable but never very deep. Some areas are moderately rocky, but many plots have little or no surface rocks. Estimated soil AWHC is low to moderate in most plots (Table 3-2), and 74 plots have estimated soil AWHC of 5 to 10 cm.

Fire: Seven plots burned in a wildfire along the north end of the study area 20 or more years prior to 1992. No other fires are known to have occurred in the study area since at least the 1940's. Trees in 41 of the plots had old fire scars.

Clearing: No known tree cutting has occurred in the area since the reservoir was constructed. Some efforts have been made to remove shrubs in the area, and a few plots in the northwest corner of the study area may be in an area that was cleared by tractor in the 1950's.

Range improvement: Other than the brush clearing efforts, no known range improvement activities have occurred within the study area, although some Soil Conservation Service test plots are located immediately to the east of the study area.

Grazing: The area has been grazed by cattle since about 1930, and possibly before this time as well. A winter grazing regime has been generally used since the reservoir was built. Since 1962, the area has been grazed by cattle every year from about November to April or May. Stocking rates have ranged from .35 to .61 animal-months/acre/year over the 763 ha (1,883 acre) parcel. Some supplemental feeding is typically used during the late fall and early winter. Cow-calf pairs are currently grazed and have been the usual type of grazing animals in the area, but Holstein feeders were grazed for a number of years. The browse line was relatively high, about 150 cm, which may be related to grazing by Holsteins. One plot was located beyond a fence which was erected around 1930. The area beyond the fence has not been grazed since that time.

Herbivores: Deer are common in the area, and we saw many around the lake shore in the early evening. Rodent populations were relatively high, and burrows of gophers or other small rodents were found in almost every plot. Ground squirrels were also present in some portions of the study area.

Vegetation: Blue oak was dominant throughout the study area, and was the sole tree species in 58% of the plots (Table 3-3). Foothill pine, interior live oak, and California buckeye were found in varying numbers of plots (Table 3-3). The only other canopy species present, a willow (*Salix* sp.), was found in a single plot. Only six plots had as many as three canopy species. The blue oak density was very low overall (Table 4-12), and only six plots had a total canopy cover greater than 50%. Blue oak/grass was the most common cover type.

Shrubs were rare (Table 3-4) and almost entirely restricted to the steep slopes in the gulches. Only three plots had more than a single shrub species present. Chamise was the only other shrub present in the area in addition to those listed in Table 3-4. Chamise was found in four plots, including the only three plots with more than 2.5% shrub cover. A large patch of chamise chaparral is found just beyond the southwest portion of the study area. Most of the shrubs other than the chamise were heavily browsed.

Herbaceous cover was generally high. Annual grasses, including medusa head, predominated in the herbaceous layer. Native bunchgrasses were almost completely absent from the entire area (Table 3-4).

Regeneration: The seven saplings located in three plots were the only saplings we saw in the entire study area. We also saw very few small seedlings. There were three live S1 saplings and one dead S1 in the grazed area. All were less than 60 cm tall, heavily browsed, and partially protected by rocks. The single nongrazed plot beyond the fence had one S1 and two S3 saplings, as well as an S0 seedling. These saplings were browsed, but not as severely as the saplings within the grazed area. We observed a number of blue oak saplings beyond the pasture fence lines along the county road that leads to the study area from the south. No regeneration by any of the other woody species was evident within the study area. Low shrub cover at this location may be the result of natural attrition and poor regeneration.

The stand appeared to be very even-aged. The blue oak trees were remarkably uniform in diameter, mostly about 30 cm dbh. There were very few large old blue oaks and few smaller than 13 cm dbh (Figure 4-4). One east-facing slope had an uncharacteristically high density of blue oak trees, including a number of small-diameter trees, which may represent a cohort of regeneration that is more recent than the majority of the stand. A moderate number of sprout-origin trees was tallied, indicating that at least some clearing occurred prior to dam construction. Our overall impression was that much of the stand may have arisen following clearing near the time of the Gold Rush or perhaps later, but that very little regeneration has occurred since that time.

Mortality of mature trees was relatively high (Table 4-12), and this estimate may be fairly reliable due to the lack of recent fires or wood removal. Most of the mortality appeared to be associated with root disease rather than canker rots. We saw several trees that had recently failed due to root decay. Current recruitment is clearly insufficient to maintain current stand density at this location (Figure 4-7). In an open stand of large-diameter trees in one portion of the study area, many of the trees were dead or in various stages of decline. There was no recruitment at all in this open, savannah-like stand, and conversion to grassland appears inevitable under current conditions.

9. Pozo (San Luis Obispo County)

Survey dates: 9/24-9/26/93

The study area is located on a private ranch adjacent to the Los Padres National Forest southeast of Pozo. The area has been settled since at least the late 1800's and has been used primarily for cattle ranching.

Physical environment: The study area is located in a rolling foothill area of the La Panza Range. The overall elevation change within the study area is relatively small (Table 3-1), but slopes within the study area ranged from nearly level up to 65%. Much of the area is cut with draws that drain toward the east and south, some of which are extremely steep. Average insolation values for the location are relatively high (Table 3-1). Plot insolation values are distributed over a broad range, with more plots represented on the high end of the range (Appendix 4).

Soils at this location are fairly deep overall, except on ridgetops. Surface textures are mostly loam to clay loam (Appendix 3). The soils are well-drained with moderate permeability, and most plots were free of rocks. Estimated soil AWHC was high in most plots (Table 3-2), and 30 plots had soil AWHC in excess of 20 cm. Discrete zones of a calcareous soil were found near the north end of the study area. The soils are mostly highly erodible, and the bottoms of many of the draws showed evidence of soil loss due to water movement.

Fire: Fifty four plots at the north end of the study area burned in a wildfire in August, 1939. The remaining 46 plots have not burned since before 1939. Fire scars were seen on trees in 49 of the plots, including 14 plots beyond the area burned in 1939.

Clearing: Five plots were cleared in 1953 to allow for power line installation. No other cutting is reported to have occurred in the prior 90 to 100 years. Some sprout-origin trees were observed (Table 4-4).

Range improvement: None is reported.

Grazing: The area has been used for year-round grazing since around 1880. The reported stocking over the last 30 years is typically one animal per 28 acres year-round, or about 0.43 animal-months/acre/year. The intensity of grazing was highly variable within the study area. Cattle use was greatest near water sources and on the more accessible broad hilltops and ridges. Narrow ridge tops and steep ravines were much less heavily used, but even the steepest slopes were pocked with deep hoof prints. The browse line was fairly strong throughout the site, but residual dry matter was high, except in the most heavily used areas.

Herbivores: Deer and elk are present at the site, and deer hunting in the study area had concluded just before our survey. Rodent populations were mostly moderate to high. Gopher burrows were common throughout. Ground squirrels were present in a few plots, and most commonly dug their burrows around tree roots. Baiting was used to reduce ground squirrel populations up until 1990. We also saw wild turkey in the study area.

Vegetation type: The study area was dominated by blue oak, with coast live oak being the most common tree associate (Table 3-3). Valley oak, which was mainly located along creeks, was the only other tree species in the study area. Only three plots contained all three canopy species. Foothill pine is common in an area west of the study area, but did not occur within the study area itself. Blue oak density was moderately high overall, but tree canopy cover was highly variable. Fifteen plots had no tree canopy, but 31 plots had more than 50% canopy cover. Tree density was generally high on north-facing slopes and sparse on south-facing slopes and broad flats. There was relatively little leaf loss in the blue oaks, in spite of the late survey date. The primary cover types present were blue oak/grass and blue oak−coast live oak/grass.

Extensive stands of chaparral are located north of the study area, and patches of chaparral were found within the study area on the calcareous soil type. These patches were dominated by chamise on south-facing slopes, but manzanita (*A. glauca*) dominated on the north-facing slopes and flats. Most of the plots within the main part of the woodland had no shrub cover (Table 3-4), although there were some thick patches of poison oak on a few of the north-facing slopes. Only eight plots had more than 2.5% shrub cover, and most of these were found at the transition between the oak woodland and chaparral. These transitional areas were generally narrow, and often contained blue and/or coast live oak and a mixture of shrubs, including manzanita, chamise, poison oak, and California sagebrush.

Native bunchgrasses were found in about half of the plots (Table 3-4), primarily on slopes and ridges. In four relatively steep plots, bunchgrass cover exceeded 2.5%. The herbaceous cover was dominated by wild oat, which was over one meter tall in places. There was relatively little medusa-head or ripgut brome.

Regeneration: There were few saplings within the study area (Figure 4-2, Table 4-6). Of particular note is the fact that 13 of the 29 seedling-origin saplings observed (45%) were dead. Only one of these dead saplings was located in the open, beyond tree canopy. Most seedling-origin saplings occurred in clusters. Eight of the 14 plots with seedling-origin recruitment had two or more saplings per plot, and one plot had seven saplings. A single sprout-origin S3 sapling was found in a plot that had been cut in connection with the installation of a power line in 1953. We saw a number of blue oak saplings along the roadsides in the vicinity of the study area, including within grazed fields. Saplings which were in areas frequented by cattle showed signs of chronic browsing damage. Small seedlings were uncommon, and also tended to be clustered in very localized areas.

Many of the saplings were found in the transitional area between the woodland and chaparral. A few coast live oak saplings and juvenile manzanitas were found in the same transitional zone. Two plots contained live oak saplings, the only saplings other than blue oak which occurred in plots.

Several of the factors associated with recruitment are summarized in Table 3-14. The presence of small diameter trees (Figure 4-4) and moderate to high levels of tree canopy appear to have the strongest positive associations with recruitment. The 1937 fire may also have influenced recruitment patterns: seven of the eight plots with several saplings were found in the burned area. However, correlations between the various factors make it impossible to determine which factor or factors are the most important.

In two plots, saplings were very clearly found in gaps created by the mortality of overstory blue oaks. Many of the other saplings may be undersized stragglers of cohorts that are now mainly in the small tree size class. This would account for the strong association with small diameter trees and the high incidence of dead, overtopped saplings. The pattern of blue oaks over the landscape was suggestive of earlier clearing, followed by recruitment mainly on the north and east aspects.

The incidence of dead trees at this location was relatively high (Table 4-12), and current recruitment is insufficient to offset recent mortality (Figure 4-7). There was mortality of some pole-sized trees in some of the denser stands which appeared to be due to competition. Wood decay caused by canker-rot and root rot fungi also appear to be involved in tree mortality at this location. We identified a fruiting body of the canker-rot fungus *I. dryophilus* on a blue oak in one plot, and saw clusters of dead trees that may have been killed by root decay.

TABLE 3-14. Occurrence of live or dead recruitment (S0-S3, seedling and sprout origin = ALLRECR) in plots with and without certain factors at location 9.

Factor	Factor present		Factor absent	
	Total number of plots	Recruitment (% of plots)	Total number of plots	Recruitment (% of plots)
Small diameter (3-13 cm dbh) trees	49	29%	51	2%
Total canopy cover > 20%	54	26%	46	2%
Shrubs in plot	22	27%	78	12%
Cut after 1950 or recent gap	37	22%	63	11%
Burned in 1937 fire	54	19%	46	11%

10. Lake San Antonio (Monterey County)

Survey dates: 10/1-10/3/92

The study area is located in the inner Coast Ranges within the 1215 ha (3000 acre) Lake San Antonio Park, which is administered by Monterey County. The area was homesteaded around the turn of the century and used for cattle and sheep grazing prior to its acquisition by the county. The dam that formed Lake San Antonio was built between 1964 and 1966.

Jepson (1910) reported that the largest specimens of blue oak occurred in Monterey County, "where there are thousands of trees 55 to 75 feet high scattered over the valley floor of the San Antonio and Nacimiento rivers." These valley floors were subsequently cleared for agriculture and later for the construction of the Lake San Antonio and Lake Nacimiento reservoirs.

Physical environment: The study area is located on an upland north of the Harris Creek arm of the reservoir. The terrain on the northern third of the study area is level to rolling. In the southern portion of the study area, the upland is cut into several more or less parallel ridges by several moderately steep draws that drain toward the south. Plot insolation values are mostly moderate (Table 3-1), because most plots were either relatively level or sloped toward the east or west.

Surface soil texture was silty clay loam in virtually all of the plots (Appendix 3). The soils in the study area are calcareous and moderately alkaline and are underlain by calcareous shale. The soils are generally deep and have moderate to high AWHC (Table 3-2). Some shallow soils with low AWHC were found where erosion had exposed the fractured parent material. Although much of the soil was gravelly and contained shale fragments, only a few plots had large exposed rocks on the soil surface

Fire: The study area has not burned since before the 1960's, and possibly not for a very extended period prior to that time. Fire scars were noted on trees in only eight plots.

Clearing: The only known clearing in the last 30 years was along some narrow firebreaks around 1965 and possibly some tree removal near the high pool level of the reservoir in the early 1960's. The firebreak is disked each year. Clearing has apparently occurred throughout the area in the past. Some of the surrounding hills had obvious clearings, and we tallied a moderately high number of sprout origin trees within plots (Table 4-4). There were a few very large blue oaks, which appeared to be remnants of the former stand.

Range improvement: There are no records of range improvement activities.

Grazing: The study area has been grazed year-round extending back to at least the early 1950's. Cow-calf grazing is the usual practice in the area, but sheep have also been grazed in the area at least once since the park was established. Grazing was discontinued on 37 plots at the north end of the study area in 1965. Year-round grazing continued on the remaining 63 plots until 1987. Due to breaks in the fences, some intermittent grazing occurred on these 63 plots for several years after 1987. Typical stocking rates in the area are one cow-calf pair per 10 acres (about 1.8 animal-months/acre/year), although stocking levels have varied. Grazing intensity was reported to be lighter in more recent years, but had previously been fairly severe. Some of the surrounding parcels had been grazed to a very low level of residual dry matter, but current residual dry matter in the study area was mostly moderate to high.

Herbivores: Local deer populations appeared to be high. Within the study area we saw many deer, and a number of deer skeletons. The browse line was very pronounced, and there was no obvious difference in the browse line between portions of the study area that had different grazing histories. Much of the toyon present was so heavily browsed that the main stems were virtually bare between ground level and the browse line.

Rodent populations were high. Ground squirrels were common throughout the study area. Since 1983, the park has used baiting to reduce ground squirrel populations in the vicinity of a few plots at the extreme southern portion of the study area. Gopher holes were also common, and in places we saw evidence of other rodents, including pack rats.

Vegetation: Blue oak was dominant in the area (Table 3-3), but often occurred with other oaks, which were the only canopy species in the plots. The most common tree associates were Tucker's oak (*Q. john-tuckeri*), which occurred in 27 plots, and the hybrid species *Q. ×alvordiana (Q. john-tuckeri × Q. douglasii),* which was found in 31 plots. Hybrids between valley oak and Tucker's oak were also found in two plots. Evidence of introgression between blue and Tucker's oaks was common in the stand. Tucker's oak and *Q. ×alvordiana* were primarily found in the southern portion of the study area, especially on the ridge tops. Due to the high incidence of Tucker's oak in the stand, the vegetation does not classify into any of the Allen et al (1989) blue oak cover types.

The oak cover was quite dense in some areas, particularly on north aspects. Tree canopy cover was greater than 50% in 35 plots and greater than 80% in 16 plots. Two or more tree species were present in 54 plots, but only three plots had as many as four canopy species. Despite the late survey date and high stand density, little leaf drop had occurred at the time of sampling.

Shrubs were common throughout the area (Table 3-4), and shrub cover was relatively high. Twenty-four plots had at least 50% shrub cover. Two plots had six shrub species present, and 32 plots had at least three shrub species. California buckwheat, chamise, honeysuckle (*Lonicera* sp.), and a *Ribes* sp. were present in addition to the species listed in Table 3-4. Poison oak was relatively uncommon.

The herbaceous layer was relatively sparse in many areas, due to heavy canopy and the calcareous soil. Fifty-eight plots were rated as having more than 50% bare soil. The herbaceous layer was dominated by wild oat in most areas. Native bunchgrasses were present in over half the plots (Table 3-4), but at very low cover values.

Regeneration: It was difficult to evaluate blue oak regeneration due to the high amount of hybridization with Tucker's oak. We saw a few saplings (Figure 4-2, Table 4-6) we classified as blue oak, as well as some which appeared to be Tucker's oak or *Q. ×alvordiana*. All blue oak recruitment was seedling-origin, and seven of the 26 saplings observed (27%) were dead. We did not observe saplings of either valley oak or coast live oak in the study area.

Due to the low levels of recruitment present, trends affecting sapling distribution were difficult to discern. Considering all saplings (live and dead), saplings were more common in plots with small diameter trees (3-13 cm dbh), moderate to high levels of canopy cover (>20%), and low levels of recent browsing damage. Saplings were also more common on ridges and upper slopes than on lower slopes and in drainages. Although plots with fire-scarred trees were uncommon, four of the eight plots with fire scars had saplings, compared to 11 with saplings in the remaining 92 plots (12%). No clear relationship was obvious between recruitment and grazing history, shrub presence, or recent canopy gaps.

Small-diameter trees were common at this location (Figure 4-4). Although small size may be due to recent recruitment to the tree stage in some individuals, for many other individuals, small size may be related to low growth rates due in part to hybridization with Tucker's oak.

Blue oak mortality in the stand was about 5% (Table 4-12). Canker rot caused by *I. andersonii* and possible root disease centers were observed within the study area. Overall, recruitment was not sufficient to offset mortality (Figure 4-7).

11. Hensley Lake (Madera County)

Survey dates: 10/8-10/10/92

The study area is located west of the northern portion of Hensley Lake, a reservoir on the Fresno River northeast of Madera. The reservoir, operated by the Army Corps of Engineers, was filled in 1976. The southern portion of the study area was located on federal land that adjoins the reservoir, and which was previously a cattle ranch. The northern portion of the study area was located on a private ranch.

Activity by American settlers in the area dates to at least the 1850's, when a trading post was established in the area to service local gold miners. The area was previously used by the native Miwok and Yokuts. We observed rocks with old grinding holes in two spots just east of the study area.

Physical environment: The study area is located in an area of rolling hills and relatively broad drainages that slope toward the south and southeast. Plot slopes were generally moderate, but 26 plots had slopes in excess of 30%. Average plot insolation values were moderately high (Table 3-1), and the distribution of plot insolation values is somewhat skewed toward the high end (Appendix 4). This location has the lowest average rainfall and the greatest ET deficit among our 15 study locations.

The soils at the location were coarse sandy loams derived from decomposed granitic rocks. Soil depth was variable. Fairly shallow soils were found on some south-facing slopes at the higher elevations, and soils were generally deeper closer to the lake. Soil AWHC ranged from very low (<5 cm) in four plots to moderate (Table 3-2). Soil rockiness was variable. Rock outcrops were present in 19 plots, but 39 plots had no significant rocks in the surface soil.

Fire: No widespread fires have occurred in the study area since at least 1946. A spot lightning-caused fire of less than 0.5 ha may have occurred in the study area in 1986. We did not see any fire scars within any of the plots.

Clearing: No reported cutting of blue oak has occurred since before 1962, but interior live oak has been cut as recently as the mid-1980's on the private ranch.

Portions of the study area have been cleared of shrubs. On the private ranch property, brush was cleared by tractor from at least 20 plots in the early 1960's. In the mid-1980's, very thorough follow-up brush clearing was conducted on the private ranch using a tractor-mounted brush rake. We estimate that about 10 plots were cleared at this time. Most of the brush was reportedly piled and burned. Some brush clearing may also have occurred in the late 1950's or early 1960's on the reservoir property. Aerial photos from the mid 1940's show little shrub cover on the reservoir property.

Range improvement: Some portions of the private ranch were fertilized once, reportedly with little apparent benefit.

Grazing: Grazing had been conducted in the entire study area since before the 1950's at least. On all plots, the original grazing regime was cow-calf grazing from October or November to May or June, with some very light summer grazing. Typical stocking rates were one cow-calf pair per 8 acres (about 1.5 animal-months/acre/year), and supplemental feeding was used in early winter. Grazing was discontinued on the 37 plots on the reservoir property in 1976. On the private ranch, grazing was changed to stockers from October to May at about one animal per three acres (about 2.5 animal-months/acre/year) in 1980, and to year-round grazing at one animal per 10 acres (1.2 animal-months/acre/year) in about 1987. The browse line was very strong on both sides of the property line. Residual dry matter was high on the reservoir property and low to moderate on the private ranch.

Herbivores: Deer are present in the area, but probably only at moderate levels, although populations may vary seasonally. Wild pigs are also reported to use the area, primarily in winter. Rodent populations were high. Gophers were common throughout the study area, but ground squirrels were more common on the private ranch than on the reservoir property. Baiting for ground squirrel control was conducted on the private ranch from before the 1960's until 1987.

Vegetation type: Other than blue oak, the only canopy species present in the plots were a willow found in one plot along a creek and a few interior live oaks. Most of the live oaks occurred among rocks, and appeared to be of sprout origin. A few foothill pines were found within the study area, including some that had recently died. Overall tree canopy and blue oak density were very low (Table 4-12). Twenty-six plots had no tree canopy at all. Only 21 plots had more than 20% canopy cover, including a single plot with more than 50% canopy. At the time of our visit most of the trees still had most of their foliage. The cover type classification is blue oak/grass.

The shrub layer was virtually nonexistent. Three plots had small amounts of coffeeberry, which was the only shrub species seen in the study area. The coffeeberry was exclusively found among rock outcrops on the reservoir property.

Herbaceous cover was high, and mainly dominated by annual grasses. Wild oat was the predominant grass on the reservoir property, and formed a dense layer. On the private ranch, large patches of forbs dominated by filaree (*Erodium* spp.) were present in some areas with shallow soils. Native bunchgrass was noted on a single plot on the reservoir property.

Regeneration: No blue oak saplings were seen in the entire study area, either in or between plots. Only a few small blue oak seedlings were seen. There was virtually no regeneration by any woody species in our study area. The only sapling we saw in the study area was a heavily-browsed live oak growing directly out of a crack in a rock. The only other woody plant regeneration was to the east of our study area. Some sapling foothill pines were present along a creekbed beyond a fence line.

Based on the appearance of the stand, the percentage of sprout origin trees (Table 4-4), and the presence of Native American grinding rocks in the study area, we believe that this area previously had a higher density of blue oaks. It appears the area was thinned or cleared in the distant past, but recruitment following past clearing(s) was sparse. Only one plot had any small-diameter (3-13 cm) trees. There were also a few old stumps, but no evidence of previous recruitment associated with any of these stumps.

Many of the existing oaks were located among rocks, which may indicate that earlier conditions had allowed only saplings protected by rocks to mature into trees. On a few north-facing slopes and some narrow drainages, there were a few trees that looked as if they might be younger than the remainder of the stand, perhaps dating from the first half of this century. Overall, it appeared that a cohort of past regeneration that was represented at most of our other locations was largely lacking at this location.

The estimate of tree mortality at this location was unusually low (Table 4-12). Removal of dead trees by the rancher may at least partially explain the small number of dead trees observed.

12. Henry Coe State Park (Santa Clara County)

Survey dates: 10/15-10/18/92

The study area is located entirely within the park, on the east end of Pine Ridge, about 2 km southeast of the park headquarters. The area was homesteaded prior to the 1880's, and individual homesteads were acquired and consolidated from the 1880's through the 1940's. The Pine Ridge Ranch house west of the study area was built in 1905, and Madrone Soda Springs, a small hot springs resort located south of the study area, was in operation from 1879 to about 1920. The area was used primarily for cattle ranching from the late 1800's through 1953 when the Coe Ranch became a county park. The California Department of Parks and Recreation took over management of the park in about 1958.

Physical environment: Our study area was located on a broad, uneven ridge that trends generally toward the southeast. The ridge top slopes gradually to the north and then drops off sharply. Plot slopes on the north slope of the ridge are as high as 85%. Slopes were generally more moderate on the south-facing slope. The distribution of plot insolations is rather broad and skewed toward the low end, but some plots had high insolation values (Appendix 4). As a result, average insolation values for the entire location were moderate (Table 3-1).

Soil textures in the study area are primarily loam and clay loam, often with intermixed gravel or larger rocks. Significant rock outcrops are uncommon, and were only seen in seven plots. The underlying parent material is primarily metamorphosed sedimentary rocks. Soil depth is generally moderate, with some shallow and some relatively deep spots. Estimated soil AWHC values are low to moderate (Table 3-2), and all fall between 5 and 16 cm.

Fire: No wildfires have occurred in the study area since at least 1930, but recent controlled burns have been conducted. A single plot was located in an area where a small controlled burn was conducted in 1985, and 33 plots were in an area that was burned in 1983. Only 11 plots contained trees with fire scars.

Clearing: Five plots were in areas that appeared to have some tree removal associated with campground construction in the late 1950's. One plot was in an area cleared in connection with the construction of a cattle pond in the late 1940's or early 1950's. No other recent cutting has occurred in the study area.

Historical information indicates that wood was cut for ranch use or for pasture clearing, starting in the 1880's. The Pine Ridge ranch reportedly used about 20 cords of wood per year for heating and cooking. There were several large clearings on the ridgetop and on some of the less steep south-facing slopes which may have been used as pastures or hay fields. A few large remnant blue and valley oaks are present in and around these fields.

Range improvement: There are no records of range improvement activities.

Grazing: The area has not been grazed since it became a state park around 1958, and grazing status from 1953 to 1958 is uncertain. Prior to 1953, the area had been operated as a cattle ranch from at least the turn of the century, but details of the grazing regime(s) are not known.

Herbivores: No hunting is allowed in the park and deer populations are relatively high, based on the amount of browsing, droppings, and trails. Poison oak, California bay, blue oak, and valley oak were heavily browsed. Coast live oak and manzanita sometimes showed lower amounts of browsing damage. There were a few localized areas with heavy ground squirrel populations. Gophers were also present, but the high grass made it difficult to evaluate how common they were. We saw some pack rat mounds among the manzanita thickets. Wild turkeys and pigs also occur within the study area.

Vegetation: The vegetation was a mosaic of blue oak and mixed oak woodlands types, intermixed with large patches of manzanita chaparral. In some areas, the manzanita was tall enough to constitute a low tree canopy. Blue oak woodland was found mainly on the ridge and in patches extending part way down the north- and south-facing slopes, but blue oaks were also present in the mixed oak woodland. Manzanita (*A. glauca*) was a common associate of blue oak, and the blue oak and manzanita had clearly grown up together in some areas. Even areas that were dominated by manzanita often contained scattered blue oaks. Blue oaks still had good leaf retention, despite the late survey date.

This location had the greatest diversity in tree species among any of our study locations. Fifty-two plots had four or more canopy species, and a maximum of seven tree species was found in a single plot. The tree canopy included big leaf maple (*Acer macrophyllum*), madrone, manzanita (*A. glauca*), and ponderosa pine in addition to the species listed in Table 3-3. A few blue-valley oak hybrids were also seen in some plots. This location also had the highest overall tree canopy cover. Tree canopy cover was greater than 50% in 72 plots, and 12 plots had essentially closed canopies.

Shrub cover was also relatively high overall. Thirty-four plots had more than 50% shrub cover, and only 20 plots lacked shrub species (Table 3-4). Manzanita was the most common shrub (Table 3-4), but a fairly diverse assortment of shrubs was found in plots on the steep north-facing slopes. In addition to the species listed in Table 3-4, plots contained oceanspray (*Holodiscus discolor)*, birch-leaf mountain-mahogany, honeysuckle, coffeeberry, California sagebrush, *Baccharis* sp., and *Ribes* sp. Two or more shrub species were present in 51 plots.

Herbaceous cover varied with canopy cover, and was scanty under heavy canopy cover. Forty plots had less than 50% herbaceous cover. In the open clearings, herbaceous cover was very heavy and dominated by annual grasses, predominantly wild oat. Medusa head and ripgut brome were absent. Native perennial grasses, including both bunchgrasses and rhizomataceous species, were fairly common (Table 3-4) but seldom attained very high cover.

Regeneration: We saw no blue oak saplings in the entire study area. A few S0 seedlings were found in the study area, one of which was in a plot. Smaller blue oak seedlings were also present in various locations. We did not see any valley oak or black oak saplings within the study area, but coast live oak saplings were seen in at least 10 plots. Coast live oak seedlings and saplings were sometimes present under fairly dense tree canopy. Reproduction of other woody species was fairly common. We saw numerous seedlings and saplings of foothill pine, manzanita, and California bay. Saplings of blue oak and valley oak were present along the sides of the paved road that leads to the park headquarters.

The stand did not appear to be even-aged. There were some dense patches of small-diameter blue oaks that looked to be cohorts that might have recruited after clearing. Many of the blue oaks in the study area appeared to be relatively young, and could have recruited following clearing that occurred during the first half of the century. Of the 81 plots containing blue oak, 40% had trees in the 3 to 13 cm dbh size class. Plots with small trees were more than twice as dense as those without (17.3 and 7.3 trees/plot, respectively). The trees in many of these dense stands were quite tall and somewhat spindly, and had few low branches. Many of the overtopped blue oaks in the dense stands were dead or declining.

Based on the total percentage of tallied blue oaks that were dead, this location had the highest estimated mortality rate. The self-thinning of dense stands described above contributes to this high level of mortality, but there was also mortality among the few remaining trees in the largest size classes. We saw fruiting bodies of a number of wood decay fungi within the study area, including *L. sulphureus*, *I. andersonii*, and *I. dryophilus*. *L. sulphureus* was most common on valley and black oak. We also saw several possible root disease centers in which clumps of mature blue oaks trees had died.

13. Mt. Diablo State Park (Contra Costa County)

Survey dates: 10/22-10/24/92

The study area was located on the north end of the park, south of the town of Clayton. Donner Creek cuts through the center of the study area. A homestead was established just west of the study area in about 1848. A brief copper mining frenzy occurred in the area in 1863-1864, and a few tunnels and prospects are located within 1 km to the south of the study area. Another old homestead site is located at the south end of the study area and the adjacent field includes a few remnants of a small orchard. The area has been used primarily for cattle grazing since at least the 1930's. Plots are located in four adjacent parcels, which were acquired by the park in 1964, 1973, 1975, and 1980. Many of these parcels also have old interior fences.

Physical environment: The study area was located among low hills and slopes at the foot of Mt. Diablo's north face. Two intermittent creeks cross the study area. Much of the area slopes to the north, but plots were located on all aspects. Slopes greater than 40% were found in 46 plots. Average insolation values are fairly low (Table 3-1), due to the preponderance of low insolations associated with northerly aspects (Appendix 4).

A comparatively large number of soil series were mapped in the study area (Appendix 3), but most plots had clay loam soils of moderate depth. Only a few plots had significant amounts of gravel or rock in the surface soil. Only five plots had rock outcrops, and most of these were along creeks. Estimated soil AWHC ranged from less than 5 cm in six plots to between 10 and 20 cm in 51 plots (Table 3-2).

Fire: The Mitchell Canyon fire in August, 1977, burned about 16 plots. We estimate that 55 plots burned in a fire in August, 1931, including eight of the plots that burned in the 1977 fire. The remaining 37 plots have not burned since at least 1891. Trees with obvious fire scars were present in 27 plots. Fire-scarred trees were found in only one plot from the area where no fires have been recorded since 1891.

Clearing: No clearing is reported during the 30 year study period. We tallied 19 stumps in 13 plots, all but one of which appeared to be much older than 30 years. Sprout-origin trees were found in 25% of the plots, providing evidence of possibly older cutting. Trees have been completely cleared from fields north of the study area and near the homestead site. Many of the old cleared fields are still visible as straight-edged grasslands surrounded by woodlands.

Range improvement: There are no records of range improvement activities.

Grazing: Except for a three-week period in September 1992, the area has been ungrazed since 1991. In 92 of the plots, grazing had been conducted on a rotating year-round schedule between the 1950's and 1975 to 1980. In this system, cattle were stocked at a rate of about three cow-calf pairs per acre and rotated between quarter sections every six to 12 weeks. Grazing is believed to have been suspended in at least some of these plots between 1975 and 1980 while part of the area was developed for housing. From 1980 through 1990, the 92 plots were normally grazed from February or March to October or November at an average stocking rate of 2 animal-months/acre/year.

Of the remaining eight plots, three have been largely nongrazed since 1973, and the other five had been nongrazed since 1964. Some trespass grazing has occurred in these fields during the nongrazed period. Grazing before park acquisition was presumably similar to that in the remaining 92 plots. The browse line was fairly strong throughout the study area, but residual dry matter levels were generally high, due to the lack of recent grazing.

Herbivores: Deer are common in the area. Pigs also occur in the park, but we did not note any evidence of pig activity in the study area. Gopher activity was especially intense over much of the study area, and ground squirrels were present in some areas.

Vegetation: Blue oak was the dominant canopy species over most of the area, but often occurred with other species (Table 3-3). Although up to six canopy species were found in a single plot, 88% of the plots with trees had only one or two species. In addition to the species listed in Table 3-3, California juniper, manzanita (*A. glauca*), and willow were occasionally in the canopy layer. The overall density of blue oaks was high (Table 4-12). Tree canopy cover was greater than 50% in 54 plots, but 14 plots fell in old clearings with no tree canopy at all. On the steeper upland slopes the blue oak trees were up to 50% defoliated, whereas there was very little defoliation in the moister areas along drainages. Blue oak/grass and blue oak−valley oak −coast live oak/grass were two of the most common hardwood cover types present.

Shrub cover was generally low, except along the creeks, and in patches of chaparral. Twenty-one plots had more than 20% shrub cover, with up to seven shrub species in a single plot. Our impression was that brush had been purposely removed over a large part of the study area. Some of the toyon present had regenerated from cut stumps. The most common shrubs are shown in Table 3-4. California juniper, California sagebrush, *Ribes* sp., *Baccharis* sp., black sage, wild grape (*Vitis californica*), and elderberry (*Sambucus mexicana)* were also present in one or more plots each.

The herbaceous cover was high overall, and dominated by annual grasses, particularly wild oat. Native bunchgrasses were relatively uncommon (Table 3-2), but were dense in two plots.

Regeneration: Only four plots had blue oak saplings (Figure 4-2, Table 4-6), all of which were in the S1 size class and heavily browsed. In addition to the five saplings seen within plots (four live, one dead), we saw two additional dead S1 blue oak saplings (one sprout origin, one seedling origin) in the area that had not been grazed since 1973. On these two dead saplings, the lowest 25 cm of bark had been shredded, presumably by rodents. We did not see this type of damage at any of the other study locations.

In two plots, the blue oak saplings appeared in gaps created by overstory mortality. One of these plots was in a brushy area that had burned in 1977, and the other was near the old homestead site near Donner Creek. Both of these plots were at the base of slopes, which would receive additional water from runoff. Another plot had a single sprout origin S1, and the fourth plot with recruitment had one dead S1 near a very dense cluster of small diameter trees. Saplings of coast live oak and foothill pine were more numerous than those of blue oak and occurred in six and four plots, respectively. No valley oak saplings were found in plots.

The stand, which was very dense in spots, largely appeared to be second growth that arose after cutting. Large-diameter trees were uncommon, but 40% of the plots with blue oaks had trees in the 3-13 cm size class. Stump resprout trees were common in some areas, but much of the regeneration from earlier clearings was apparently seedling-origin. However, regeneration did not follow clearing in all cases. A number of fields and other clearings remain free of trees.

Dead blue oak trees were present in a 41% percent of the plots (Table 4-12), and dead trees made up 6% of the tree total. The 1977 fire would have removed any dead trees from the burned plots, so the mortality estimate for this location is probably lower than actual mortality. Even with this potential underestimation of mortality, recruitment lags far behind mortality at this location (Figure 4-7). *I. andersonii* was found within the study area.

14. California Hot Springs (Tulare County)

Survey dates: 10/29-11/1/92

The study area is located on a portion of a 160 ha (400 acre) private ranch. According to the local historian, the area was first used by sheep herders in the latter half of the 1800's. Sheep gave way to cattle, and homesteading occurred in the area around the turn of the century, later followed by consolidation of parcels. An old stagecoach road crosses through the area, and a house on the ranch dates to about 1910. A small tungsten mine which operated in the 1940's is located on the ranch about 0.5 km west of our study area.

Physical environment: Our study area was located on the slopes above a high narrow valley which is located at an elevation of about 850 m. The eastern half of the study area consisted of rolling hills with mostly west to northwest aspects, and included a creek of moderate size. The western half of the study area was on moderate to steep slopes that faced the south and southeast, and covered a wide range of elevations. Due to the preponderance of southerly aspects, relatively high elevation, and low latitude, this location had the highest average insolation values among the study locations (Table 3-1, Appendix 4).

Soils in the study area are sandy loams to coarse sandy loams of mostly moderate depth (Appendix 3). Soils are noticeably sandier near the creek. Estimated soil AWHC within the plots was generally low to moderate (Table 3-2), ranging from about 6 to 17 cm. Outcrops of quartz diorite rock were common, particularly in the western portion of the study area.

Fire: No wildfires have burned in the area since well before the 1960's. Two plots burned around 1962 in a small spot fire, and three plots were in areas where cleared buckeye was burned around 1970. Thirty plots contained trees with obvious fire scars.

Clearing: Six plots near fence lines were cleared by tractor between 1970 and 1973, and two plots were in an area in which buckeye was removed by tractor in 1970. Two plots were in an area where trees were cut in connection with the installation of a water pipeline around 1960. No other plots were known to have been cut within the past 30 years.

Blue oaks have historically been cut in the area for fence posts and fuelwood. Historical fuelwood consumption was reported to be about 15 cords/year. A number of old large-diameter stumps cut at about 30 cm were found in 12 plots. These were similar in appearance to the stumps at location 6 (Sequoia) which were reportedly cut in the 1930's. In addition, sprout-origin trees, apparently from earlier cutting, were found in more than half of the plots (Table 4-4).

Range improvement: Several stock ponds were built in the 1960's.

Grazing: Three plots were located in a two-acre pasture where one or two horses have been kept an average of eight months out of the year since at least 1962. The remaining plots were in areas that have primarily been used for cattle grazing for at least the past 30 years, although a few horses and mules have typically been grazed in these areas in the spring. Since 1962 or earlier, the 92 plots in cattle-grazed areas were generally grazed with stockers from November to May at moderate but uncertain stocking rates. From about 1983 through 1985, 47 plots were grazed year-round at one cow-calf pair per 10 acres (about 1.8 animal-months/acre/year). Since 1986, the cattle grazed areas have been grazed with cows and heifers from February or March through July at one animal per 5 acres (about 1 animal-month/acre/year).

Residual dry matter was variable but mostly high throughout the study area. The intensity of browsing damage was generally high, except in a few plots that were especially rocky or steep.

Herbivores: Deer populations were moderately high in the area. Most plots had evidence of gopher and/or ground squirrel activity, and pack rat was noted in one plot. Ground squirrel populations were very high in some areas, particularly around the cattle ponds. In a few places, branches of California buckeye had been girdled by ground squirrels which had chewed off the bark. Baiting was used to control ground squirrels in some areas from the 1960's until the late 1970's.

Vegetation: Blue oak was dominant on most of the slopes and ridges. There were also bands of buckeye that were mixed with blue and/or interior live oak. These three species comprised the majority of the trees present (Table 3-3), and only 10 plots had more than three canopy species. Interior live oak was also prominent along drainages and creeks. The major creek supported a riparian woodland which included interior live oak, valley oak, California bay, sycamore, white alder (*Alnus rhombifolia*), and canyon live oak (*Q. chrysolepis*). Canopy cover was mostly quite high, with 63 plots having more than 50% cover. The average density of blue oak at this site was also high (Table 4-12). The most common hardwood cover type within the plots was blue oak−interior live oak/grass.

Although almost half of the plots contained shrubs (Table 3-4), shrub cover was generally sparse. Only 13 plots had more than 2.5% shrub cover, and only a single plot had more than 20% shrub cover. Most of the shrubs, especially redberry, were heavily browsed. Birch-leaf mountain-mahogany and flannelbush (*Fremontodendron californicum* ssp. *californicum*) were found in a few plots, and in most cases had attained an arborescent form, with trunk diameters of 10-20 cm and 20-30 cm, respectively. We saw one manzanita, which is reported to be the only one on the ranch. We did not see any poison oak, although some reportedly occurs near the creek. Either intentionally or as a consequence of the prior management, it appears that shrub cover has been reduced in the area, and that some species, such as manzanita, have been virtually eliminated.

The herbaceous layer was dominated by annual grasses, especially wild oat, soft chess (*Bromus hordeaceus* L.), and ripgut brome. A fairly high proportion of plots had native bunchgrasses (Table 3-4), but bunchgrass cover was greater than 2.5% in only three plots. Bunchgrassses tended to be more common in areas with shallow soil and in a few spots near the creek. We saw a number of patches in which annual grasses were almost entirely lacking, and the sparse herbaceous cover was limited to a scattered bunchgrasses and small forbs. These patches were usually less than 800 m^2 in area.

Regeneration: We found a few blue oak saplings (Figure 4-2, Table 4-6) in widely scattered locations in the study area. In almost all cases, these saplings occurred in places where they were somewhat protected by rocks. All of the saplings were of seedling origin, and all but two were in the S1 size class. There were a few old S1 saplings in the horse pasture, and the growth of all of these had been suppressed by browsing. We also saw a number of blue oak saplings in a small fenced area from which cattle and horses were excluded, which is also downslope from an irrigated pasture. Blue oak saplings also occurred along road cuts in the area. We saw seedlings of blue oak in only a few places within the study area, but a high population of seedlings was present in a small 10-year old cattle exclosure on the property.

Interior live oak saplings were more common than blue oak saplings, and occurred in 13 of the study plots. We saw no seedlings or juveniles of any of the shrub species, and foothill pine seedlings and saplings were also absent.

The stand appears to consist mainly of second growth blue oak that regenerated following cutting. Most of the regenerated oaks are of seedling origin, although stump sprouts trees predominate in some areas. It did not appear that the entire area had been cleared at one time in the past. Based on the patterns of past regeneration within the stand, it appears that trees were cut in patches over a prolonged period of time, and many, but not all of these areas regenerated.

This location had the highest frequency of plots with dead trees (50%), and had the third highest apparent rate of blue oak mortality at 8.5% (Table 4-12). Observed mortality was far in excess of current sapling recruitment (Figure 4-7). We saw fruiting bodies of several canker-rot and wood decay fungi, including *I. andersonii, I. dryophilus, and L. sulphureus,* which were associated with blue oak decay and mortality. The decay fungi *Hypoxylon thouarsianum* (Lev.) Lloyd and *Hericium erinaceus* (Bull:Fr.) Pers. were also seen in the area on dead or decayed interior live oak. Bark beetles and wood borers were seen on both blue and live oak. In some areas, it appeared that these agents might be interacting with drought stress to kill trees.

15. Jamestown (Tuolumne County)

Survey dates: 11/6-11/8/92

The study area is located on a private ranch several kilometers south of Jamestown. The area has been settled since the Gold Rush in 1849. The rapid influx of miners and others boosted the local population to about 6,000 people by the 1850's. A large number of old rock foundations were found along a creek at the south end of the study area, where a gold-mining camp with a population of 1,200 was located during the 1850's. Old stonework was also present along some of the other drainages, and an old water ditch cuts through the study area. Remnants of past excavations were also visible in these areas.

Peak mining activity in the study area occurred between 1852 and 1860, and the area was subsequently homesteaded. One of the old homestead sites is located at the north end of the study area. A number of homesteads were consolidated by 1868 into a 2,025 ha (5,000 acre) cattle ranch which was managed as a unit. The original ranch has since been divided into somewhat smaller parcels.

Physical environment: The rolling terrain in the study area is typical of much of the Mother Lode area. The study area is on a rolling upland cut by several drainages. Small creeks are located at the north and south ends of the study area, and a bend of a larger creek intrudes into the center of the two easternmost transects. A few plots have moderately steep slopes (maximum 50%), but most slopes are moderate, and 31 plots have slopes of less than 15%. Most plots have north, west, or south aspects, with the first two aspects being more common. Average insolation values are relatively low (Table 3-1). Due to relatively high levels of precipitation, this location has the third lowest ET deficit among the study locations (Table 3-2).

Surface soils textures are gravelly loams and silt loams of generally moderate depth. Estimated soil AWHC is moderate in most plots (Table 3-2). Although varying amounts of rock were intermixed with the soil, substantial amounts of exposed rock were mainly found along the creeks. Some of the soil series occurring here were also found at locations 4 and 8 (Appendix 3).

Fire: Fires were common in the area during the Gold Rush period. Approximately nine plots near the south end of the study area burned in a 1967 wildfire, and two plots were in area where cut material was burned in 1988. The remaining 89 plots have not burned since well before 1962. Only 17 plots had fire-scarred trees.

Clearing: Some firewood harvesting has been conducted in the area in recent history. Three plots were located in an area of pure blue oak which was clear cut 30 to 40 years prior to 1992. An additional 32 plots were located in a strip of land that was clear-cut between 1974 and 1976. In eight of these plots, interior live oaks that sprouted from cut stumps were cut again in 1989. The remaining 65 plots have not been cut for more than 40 years.

Based on the high percentage and wide distribution of sprout-origin trees throughout the site (Table 4-4), and the almost complete lack of large-diameter trees, it appears likely that most of the area has been cleared since the Gold Rush. There were several treeless clearings of varying sizes, some of which appear to have been cultivated fields in the distant past.

Range improvement: Seeding of subclover has been conducted in some areas since 1987.

Grazing: Cattle grazing has occurred in the study area since about 1868, but based on the presence of old fence lines and clearings within in the study area, land use was more varied during the early history of the area.

Since at least the 1950's and probably earlier, the study area has been managed as a single 240 ha (600 acre) cattle pasture. From at least the early 1950's through 1973, the study area was generally grazed from May to October with one cow-calf pair per 10 to 12 acres (about 0.9 to 1.5 animal-months/acre/year). From 1974 through 1982, the grazing season remained unchanged but the stocking rate was about doubled to one pair per six acres (2.2 animal-months/acre/year). Between 1983 and 1988, a winter grazing regime was used (October to April or May), and stocking was reduced to about one pair per 15 acres (about 0.7 animal-months/acre/year). Since 1988, the area has been grazed year-round at one pair per 12 acres (1.5 animal-months/acre/year). During the period from about 1974 through 1988, cattle were kept off the pasture every sixth year.

Browsing within the study area varied from light to heavy, depending on how easily the cattle could access the area. Residual dry matter was low, except in rocky areas that were less accessible to cattle.

Herbivores: Deer populations in the area appear to be relatively low. We saw no deer or signs of their presence, and browsing damage was light in areas that were not used by cattle. High gopher populations were found throughout the area, except in the rocky areas along the creeks. We saw no evidence of ground squirrels other than one possible ground squirrel burrow.

Vegetation type: Blue oak and interior live oak were the most common trees (Table 3-3). As noted above, many of the relatively level areas were open grasslands due to past clearing. Twenty-one plots had no tree cover. Only location 11 had more treeless plots. On the relatively level areas and more moderate slopes most of the trees were blue oak. Some interior live oak and foothill pine was present in these areas, but shrubs were generally lacking. The cover type in these areas was blue oak−interior live oak/grass, and plots in these areas showed the greatest intensity of livestock use.

The slopes near the larger drainages were generally more heavily canopied, and interior live oak generally had greater cover in these areas than did blue oak. Many of these areas also had understory interior live oak saplings and some shrub cover, but there was often little herbaceous growth in these areas. Manzanita (*A. viscida*), poison oak, redberry, buck brush, and honeysuckle were the most common shrubs in these areas. The creeks supported a narrow riparian woodland, with a greater diversity of shrub and tree species, including willows, valley oak, Oregon ash (*Fraxinus latifolia*) coffeeberry, elderberry, toyon, and California button willow (*Cephalanthus occidentalis* var. *californicus*). Up to eight shrub species were recorded in one plot located in the riparian area. Tree canopy cover in the riparian and live-oak dominated areas was often quite dense. Twenty-nine plots had more than 50% canopy cover, including seven plots with essentially closed canopies. Twenty plots located in riparian areas had more than 50% shrub cover.

The herbaceous layer throughout was dominated by annual grasses, and only one plot had any native bunchgrass. We saw two oracle oaks (*Q.* ×*morehus* = *Q. wislizenii* × *Q. kelloggii*) in the study area, but no black oaks.

Regeneration: This was the only location at which sprout-origin saplings outnumbered those of seedling origin (Figure 4-2). Even though 75% of the saplings tallied were of sprout origin, (Table 4-4), the number of plots with live sprout-origin saplings was similar to the number of plots with live seedling-origin saplings (17 and 19, respectively). Considering all seedling-origin recruitment, 28 plots contained either S0 seedlings and/or live seedling-origin saplings. Only two plots contained both sprout- and seedling-origin recruitment (Table 4-6). About 21% (13/62) of the sprout-origin S1 saplings seen were dead, compared with 3% (1/29) of the seedling-origin S1 saplings. We saw no dead S2 or S3 saplings of either origin type.

Production of stump sprouts was not uniform between different years of cutting or between different areas within a single cut. Three plots are located within a nearly pure blue oak stand that had been clear cut between about 1952 and 1962. No sprout origin saplings were recruited from this cutting, even though the landowner indicated that these stumps had not been treated with herbicides. Lack of sprouting from this cut may be associated with sapwood decay, which was severe in virtually all of the stumps. In contrast, stump sprouting was fairly successful in mixed stands of blue and interior live oak that were cut in 1975 (Table 3-15). Both oak species produced stump sprouts, with the interior live oak sprouts being much larger (to 3 to 4 m tall), more vigorous, and less browsed than the blue oak sprouts. Blue oaks stumps sprouted more successfully in the drainages than on the upper slope positions and hilltops (Table 3-16). Live oak stump sprouts formed dense thickets in some areas, and many were cut down in 1989.

There was no seedling-origin recruitment in plots that lacked tree canopy, and seedling-origin recruitment was more common in plots that had moderate to high levels of canopy cover (Table 3-17). Seedling-origin saplings were most common along the lower portions of slopes and along creeks and drainages (Table 3-16). In general, plots in these areas also had higher levels of canopy and shrub cover, greater diversity in tree and shrub species, and lower levels of browsing damage than plots in other topographic positions (Table 3-16). We saw a few small blue oak seedlings, particularly along the creeks. Seedling-origin saplings of interior live oak were noted in 16 plots, and seedlings and saplings of foothill pine and manzanita were seen in some areas.

Virtually the entire stand appeared to be second growth. Sprout-origin blue oak trees were more common here than at any other site (Table 4-4). Many of the live oak trees were also of sprout origin. We saw only a few large-diameter old trees of any sort. Although regeneration had apparently been successful in some portions of the site, blue oak had been effectively eliminated from some large areas, particularly on the uplands and hilltops. There has been no recolonization of these large clearings, even though seedling origin saplings are found within in the study area.

There were few dead blue oak trees in the study area (Table 4-12), which may be due to the removal of dead trees and downed wood. Low mortality could also be due to the fact that there were few old trees in the stand, and that stand density was not overly high in most areas. Even though our survey followed some rainy weather, we saw very few fungal fruiting bodies on any of the trees, and no obvious canker-rot symptoms or fruiting bodies.

TABLE 3-15. Sapling occurrence in plots with different histories of wood cutting at location 15.

Year(s) when trees were cut	Number of plots	Live sprout-origin S1-S3 saplings (% of plots)	Live seedling-origin S1-S3 saplings (% of plots)	Live seedling-origin recruitment (S0-S3) (% of plots)
None or prior to 1950	65	2%	22%	27%
Between 1952 and 1962 (estimated)	3	0%	33%	33%
1975	24	42%	12%	21%
Both 1975 and 1989	8	75%	12%	50%

TABLE 3-16. Sapling recruitment and certain characteristics of the tree and shrub layer by topographic position at location 15.

	Plot topographic position			
	Hilltop	Upper 1/3 slope	Middle 1/3 slope	Lower 1/3 slope, drainage bottoms
Number of plots	15	30	23	32
Average tree canopy cover rating	2.13	2.07	2.87	3.03
Three or more canopy species (% of plots)	0%	7%	13%	31%
Average shrub cover rating	.27	.57	1.39	1.75
Average number of shrub species	.33	.73	1.43	2.06
High current browsing intensity (% of plots)	87%	80%	52%	42%
Live S1-S3 sprout-origin saplings (% of plots)	7%	10%	17%	39%
Live S0-S3 seedling-origin recruitment (% of plots)	7%	20%	35%	41%

TABLE 3-17. Seedling-origin recruitment by canopy cover class at location 15.

Total tree canopy cover	Number of plots	Live S0-S3 seedling-origin recruitment (% of plots)
0	20	0
>0% to 20%	27	19%
20% to 50%	24	29%
> 50%	29	48%

4. OVERALL RECRUITMENT AND REGENERATION PATTERNS

Recruitment by size and origin class

Seedlings (S0)

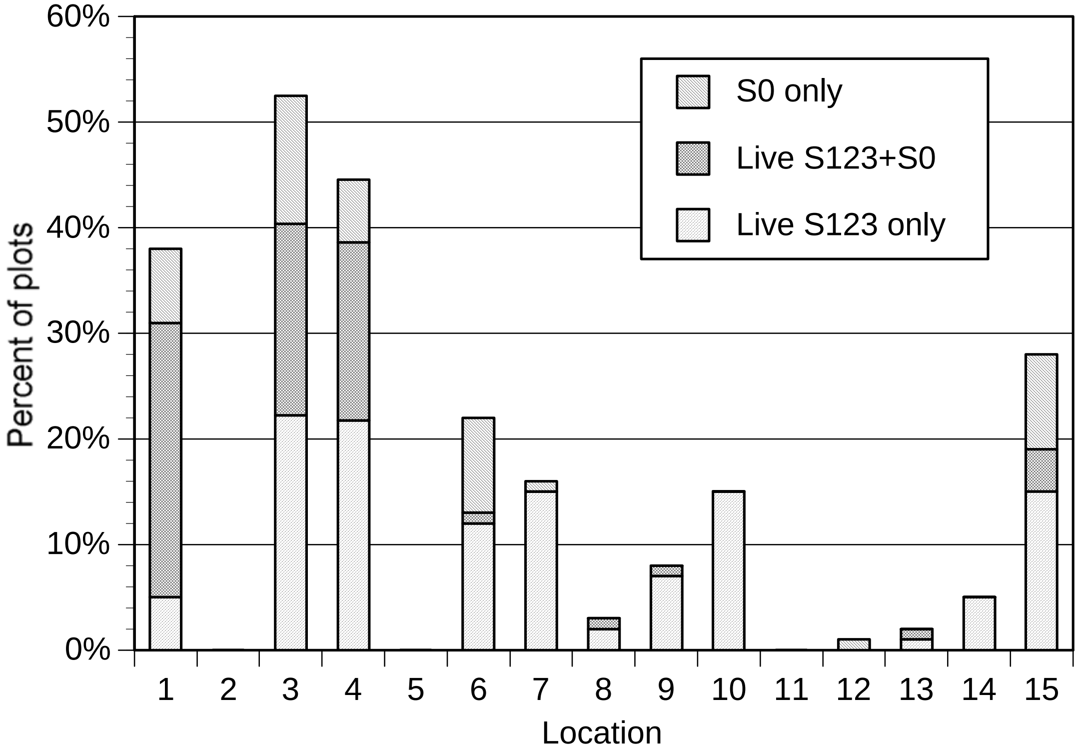
The S0 size class consists of large seedlings that are readily detectable. Based on shoot morphology, it was clear that virtually all of the S0 seedlings we observed were a number of years old. Many showed signs of having been repeatedly browsed. In most cases, S0 seedlings appeared to be in a transitional stage between the persistent small seedling stage and the S1 sapling class. Seedlings in the S0 size class were found in at least one plot at 10 of the 15 study locations (Table 4-1). At location 12, S0 seedlings represented the only form of blue oak regeneration seen. The three locations with the highest incidence of S0 seedlings (locations 1, 3, and 4) also had the greatest number of plots with seedling-origin saplings (Table 4-1). S0 seedlings were most numerous overall at location 1, where 11 plots had 10 or more S0 seedlings per plot. Only one other plot, at location 3, had as many as 10 S0 seedlings in a single plot, and in most cases, only a single S0 seedling was found in a given plot.

TABLE 4-1. Seedling-origin recruitment at the 15 study locations.

Location	S0 seedlings (% of plots)	Live seedling-origin S1-S3 saplings (% of plots)	Dead seedling-origin S1-S3 saplings (% of saplings)
1	33%	31%	1.6%
2	0%	0%	--
3	30%	40%	8.5%
4	23%	39%	20.6%
5	0%	0%	--
6	10%	13%	5%
7	1%	15%	20.6%
8	1%	3%	14.3%
9	1%	8%	44.8%
10	0%	15%	27%
11	0%	0%	--
12	1%	0%	--
13	1%	2%	25%
14	0%	5%	40%
15	13%	19%	2.9%
Totals	7.6%	12.7%	6.9%

The degree to which S0 seedlings occurred in the same plots as larger seedling-origin saplings varied by location (Figure 4-1). Location 1 had the largest overlap between plots with S0 seedlings and those with seedling-origin S1, S2, and S3 saplings. In other locations, such as 6 and 15, S0 seedlings were more likely to occur in plots that did not have saplings.

FIGURE 4-1. Overlap in occurrence of S0 seedlings and live seedling-origin saplings (S1, S2, and S3).



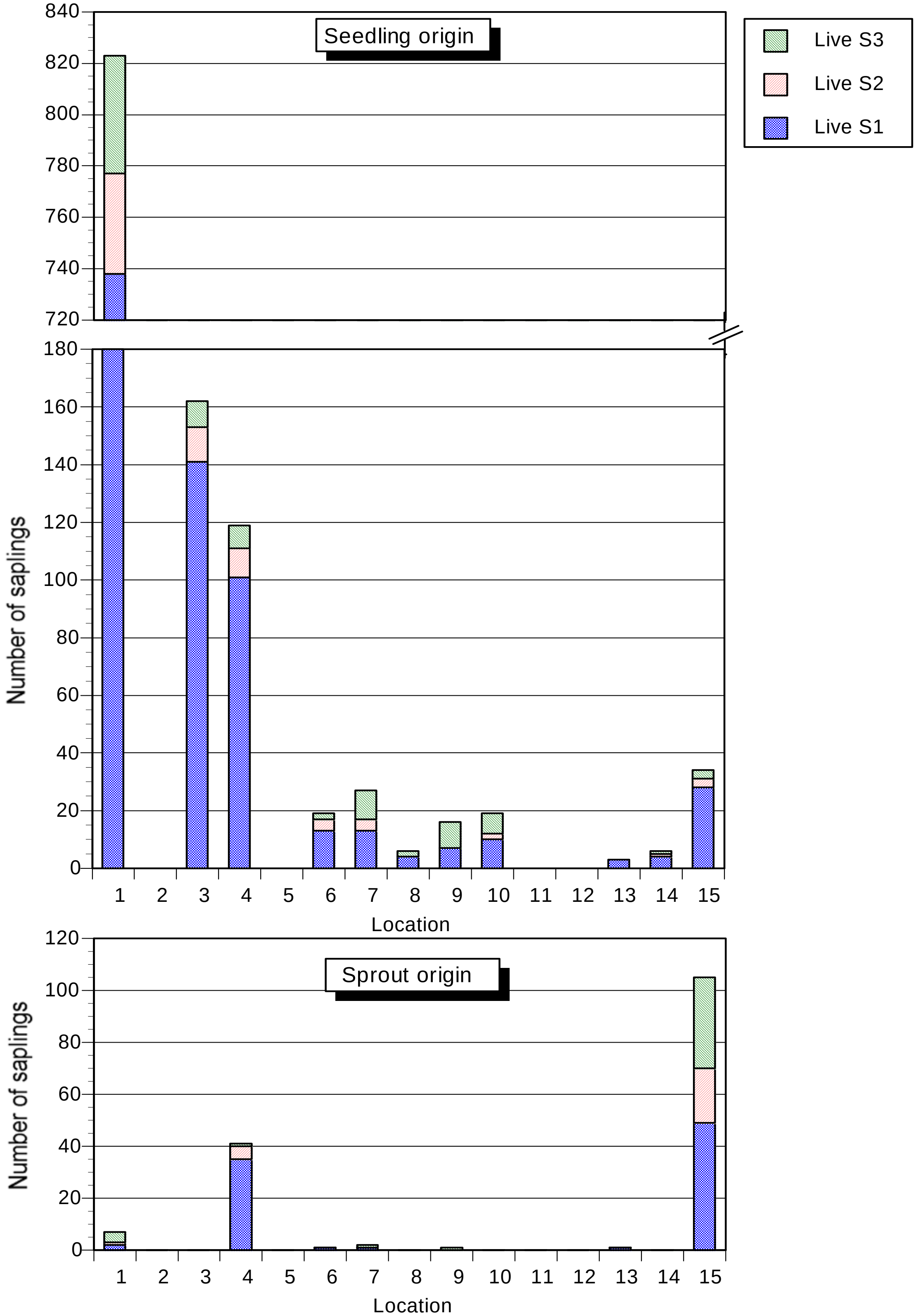
Seedling-origin saplings

Except at locations 7 and 9, the majority of all saplings tallied within a location were in the S1 size class (Figure 4-2). The overall ratio of all live seedling-origin saplings tallied in the S1, S2, and S3 size classes was 14.2:1:1.3. Among the 11 study locations with seedling-origin saplings, S1 saplings were found at all 11 locations, S3 saplings were found at 10 locations, and S2 saplings were found at 8 locations. Overall counts, frequency of occurrence in plots, and mortality by sapling class are listed in Table 4-2 below.

TABLE 4-2. Overall totals by sapling class for seedling-origin saplings from all locations.

Sapling class	Total seedling-origin saplings (live and dead)	% of total	Frequency (% of all plots)	% dead
S1	1132	85.4%	11.3%	6.2%
S2	82	6.2%	2.9%	8.5%
S3	112	8.4%	4.1%	13.4%
Total	1326	100%	13.8%	6.9%

FIGURE 4-2. Total numbers of live saplings found at each location by size and origin class.



Of the 207 plots with seedling-origin saplings, 81.6% had saplings in the S1 size class. Among these plots, 57.5% had saplings only in the S1 class, compared with 4.8% having exclusively S2 saplings and 12.1% having exclusively S3 saplings. The remaining 25.6% of the plots had seedling-origin saplings of more than one size class. The majority of both S2 and S3 seedling-origin saplings were found in plots that also contained S1 saplings (Table 4-3).

TABLE 4-3. Observed combinations of size stages among seedling-origin saplings occurring within a plot.*

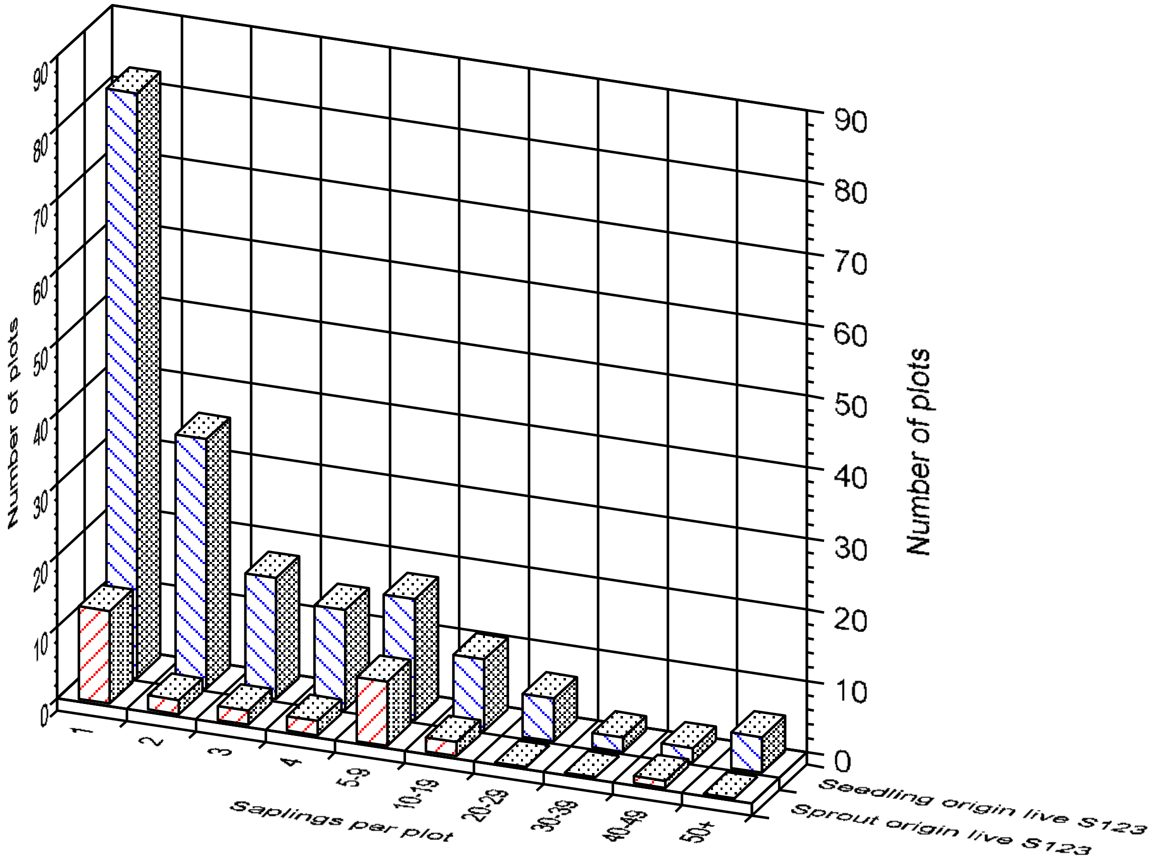
Sapling size stages in plot	Number of plots		
S1+S2+S3	14		
	S1	S2	S3
S1	119	16	20
S2	16	10	3
S3	20	3	25
Totals	169	43	62

*Based on a total of 207 plots from all locations with seedling-origin saplings.

Relatively few dead saplings were observed, but at least one dead sapling was found at every location where live saplings were present (Table 4-1). We presume that most of the dead saplings we observed died within the past 10 to 15 years. Due to their small size, it seems unlikely that dead saplings would persist much longer than a decade and still be recognizable. Furthermore, dead saplings would probably not persist even that long if they were exposed to destructive agents such as fire or livestock. Mortality rates based on counts of dead saplings will therefore underestimate the true mortality rate for saplings. Furthermore, since large dead saplings are likely to persist longer than smaller ones, these counts cannot be used to reliably separate mortality rates between the three sapling classes.

The number of saplings per plot was generally low (Figure 4-3). Among plots with live saplings, 43.2% had only a single sapling present, and 81.6% had no more than five saplings. However, 7.9% of all plots with live saplings had 20 or more saplings (14 of these plots were at location 1, one plot at location 3, and one plot at location 15). One plot at location 1 had 207 live saplings present.

FIGURE 4-3. Frequency distributions for counts of live seedling origin S1-S3 saplings per plot and sprout origin S1-S3 saplings per plot.



Sprout-origin saplings

Overall, saplings of sprout-origin were observed less frequently than those of seedling-origin, and were only found at seven of the study locations (Figure 4-2). Sizable numbers of sprout saplings were found only at locations 4 and 15, and only at the latter location did sprout-origin saplings outnumber seedling-origin saplings (Figure 4-2, Table 4-4). Sprout-origin saplings made up only 12.1% of all saplings (live + dead) observed, and occurred in a much smaller percentage of plots than seedling-origin saplings (Tables 4-2, 4-4, 4-5).

TABLE 4-4. Blue oak stumps, sprout-origin trees and saplings, and cutting history at the 15 study locations.

Location	Trees cut within the last 42 years (% of plots)	Blue oak stumps (% of plots)	Sprout-origin trees (% of plots)	Live sprout-origin trees (% of live trees)	Live sprout origin saplings (% of plots)	Live sprout origin saplings (% of live saplings)	Dead sprout origin saplings (% of all sprout saplings)
1	63%	33%	1%	1.3%	3%	0.8%	53%
2	4%	10%	6%	1.3%	0%	--	--
3	6%	1%	5%	2.7%	0%	0%	--
4	16%	7%	43%	12.3%	7%	25.6%	6.8%
5	3%	4%	17%	4.0%	0%	--	--
6	0%	16%	20%	2.4%	1%	5.0%	0%
7	2%	2%	6%	5.3%	1%	6.9%	0%
8	0%	0%	15%	6.3%	0%	0%	--
9	5%	1%	13%	2.6%	1%	5.9%	0%
10	4%	0%	25%	7.3%	0%	0%	--
11	0%	3%	13%	14.6%	0%	--	--
12	5%	0%	13%	2.3%	0%	--	--
13	0%	13%	25%	3.4%	1%	25.0%	0%
14	10%	12%	52%	10.6%	0%	0%	--
15	35%	27%	52%	33.3%	17%	75.5%	11.0%
Totals	11%	9%	20%	6%	2%	11.4%	13.2%

TABLE 4-5. Overall totals of sprout-origin saplings in each sapling class.

Sapling class	Total live and dead saplings	Percent of total	Frequency (percent of all plots)	Percent dead
S1	112	61.5%	2.1%	20.5%
S2	27	14.8%	0.5%	0.0%
S3	43	23.6%	0.8%	2.3%
Total	182	100%	2.2%	13.2%

As with seedling-origin saplings, most of the sprout-origin saplings were in the S1 size class. However, S2 and S3 saplings were relatively more common among sprout-origin than among seedling-origin saplings, with the overall ratio of 3.3:1:1.6 for all live sprout-origin saplings in the S1, S2, and S3 size classes. The 182 sprout-origin saplings were found in only 33 plots, 31 of which (94%) contained S1 sprout-origin saplings. About half of these plots (17/33) had only S1 sprout saplings.

Since virtually all of the sprout-origin saplings we tallied resulted from tree cutting, it is not surprising that a relatively high percentage of the plots with sprout saplings had more than one such sapling. Among plots with live sprout saplings, 42% had only a single sprout sapling present, but 39% had 5 or more (Figure 4-3).

Only ten plots had both live seedling-origin and sprout-origin saplings (Table 4-6). This represents a larger percentage of all plots with sprout saplings (27.3%) than it does of the plots with seedling-origin saplings (4.7%).

TABLE 4-6. Counts of plots with different categories of recruitment (including both live and dead saplings) by location.

Location	All S0-S3 recruitment (ALLRECR)	All S1-S3 sapling recruitment	Sprout-origin sapling recruitment only	Sprout- and seedling- origin sapling recruitment
1	38	31	0	4
2	0	0	0	0
3	52	40	0	0
4	52	48	5	2
5	0	0	0	0
6	22	13	0	1
7	20	19	0	1
8	3	3	0	0
9	15	15	1	0
10	15	15	0	0
11	0	0	0	0
12	1	0	0	0
13	4	4	1	0
14	7	7	0	0
15	41	35	16	2
Overall (% of plots)	18%	15.3%	1.5%	0.7%

Mortality of sprout-origin saplings was seen at locations 1, 4, and 15. Sprout-origin S1 saplings had a higher apparent mortality rate than the larger sprout classes, although relatively few sprout-origin saplings in classes S2 and S3 were tallied (Table 4-5). The proportion of dead saplings among S1 sprout saplings was also higher than the proportion of dead saplings in any of the seedling-origin size classes (Table 4-2).

Table 4-4 shows a comparison between current sprout-origin recruitment and several indicators of cutting and past sprout-origin recruitment. Locations 4 and 15 have relatively high numbers of both sprout-origin trees from past cutting and sprout-origin saplings from recent cutting. In fact, some of the sprout saplings at location 15 originated from stumps of trees which were themselves of sprout origin. In contrast, locations 1 and 2 have low percentages of sprout origin trees, and also have few or no sprout-origin saplings, even though some recent cutting has occurred at both locations. At many of the locations we found stumps from recent and older cuttings which had failed to produce sprouts.

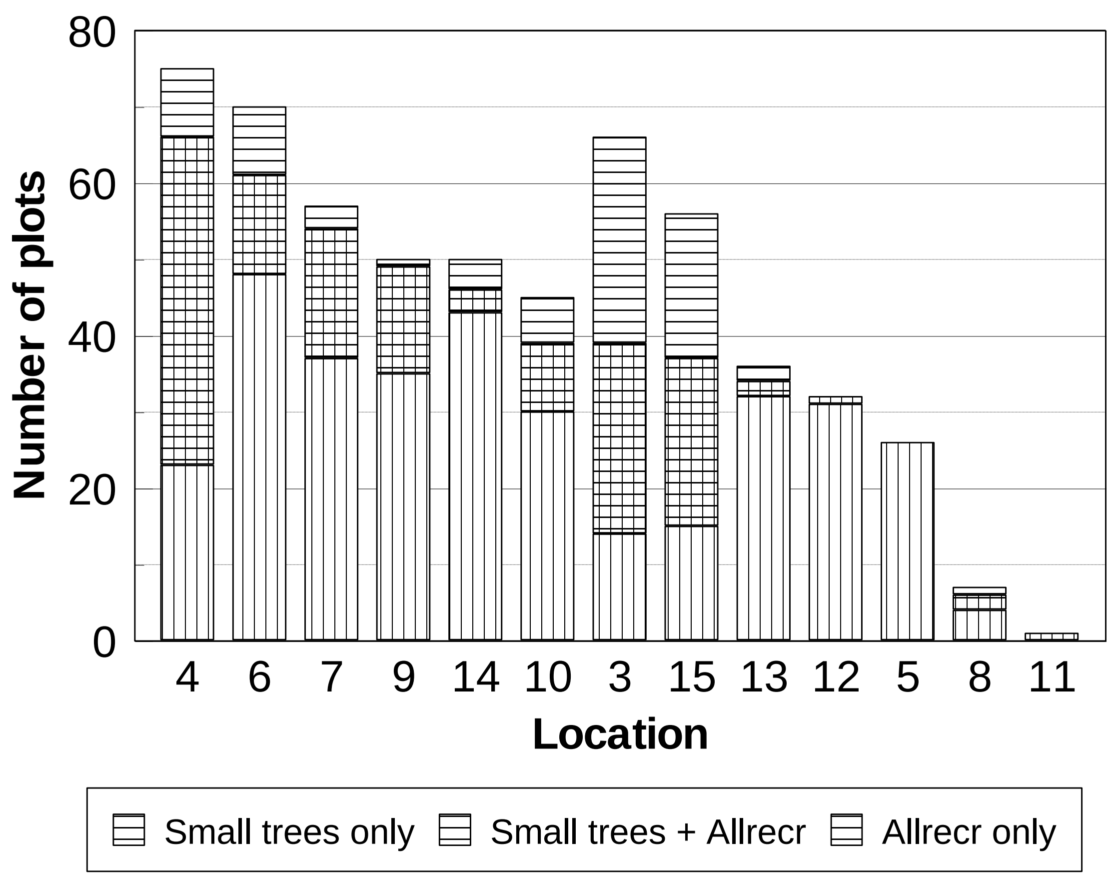
Sprout-origin trees were generally well-dispersed among plots at a location. With the exception of locations 1, 7, and 11, the percentage of plots with sprout-origin trees was generally much higher than would be expected from the overall frequency of sprout-origin trees (Table 4-4). Among the 303 plots with sprout-origin trees, 47% had a single sprout tree per plot, and 11% had five or more sprout trees per plot.

There was a relatively poor correlation between recent clearing history and stump presence. In some locations, we did not see stumps in areas where recent (within 30 years) clearing had occurred. In other locations, stumps detected in plots were apparently from older tree cutting. For example, at location 6 (Sequoia), most of the stumps we saw in plots were dated through historical information to cutting that occurred in the 1930's.

Small trees

Small-diameter trees (3-13 cm dbh) are not considered to be saplings for the purposes of this study, but have been defined as saplings by Bolsinger (1988). In order to facilitate comparisons with Bolsinger's data, we noted whether trees in the 3 to 13 cm dbh size class (SMALLTREES) were present within plots, starting with location 3. Among locations 3 through 15, the number of plots with small-diameter trees ranged from 1 (location 11) to 66 (location 4). The lowest numbers of plots with small trees were found at locations with few or no saplings, but high frequencies of plots with small trees were not consistently associated with high levels of sapling recruitment (Figure 4-4). The extent to which S0-S3 recruitment (ALLRECR) occurred in plots with small-diameter trees varied between locations (Figure 4-4). At locations 3, 4, and 15, the majority of plots with small trees also had sapling or S0 seedling recruitment. At locations 4, 7, and several others, a large majority of the plots with S0-S3 recruitment also had small blue oak trees.

Figure 4-4. Overlap in the occurrence of small trees (3-13 cm dbh) and all S0-S3 recruitment (ALLRECR).



Tree canopy and sapling recruitment

Based on combined data for all locations, both S0 seedlings and seedling-origin saplings were most likely to found in plots with intermediate levels of canopy, and were least likely to occur in plots without tree canopy (Figure 4-5, Table 4-7). In addition, plots with intermediate levels of canopy cover had the greatest number of live saplings per plot (Table 4-7). Although the seedling totals and average number of seedlings per plot are inflated by the high seedling counts in some plots at location 1, the overall trend does not change when data from location 1 are omitted.

S0 seedlings and seedling-origin saplings were only rarely found in plots that lacked any blue oak canopy (Table 4-8). S0 seedlings were not found in plots with very high levels of blue oak canopy (Table 4-8). In contrast, in plots with at least some blue oak canopy, there is no obvious relationship between blue oak canopy cover and the recruitment of seedling-origin saplings (Table 4-8).

FIGURE 4-5. Percentage of plots in each total canopy class with seedling-origin recruitment. Percent canopy for each canopy cover class is the same as shown in Table 4-7.

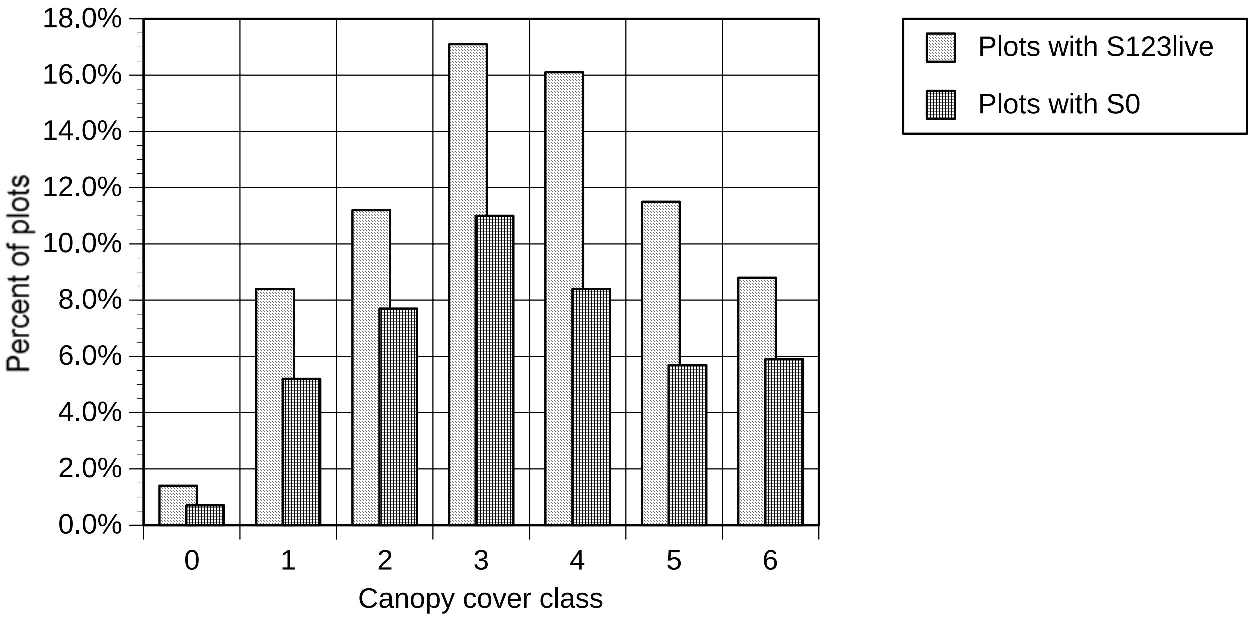


TABLE 4-7. Distribution of plots and live seedling-origin blue oak saplings by total canopy cover class.

Total canopy cover class	Percent canopy cover	Number of plots [% of plots]	Number of live seedling-origin S1-S3 saplings [% of saplings]	Average number of live seedling-origin S1-S3 saplings per plot
0	0	144 [9.6%]	18 [1.4%]	0.13
1	<2.5%	155 [10.3%]	75 [6%]	0.48
2	2.5% - 20%	259 [17.3%]	337 [27.3%]	1.30
3	20% - 50%	428 [28.5%]	632 [51.2%]	1.47
4	50% - 80%	323 [21.5%]	134 [10.8%]	0.41
5	80% - 97.5%	157 [10.5%]	35 [2.8%]	0.22
6	>97.5%	34 [2.3%]	3 [0.2%]	0.09

TABLE 4-8. Percentage of plots with live seedling-origin S1-S3 saplings and S0 seedlings among plots with different levels of blue oak canopy cover.

Blue oak canopy class	Percent canopy cover	Number of plots	Live seedling-origin S1-S3 saplings (% of plots)	S0 seedlings (% of plots)
0	0	217	2.3%	2.3%
1	<2.5%	200	14%	9%
2	2.5% - 20%	397	14.6%	10%
3	20% - 50%	433	15%	8.5%
4	50% - 80%	194	12.9%	7.2%
5	80% - 97.5%	58	15.5%	0%
6	>97.5%	1	0%	0%

To determine whether saplings were more likely to occur in the open, near the canopy edge, or under tree canopy, we noted the position of each tallied sapling relative to tree canopy during our field survey. In the three locations with the most seedling-origin saplings, the majority of all saplings were found in the open, beyond the edge of overstory tree canopy (Table 4-9). The fewest seedling-origin saplings were found directly beneath tree canopy, despite the fact that most acorns fall in this area.

TABLE 4-9. Counts and percentages of live seedling-origin S1-S3 saplings in each position relative to the canopy for locations 1,3, and 4.

	Position relative to canopy		
Location	open	edge of canopy	under canopy
1	561 (68%)	204 (25%)	58 (7%)
3	112 (69%)	39 (24%)	11 (7%)
4	59 (50%)	34 (29%)	26 (22%)

Predictably, sprout origin saplings were almost always found in the open beyond tree canopy (Table 4-10). Except at the edges of clearing and near residual trees, sprout origin saplings are initially in the open due to the removal of the overstory. With time, sprout saplings may become overtopped by faster-growing adjacent trees and saplings, and thereby end up beneath tree canopy. Four of the five saplings under the canopy at location 15 were in the S3 size class, which suggests that they had been growing long enough to have become overtopped by adjacent trees.

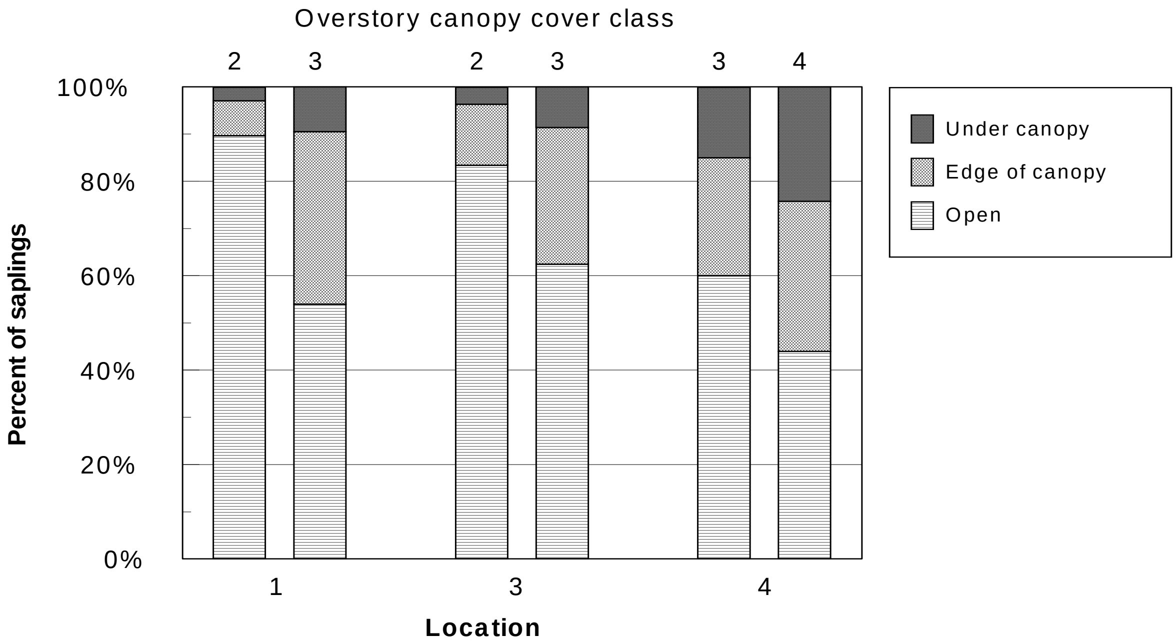
TABLE 4-10. Counts and percentages of live sprout-origin S1-S3 saplings in each position relative to the canopy at locations 4 and 15.

	Position relative to canopy		
Location	open	edge of canopy	under canopy
4	40 (100%)	0 (0%)	0 (0%)
15	98 (93%)	2 (2%)	5 (5%)

The proportion of plot area that falls under each of the canopy positions (open, edge, canopy) is related to total plot canopy cover. Therefore, the position of saplings relative to the canopy is potentially confounded with total canopy cover within the plot. To examine the relationship between sapling position relative to the canopy further, we compared the position of seedling-origin saplings relative to the canopy in plots with different levels of canopy cover. We restricted this analysis to location/canopy class combinations having at least 40 saplings. As shown in Figure 4-6, the percentage of saplings found in the canopy and edge positions increased as total plot canopy cover increased. In each canopy class, the percentage of saplings found in open positions falls within the range of the percentage of the plot area which would be classified as open.

We also examined the relationship between position relative to the canopy and sapling mortality for all locations that had substantial numbers of dead seedling-origin saplings. At locations 1, 4, and 9, substantially higher levels of mortality were seen under tree canopy than in the open position (Table 4-11). This relationship was not observed at location 3 and 7, which showed high levels of sapling mortality in the open position.

FIGURE 4-6. Percentage of live seedling-origin saplings occurring in each position relative to tree canopy for selected total plot canopy cover classes at locations 1,3, and 4.



Canopy class	% canopy cover	midpoint
2	2.5 - 20%	11%
3	20 - 50%	35%
4	50 - 80%	65%

TABLE 4-11. Mortality of seedling-origin saplings by position relative to the canopy at locations 1, 3, 4, 7, and 9.

	Sapling position relative to canopy		
	Open	Edge	Canopy
Location	% mortality [total number of saplings]		
1	0.7% [565]	1.9% [208]	7.9% [63]
3	8.2% [122]	9.3% [43]	8.3% [12]
4	4.8% [62]	29.2% [48]	31.6% [38]
7	40% [5]	17.6% [17]	16.7% [12]
9	16.7% [6]	66.7% [15]	87.5% [8]

Tree mortality and regeneration

Mortality of mature trees.

We used our data on dead trees and stumps to calculate approximate rates of natural and total tree mortality at each location. As with the data for dead saplings, mortality estimated from observations of dead trees and stumps will generally underestimate actual mortality. At many locations, dead trees have been removed or destroyed by fire or decay, and were therefore not observed. The estimates are further clouded by the fact that the year in which mortality occurred is unknown. Dead trees were only counted if they appeared to have died within the past 30 years, based on the condition of the dead material. These evaluations are subjective and are thus subject to some error, which may lead to overestimates or underestimates in mortality rates.

Natural mortality, based on dead tree totals, varied between locations (Table 4-12). Overall, nearly 6% of the blue oak trees within surveyed plots were scored as having died within the past 30 years. The highest rate of mortality was seen at location 12, where blue oak mortality was associated with high levels of total canopy cover and dense stands of mixed hardwoods. Locations 12 and 14 had the highest overall average plot canopy cover ratings (Table 4-12), and both locations had high rates of mortality. However, canopy cover was relatively sparse at location 8, and high levels of mortality at this location appeared to be associated with root disease.

TABLE 4-12. Blue oak stand density, plot canopy cover, and mortality by location.

Location	Average blue oak density (live trees/ha)	Average total canopy cover rating*	Total live blue oak trees	Total dead blue oak trees	Dead blue oak trees (% of trees)	Dead blue oak trees (% of plots)	All blue oak mortality (dead + recent stumps**) (% of plots)
1	159	3.34	1278	49	3.7%	23%	49%
2	98	2.16	790	31	3.8%	23%	25%
3	71	2.15	562	30	5.1%	23%	23%
4	161	3.50	1305	31	2.3%	18%	24%
5	99	3.00	794	60	7.0%	33%	33%
6	157	3.44	1266	69	5.2%	47%	47%
7	113	2.06	911	63	6.5%	37%	38%
8	38	2.14	309	34	9.9%	26%	26%
9	135	2.56	1085	88	7.5%	46%	46%
10	101	2.99	812	41	4.8%	28%	28%
11	16	1.44	130	4	3.0%	4%	4%
12	113	4.11	905	110	10.8%	42%	42%
13	150	3.16	1207	79	6.1%	41%	41%
14	128	3.74	1027	96	8.5%	50%	50%
15	59	2.57	474	14	2.9%	7%	32%
Overall	107	2.83	12855	799	5.9%	30%	34%

* Canopy cover was rated on a 0 (none) to 6 (>97.5%) scale, as shown in Table 4-7.
**Stumps are considered recent if they were likely to have originated between 1950 and 1992 based on appearance and/or cutting history data.

Assuming that all dead trees tallied had died within a 30 (± 10) year period, the overall rate of natural mortality observed for all locations would be about 2 deaths (1.5-3)/100 trees/decade, or between 1.6 and 3.2 trees/ha/decade. Location 12 had the maximum calculated rate of mortality, between 2.7 and 5.4 deaths/100 trees/decade, or 3 to 6 trees/ha/decade.

Based on the number of plots with dead trees, location 11 appears to have an unusually low rate of tree mortality relative to the other locations (Table 4-12, Figure 4-7). It is likely that downed and possibly standing dead trees were previously removed by the land manager at this location, giving the appearance of low mortality rates. Mortality due to recent tree cutting was most significant at locations 1, 4, and 15 (Table 4-12), all of which also had relatively high rates of sapling recruitment.

We did not attempt to analyze our data in detail to look for factors that might be related to tree mortality within the plot. However, we did look at the relationship between blue oak canopy cover and blue oak mortality, since our field observations indicated that tree mortality was common in densely stocked stands, which typically have a high level of canopy cover. The occurrence of blue oak tree mortality does increase with increasing blue oak canopy cover and total blue oak density (Table 4-13). However, the overall rate of mortality is greatest in plots with the lowest levels of blue oak canopy, and remains relatively constant at higher levels of blue oak canopy. Thus, although dead trees are more common in more densely stocked plots, this is apparently not due to a greater mortality rate in these plots, but is simply due to a higher probability of encountering a dead tree in plots that have more trees.

TABLE 4-13. Total blue oak density and natural mortality of blue oak trees by blue oak canopy cover class.

Blue oak canopy cover class	Number of plots	Average number of live and dead blue oak trees per plot	Dead blue oak trees (% of trees)	Dead blue oaks trees present (% of plots)
0	217	.07	100%	4.6%
1	200	1.85	11.4%	14.0%
2	397	4.98	6.7%	24.4%
3	433	11.42	6.1%	40.0%
4	194	23.36	4.7%	53.6%
5	58	30.86	5.1%	60.3%
6	1	22	9.1%	100%

Regeneration

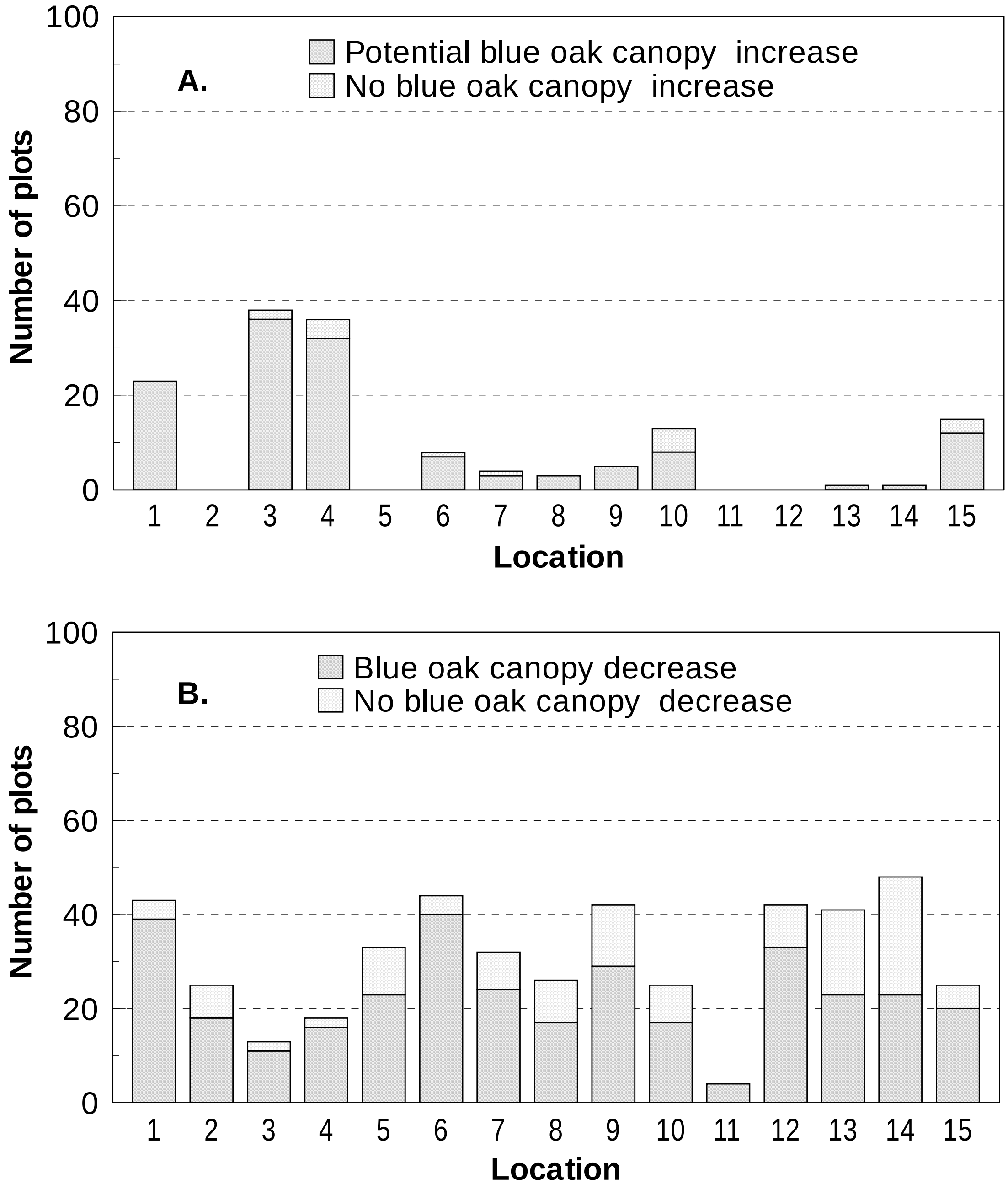
In order to evaluate net regeneration at each location, we looked at the balance between sapling recruitment and tree mortality on a plot by plot basis. One way to evaluate regeneration is to look at the net change in blue oak density within plots due to mortality and recruitment. If we make the simplifying assumption that every live sapling represents a potential tree, tree density within a plot will increase if the number of saplings exceeds the number of recent (past 30 to 42 years) dead and/or cut trees in the same plot. A net loss in density will result if there is no sapling recruitment to offset tree mortality. Given that true mortality rates are probably higher than observed rates and that at least some saplings may not be recruited to the tree stage, this calculation will tend to overestimate actual rates of regeneration.

Using this type of calculation, all locations show a net loss in blue oak density due to unreplaced tree mortality in at least some plots, and in six locations, over 40% of all plots show unreplaced tree mortality (Figure 4-7B). Only locations 3 and 4 have more plots with net gains in blue oak density than net losses (Figure 4-7). At most locations, the majority of plots show no recent net change in blue oak stand densities.

We can refine these regeneration estimates somewhat by taking into account the effects of tree canopy cover. Although blue oak tree mortality normally reduces stand density, it may not reduce blue oak canopy cover if dead trees are overtopped by other blue oaks. Similarly, saplings that are located under blue oak canopy are not likely to increase the total canopy cover of blue oak in the plot, whereas saplings located in the open or at canopy edge may. Based on plot data we collected, we were able to adjust the mortality data to reflect only mortality which resulted in a decrease in blue oak canopy cover within each plot. We also used sapling position data to adjust recruitment counts by eliminating saplings that occurred under canopy as a potential source of new blue oak canopy. These adjusted numbers are shown as the lower portions of the bars in Figure 4-7.

Incorporating the canopy criteria into the regeneration estimates has little effect on the estimates of plots showing increases in blue oak dominance (Figure 4-7A). However, discounting mortality of suppressed understory trees substantially decreases the estimates of blue oak loss for many locations, especially locations 13 and 14 (Figure 4-7B). Even with these adjustments, only at locations 3 and 4 are plots with net gains more common than plots with net losses.

FIGURE 4-7. Balance between live blue oak sapling recruitment and recent blue oak tree mortality at each location. A. Number of plots at each location in which recruitment exceeds mortality. Potential cover increase within a plot was assumed if saplings were in the open or edge position. B. Number of plots at each location in which mortality exceeds sapling recruitment. Cover decrease within a plot was based on plot ratings of blue oak canopy decrease (Appendix 2).



5. STATISTICAL MODELING OF FACTORS AFFECTING RECRUITMENT

Many factors have been suggested to affect sapling recruitment in blue oak, so we initially considered a large variety of predictor variables and possible outcome variables (Appendix 2). However, it was clearly not possible to include all of these variables in the statistical analyses. We therefore screened the variables to select a smaller subset that could be used to construct statistical models.

Some variables were eliminated from the analysis because they did not vary in enough plots to provide meaningful information. We also had to choose between variables that were highly correlated with each other because it is not possible to fit a model than contains highly correlated predictor variables. Certain variables which were nominally distinct turned out to describe the same subsets of plots, and were therefore redundant. This situation arose most frequently among the history variables. For example, at location 4, plots were separated into the same two subsets using the grazing variables GRCONT30, GRSEASON30, GRLAST, GRYEARS30, and several others, even though these variables measure different aspects of grazing history (Appendix 2). Although the effects of these history variables could be different, we did not encounter enough variability in these factors within our plots to allow us to separate potential effects.

It was also necessary to combine several levels of certain categorical variables to reduce the total number of factors in the models. For example, although topographic position was originally coded in seven categories, these were collapsed to three for use in the logistic regression models. Some categorical and continuous variables were similarly recoded as binary variables. We considered both the distribution of the variables and the ecological interpretation of the resulting combined classes when recoding variables, and in some cases several alternative reclassifications were tested. These recoded variables are given the name of the original variable followed by a letter, e.g. TOPOPOSA. In considering the final models, it should be borne in mind that the level of significance of a categorical variable can be affected by the manner in which the categories have been grouped, especially if the relationship between the variable and recruitment is nonlinear.

Within-location models

We conducted some exploratory analyses that considered data from all locations with at least low levels of recruitment in a single model. However, it was not possible to construct valid statistical models using all 1500 plots for the following reasons:

- In general, it is likely that plots within a location are more similar to each other than they are to plots in other locations. This correlation structure should be accounted for in any combined analysis, but no practical methods for handling this complex situation are currently available.
- For some predictor variables, certain levels occur at only one of the study locations. The effects of these variables are confounded with the effect of location, and it would not be possible to separate these effects in a combined model.
- Distributions of many of the predictor variables differ between locations, which indicates inhomogeneity between locations. Given that this situation exists, it is likely that the effects that some variables have on recruitment may vary between the

locations. If this is the case, combining data across locations will only tend to obscure relationships that exist between predictor and outcome variables.

- Some locations have very low levels of recruitment or no recruitment at all. It is not possible to fit a model that adjusts for location to a combined data set that includes locations with such low levels of recruitment.

Due to these considerations, model building based on individual plot data was confined to individual locations. Only six locations, namely 1, 3, 4, 6, 7, and 15, had sufficient levels of recruitment to be considered for the fitting of location-specific models (Table 4-6). Although many different variables were considered in the construction of preliminary models, only eight to twelve variables were used to construct the final models. Models for individual locations include only factors which varied sufficiently within the location to be meaningful. Therefore, fire-related variables were considered only at locations 3, 6, and 7 and grazing history variables were only included for location 4.

We restricted our within-location model building to three different outcome variables: ALLRECR, S0PRESENT, and S123SEED. The ALLRECR variable was selected as the basic outcome variable. This binary variable is the most inclusive, and indicates whether any sort of recruitment beyond the small seedling stage (i.e., S0-S3) is present in the plot. Although ALLRECR includes plots with both live and dead saplings, the number of plots with only dead saplings was very small, so that restricting the model only to plots with live recruitment would probably not have yielded different results. Dead saplings were sufficiently rare that it was not possible to separately model factors affecting their occurrence. We also constructed some models using S0 seedlings as the outcome variable. The S0 occurrence data was dichotomized to produce a binary variable (S0PRESENT).

S123SEED was selected as the outcome variable for Poisson regressions of sapling counts per plot. This count variable includes both live and dead saplings, but excludes S0 seedlings and sprout-origin recruitment. S0 seedlings could not be included in count models since they were only recorded as count classes rather than exact counts. Sprout-origin saplings were uncommon at all locations except location 15 (Table 4-6). Since factors that influence the *number* of sprout-origin saplings per plot could differ from factors affecting the number of seedling-origin saplings per plot, we normally did not combine both origin classes in the analysis of counts. However, we did test a combined count model using the variable LIVESAPL at location 15.

TABLE 5-1. Alphabetical listing of names for individual plot variables cited in text. Full descriptions of these and other variables considered are included in Appendix 2.

Variable name	Type	Category	Description
ALLRECR	Binary	Outcome	Any form of recruitment is present in plot, including S0, and/or live or dead S1, S2, or S3 of either seedling or sprout origin
LIVESAPL	Count	Outcome	Total number of all live S1, S2, and S3 saplings, of both seedling and sprout origin
S0123LIVE	Binary	Outcome	Live seedling-based recruitment is present, including S0, S1, S2, or S3
S0PRESENT	Binary	Outcome	S0 stage seedlings present in plot
S123SEED	Count	Outcome	Total number of S1, S2, and S3 seedling-origin saplings, including both live and dead
ALTITUDE	Continuous	Site factor	Plot altitude in feet
CHRVERTBR	Categorical	Site factor	Rating of the chronic vertebrate browsing intensity within the plot (0 - 3)
CHRVERTBRA	Binary	Site factor	Chronic vertebrate browsing intensity in plot is rated as high (CHRVERTBR = 3)
CUMGRAZE	Continuous	History factor	Cumulative grazing score, calculated as the sum of (months grazed)$\times$(relative stocking)$\times$(season factor) over the 30 years prior to 1992, where stocking is rated on a scale of 0 (none) to 3 (high) and the season factor is 1 for winter and 2 for summer or year-round
CURRVERTBR	Categorical	Site factor	Rating of the current vertebrate browsing intensity within the plot (0 - 3)
CURRVERTBRA	Binary	Site factor	Current vertebrate browsing intensity in plot is rated as high (CURRVERTBR = 3)
CUT42YR	Binary	History factor	Tree cutting has occurred in the plot within the 42 years prior to 1992
FIRE30YR	Binary	History factor	Plot has burned one or more times in the 30 years prior to 1992.
GAPORCUT42	Binary	Site/history factor	Tree cutting has occurred in the plot within the 42 years prior to 1992 or a canopy gap due to other factors has developed in the plot within the past 30 years (estimated)
GRSEASON30	Categorical	History factor	Predominant season of grazing during the 30 years prior to 1992
GRYEARS30	Continuous	History factor	Number of years that plot was grazed between 1962 and 1992
INSOL12	Continuous	Site factor	Calculated total daily insolation (MJ/m^2) for plot on the average day in December (December 10)
OTHCANSPP	Continuous	Site factor	Number of species in the tree canopy other than blue oak
REBURN30	Binary	History factor	Plot has been burned at least two times in the past 30 years
SHRUBCOVER	Categorical	Site factor	Estimate of the total shrub cover in the plot (0-6 scale)
SHRUBCOVERA	Binary	Site factor	Estimated shrub cover in the plot is greater than 2.5%
SHRUBPRESENT	Binary	Site factor	Shrubs are present within the plot
SMALLTREES	Binary	Site factor	Small-diameter trees (3 to 13 cm dbh) present in plot
SOILAWC	Continuous	Site factor	Estimated total available water-holding capacity within the rootzone, in inches
STANDEDGE	Categorical	Site factor	Number of adjacent plots on the sampling grid that fall outside of the blue oak stand (0 - 4)
STANDEDGEA	Binary	Site factor	One or more of the adjacent plots on the sampling grid falls outside of the blue oak stand
TOPOPOS	Categorical	Site factor	Plot topographic position
TOPOPOSA	Categorical	Site factor	TOPOPOS recoded to 3 classes: hilltop, upper 1/3 hill, lower 2/3 hill and low flats
TOTCANOPY	Categorical	Site factor	Estimate of the total tree canopy cover within the plot (0-6 scale)
TOTCANOPYA	Categorical	Site factor	TOTCANOPY recoded to three classes: $\leq$2.5%, >2.5% to 20%, >20%
TOTCANOPYB	Categorical	Site factor	TOTCANOPY recoded to three classes: $\leq$20%, >20% to 80%, >80%

Location 1 - Wantrup

The following predictor variables were considered for inclusion into the logistic and Poisson regression models: ALTITUDE, TOPOPOS, INSOL12, SOILAWC, TOTCANOPY, OTHCANSPP, SHRUBPRESENT, CUT42YR, and CURRVERTBR. CUT42YR was used at this location in preference to the GAPORCUT42 variable. We believed that the clearing history, which was based on information from the land manager and aerial photo analysis, was more reliable than the assessment of recent canopy gaps for this first location.

ALLRECR outcome. A fairly good fit was obtained with the single variable model for CUT42YR (odds ratio 23.3, P<0.01). Plots in which trees had been cut within the past 42 years were about 15 times more likely to have recruitment than plots where no cutting had occurred in this interval. As shown in Figure 4-2, almost all of this regeneration was of seedling origin. ALTITUDE and CURRVERTBRA were also fitted into the final model (Table 5-2), but the model fit was not substantially better than in the model with CUT42YR alone. At this location, blue oak recruitment was less likely to be found at higher elevations than at lower elevations. In both the single variable and multivariate models, CURRVERTBRA was positively correlated with recruitment, although this factor was only significant at P=.083 in the multivariate model.

Using P(ALLRECR) ≥ 0.5 as the criterion for predicting recruitment in a plot, the final model correctly predicted the ALLRECR outcome in 84% of the plots (Table 5-3). The model correctly classified 87% of the plots with recruitment and 82% of the plots that lacked recruitment. Recruitment at this location was strongly clustered in the northeast portion of the site (Figure 5-1), and the model correctly predicts that most of the recruitment occurs in this area. However, the model predicts very low recruitment probabilities (P<.15) for the two most southerly plots that have recruitment, both of which occur at relatively high elevations.

TABLE 5-2. Logistic regression model for ALLRECR outcome variable at location 1 (Wantrup).

Factor	Odds ratio	95% confidence limits
CUT42YR	14.97***	2.982 - 76.50
ALTITUDE (ft)	.9941***	.9911 - .9972
CURRVERTBRA	3.217*	.8598 - 12.04

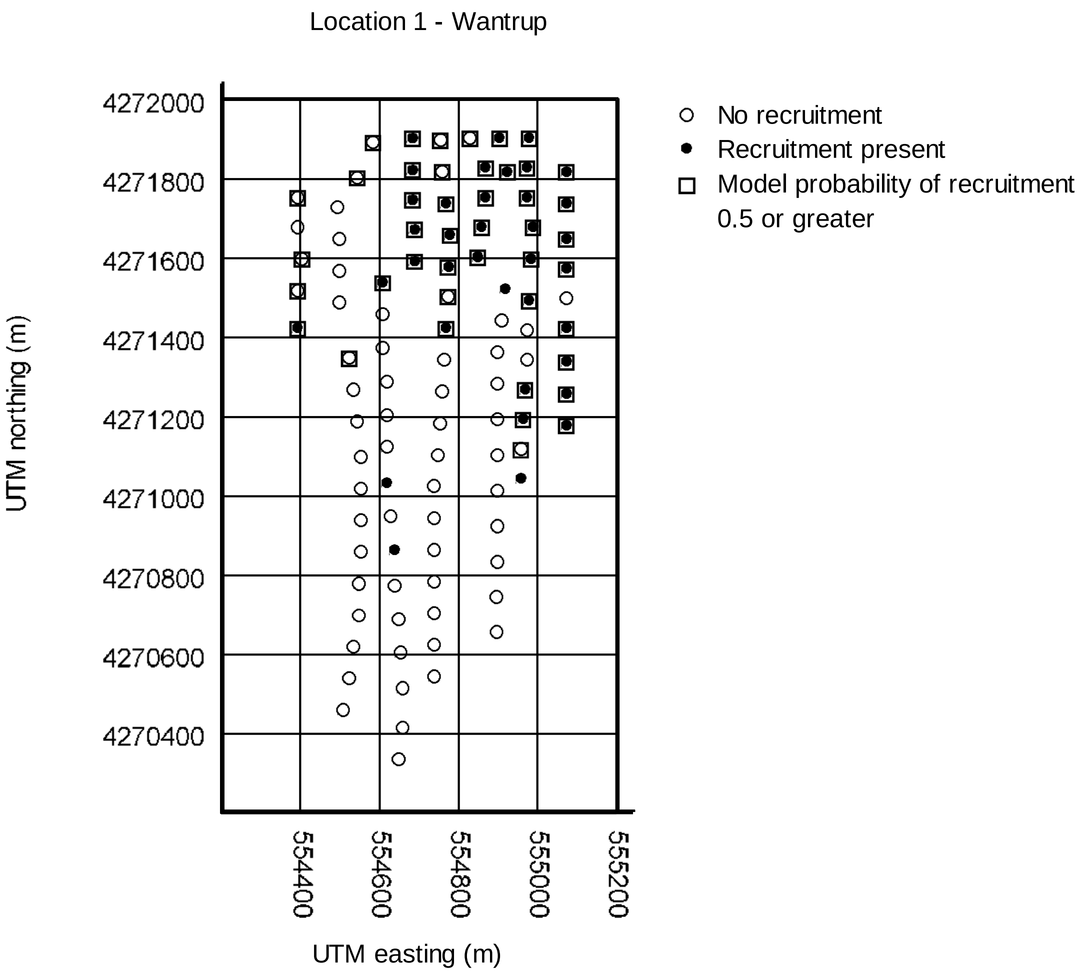
Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

TABLE 5-3. Counts of plots with observed recruitment (ALLRECR) versus recruitment predicted by logistic regression model for location 1 (Wantrup).

	Predicted*		
Observed	No recruitment	Recruitment	Totals
No recruitment	51	11	62
Recruitment	5	33	38
Totals	56	44	100

* Recruitment was considered to be predicted if the calculated probability of recruitment was ≥ 0.5.

FIGURE 5-1. Predicted and actual recruitment (ALLRECR) at location 1.



S0PRESENT outcome. The model for this outcome was very similar to that for the ALLRECR variable (Table 5-4), presumably due to the high degree of overlap between plots with S0 seedlings and other forms of recruitment (Figure 4-1).

TABLE 5-4. Logistic regression model for S0PRESENT outcome variable at location 1 (Wantrup).

Factor	Odds ratio	95% confidence limits
CUT42YR	12.33***	2.587 - 58.81
ALTITUDE (ft)	.9957***	.9931 - .9983

Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

S123SEED outcome. In single variable models, all of the factors tested were significant at P<0.05. Although a number of variables were fitted into the Poisson regression model (Table 5-5), the final fit of the model was rather poor. As in the logistic models, CUT42YR and ALTITUDE were highly significant and strongly related to the sapling count per plot. The presence of shrubs in the plot (SHRUBPRESENT) was also positively correlated with sapling recruitment, whereas saplings were less likely to occur as the number of canopy species (OTHCANSPP) increased. The upper one-third slope position had the lowest numbers of saplings per plot among the three topographic position categories (TOPOPOSA). SOILAWC was negatively correlated with sapling counts, i.e., higher numbers of saplings were found in plots with lower soil AWHC. CURRVERTBRA was originally entered into the model, but was not significant once the model was adjusted for the other factors.

TABLE 5-5. Poisson regression model for S123seed outcome variable at location 1 (Wantrup).

Factor	Levels	Rate ratio	95% confidence limits
ALTITUDE (ft)		.9929***	.9918 - .9940
CUT42YR		46.73***	17.44 - 125.2
SHRUBPRESENT		3.232***	2.788 - 3.746
OTHCANSPP		.4553***	.3982 - .5205
TOPOPOSA	hilltop vs. upper 1/3 slope	.3700***	.1830 - .7481
	hilltop vs. lower 2/3 slope	.9646	.6738 - 1.381
SOILAWC (in)		.9407***	.9018 - .9812

Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

Location 3 - Pinnacles

The following predictor variables were considered for inclusion into the logistic and Poisson regression models: ALTITUDE, TOPOPOS, INSOL12, SOILAWC, TOTCANOPY, OTHCANSPP, SMALLTREES, STANDEDGE, SHRUBPRESENT, GAPORCUT42, FIRE30YR, REBURN30, and CURRVERTBR.

Allrecr outcome. The fit of the final model for this outcome was fair. Recruitment was least likely to occur in plots where the total tree canopy cover was less than 2.5% (TOTCANOPYA=1). The highest level of plot canopy cover (>20%) was the most favorable for recruitment, but since only eight of the 42 plots in this group had more than 50% canopy cover, the model compares very low levels of canopy with moderate levels. Soil available water-holding capacity within the plot (SOILAWC) was positively correlated with recruitment. Soils at this location generally had low available water-holding capacities: 80% of the plots were rated as having soil available water-holding capacities of less than 5 cm (2 inches).

Plots within the main portion of the blue oak stand were also more likely to have recruitment than plots that were adjacent to large patches (>160 m diameter) of chaparral or open grassland (STANDEDGEA=1). The variable REBURN30 had a highly significant negative effect on recruitment when it was included in a model by itself (odds ratio .3242, P=.008), but its significance level dropped to P=.111 in the final model, presumably due to correlations with other factors included in the model (Table 5-6). FIRE30YR was not significant for this outcome in the single variable or mutivariate models.

The final model correctly predicted the ALLRECR outcome in only about 69% of the plots with P(ALLRECR)≥0.5 as the criterion for predicting recruitment in a plot (Table 5-7). Lowering the prediction criterion to P(ALLRECR) ≥ 0.4 increased the percentage of correct classifications slightly, to 73%. At P(ALLRECR) ≥ 0.5, the model correctly classified 73% of the plots with recruitment but only 64% of the plots that lacked recruitment. Recruitment was also somewhat clustered at this location. Recruitment was seen in a rather high proportion of the plots on the relatively level plateau at the north end of the site (Figure 5-2). Most of the plots in this area had only been burned once in the past 30 years, in 1979.

TABLE 5-6. Logistic regression model for ALLRECR outcome variable at location 3 (Pinnacles).

Factor	Levels	Odds ratio	95% confidence limits
REBURN30		.4362	.1571 - 1.211
TOTCANOPYA	≤2.5% vs. >2.5 to 20%	4.228**	1.155 - 15.48
	≤2.5% vs. >20%	5.764***	1.521 - 21.84
SOILAWC (in)		2.217**	1.069 - 4.596
STANDEDGEA		.2836**	.09442 - .8515

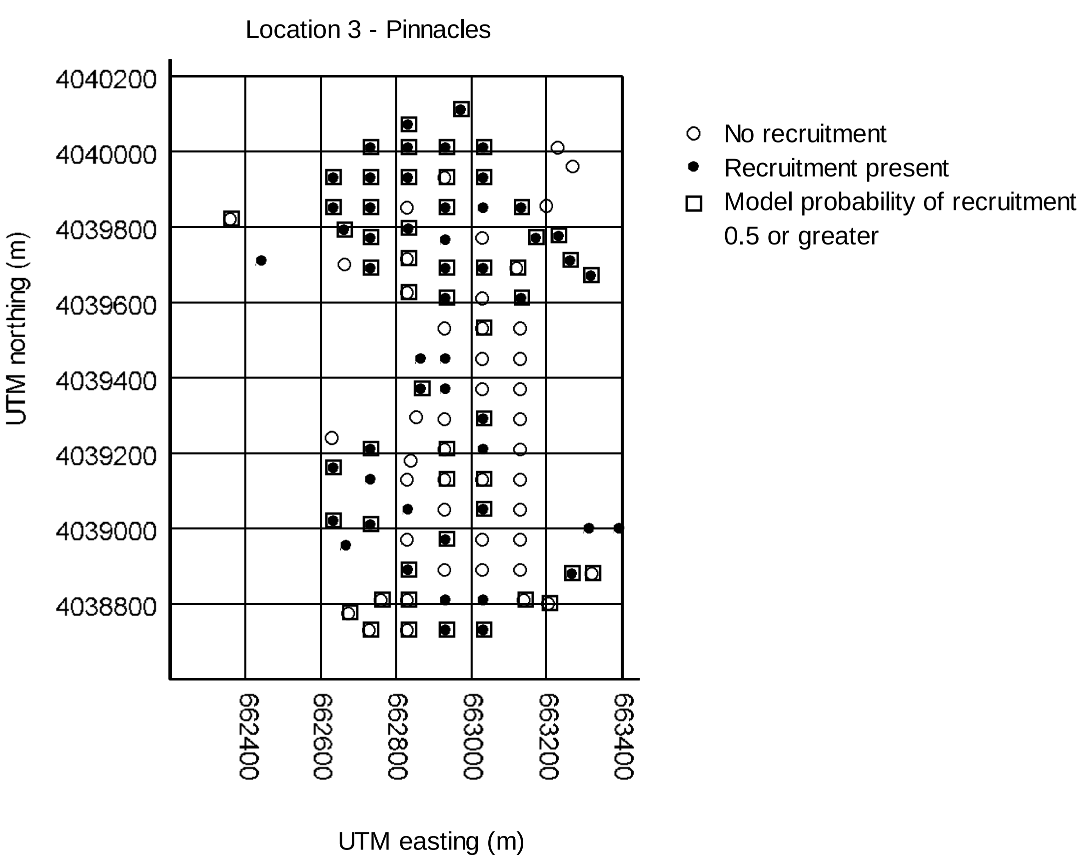
Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

TABLE 5-7. Counts of plots with observed recruitment (ALLRECR) versus recruitment predicted by logistic regression model for location 3 (Pinnacles).

	Predicted*		
Observed	No recruitment	Recruitment	Totals
No recruitment	30	17	47
Recruitment	14	38	52
Totals	44	55	99

* Recruitment was considered to be predicted if the calculated probability of recruitment was ≥ 0.5.

FIGURE 5-2. Predicted and actual recruitment (ALLRECR) at location 3.



S0PRESENT outcome. The model for this outcome was very similar to that for the ALLRECR outcome. The final model fit was fair. S0 seedlings were more likely to occur in plots with more than 20% tree canopy cover (TOTCANOPYA) than in plots with lower levels of canopy cover. Available soil water-holding capacity (SOILAWC) was also positively associated with the presence of S0 seedlings. Although the significance level was above the 5% level (P=0.068), REBURN30 was fitted into the model. Plots that had burned more than one time in the past 30 years were less likely to have S0 seedlings than those that had either not burned or had burned only once. At this location, repeated fires had occurred within five years of each other in plots that had burned more than once in the past 30 years (see fire history, page 19). As with the ALLRECR outcome, REBURN30 was more strongly related to recruitment than FIRE30YR.

TABLE 5-8. Logistic regression model for S0PRESENT outcome variable at location 3 (Pinnacles).

Factor	Levels	Odds ratio	95% confidence limits
TOTCANOPYA	≤2.5% vs. >2.5 to 20%	3.850	.6752 - 21.95
	≤2.5% vs. >20%	8.447**	1.506 - 47.38
SOILAWC		1.985**	1.024 - 3.848
REBURN30		.3334*	.1026 - 1.083

Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

S123SEED outcome. The fit of the Poisson regression model was poor, despite the fact that numerous variables were fitted into the model (Table 5-9). This indicates that other variables not included in the model significantly affect this outcome and that the Poisson model may not be the most appropriate model for this data. The effects of the factors REBURN30 and SOILAWC were the same as seen in the S0PRESENT outcome. Plots with more xeric exposures, as indicated by higher levels of INSOL12, had fewer saplings than plots with more mesic slope/aspect combinations. At this site, plots in the upper slope positions tended to have higher sapling counts than plots on hilltops or lower topographic position (TOPOPOSA). The presence of recent cutting or a natural gap within the plot was also positively associated with recruitment.

Our study area had been free of domestic livestock for at least 60 years, and deer were the only browsing animals at this location. There was a positive association between high levels of recent browsing (CURRVERTBRA) and sapling counts per plot, according to the Poisson model. SHRUBPRESENT was also positively associated with sapling counts at this location in the final model. The significance of this factor in the model was strongly affected by other predictor variables included in the model, indicating that the presence of shrubs is correlated with some of the same factors that are correlated with the presence of saplings.

TABLE 5-9. Poisson regression model for S123SEED outcome variable at location 3 (Pinnacles).

Factor	Levels	Rate ratio	95% confidence limits
INSOL12		.9534**	.9118 - .9968
TOPOPOSA	hilltop vs. upper 1/3 slope	3.272***	1.831 - 5.848
	hilltop vs. lower 2/3 slope	1.353	.7592 - 2.410
REBURN30		.3373***	.2084 - .5458
GAPORCUT42		1.709***	1.240 - 2.356
CURRVERTBRA		1.556***	1.133 - 2.135
SOILAWC		1.410***	1.174 - 1.692
SHRUBPRESENT		1.490*	.9566 - 2.321

Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

Location 4 - Sierra

The following predictor variables were considered for inclusion into the logistic and Poisson regression models: ALTITUDE, TOPOPOS, INSOL12, SOILAWC, TOTCANOPY, SMALLTREES, OTHCANSPP, SHRUBPRESENT, GAPORCUT42, and CUMGRAZE. The variable CURRVERTBR was highly collinear with CUMGRAZE, and could not be included together with CUMGRAZE in the model for this location.

ALLRECR outcome. The fit of the final model was reasonably good. Several factors showed strong positive associations with recruitment. Plots that had 3 to 13 cm dbh trees (SMALLTREES), recent (within 42 years) cutting or natural gaps (GAPORCUT42), or canopy species besides blue oak (OTHCANSPP) were more likely to have some form of recruitment than plots that lacked these factors. INSOL12 also showed a positive association with recruitment, although the strength of this association was weaker. The INSOL12 variable indicates that plots with more xeric slope/aspect combinations (higher INSOL12) were more likely to have recruitment than plots with more mesic exposures. However, extremely xeric exposures are not represented at this location. There were only 10 plots with southerly aspects (135° to 225°) at this location, and only 4 of these had slopes greater than 20%.

Two factors showed negative effects on recruitment. Plots that were located in the nongrazed area were eight to nine times more likely to have recruitment than those located in the currently-grazed areas, which had higher CUMGRAZE scores (Table 3-8). High levels of overall canopy cover (>80%) were also unfavorable for recruitment. There was no significant difference between the low (≤20%) and moderate (>20% to 80%) canopy cover classes with respect to recruitment.

SHRUBPRESENT was highly significant and positively correlated with ALLRECR in the single variable model, but it was not significant in the multivariate model. As noted earlier, this suggests that shrub presence is strongly correlated with other factors included in the final model.

The final model correctly predicted the ALLRECR outcome in about 73% of the plots with P(ALLRECR)≥0.5 as the criterion for predicting recruitment in a plot (Table 5-11). The model correctly classified 75% of the plots with recruitment and 71% of the plots that lacked recruitment. Recruitment was rather scattered throughout the entire site (Figure 5-3), but two distinct areas had particularly high proportions of plots with recruitment: the nongrazed area (southern portion of the eastern transects), and a recently (1988-1990) cut area in the southern portion of the site.

TABLE 5-10. Logistic regression model for ALLRECR outcome variable at location 4 (Sierra).

Factor	Levels	Odds ratio	95% confidence limits
SMALLTREES		9.449***	2.475 - 36.08
GAPORCUT42		6.131***	1.989 - 18.89
OTHCANSPP		2.853***	1.336 - 6.090
CUMGRAZE		.9913***	.9853 - .9974
TOTCANOPYB	≤20% vs >20% to 80%	.3941	.07387 - 2.102
	≤20% vs >80%	.04317**	.003812 - .4889
INSOL12		1.269*	.9716 - 1.658

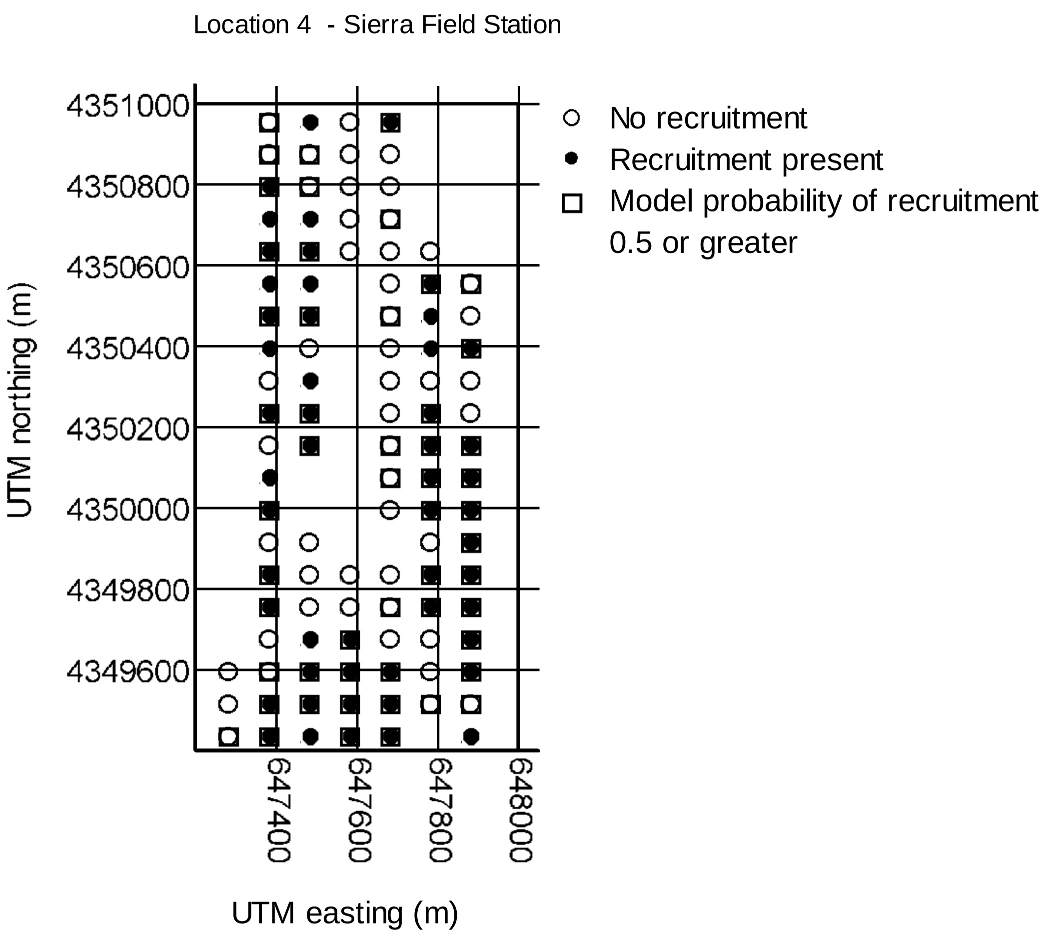
Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

TABLE 5-11. Counts of plots with observed recruitment (ALLRECR) versus recruitment predicted by logistic regression model for location 4 (Sierra).

Observed	Predicted*		Totals
	No recruitment	Recruitment	
No recruitment	35	14	49
Recruitment	13	39	52
Totals	48	53	101

* Recruitment was considered to be predicted if the calculated probability of recruitment was ≥ 0.5.

FIGURE 5-3. Predicted and actual recruitment (ALLRECR) at location 4.



S0PRESENT outcome. The model fit for this outcome was fair. The effects of OTHCANSPP, CUMGRAZE, and TOTCANOPYB on the S0PRESENT outcome were similar to that seen for the ALLRECR outcome. In addition, plots at higher elevations were less likely to have S0 seedlings than plots at lower elevations. Blue oak was generally more dominant in the lower elevation portions of this study location. Species composition was much more varied at the higher elevations in the study area, grading into ponderosa pine forest at the highest elevations.

TOPOPOSA and SHRUBPRESENT were highly significant in single variable models, but were not significant when fitted into the multivariate model. In single variable models, the hilltop/upper slope position was the least favorable level of TOPOPOSA, and plots with shrubs were more likely to have S0 seedlings than plots without shrubs.

TABLE 5-12. Logistic regression model for S0PRESENT outcome variable at location 4 (Sierra).

Factor	Levels	Odds ratio	95% confidence limits
OTHCANSPP		3.186***	1.400 - 7.250
ALTITUDE (ft)		.9944**	.9898 - .9991
CUMGRAZE		.9930**	.9873 - .9986
TOTCANOPYB	≤20% vs >20% to 80%	.7690	.1317 - 4.491
	≤20% vs >80%	.04639**	.002160 - .9961

Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

S123SEED outcome. As with the Poisson regression models for locations 1 and 3, the fit of the final model was poor. Five variables were entered into the final model (Table 5-13), but the inclusion of the last variable, SHRUBPRESENT, reduced the effect of OTHCANSPP to nonsignificance (P=.198). OTHCANSPP had been marginally significant (P=.060) in the four-variable model and highly significant in a single variable model, and was positively correlated with sapling counts. The overall effect of ALTITUDE, CUMGRAZE, and SMALLTREES was the same as noted for the other two outcome variables. Increasing levels of ALTITUDE and CUMGRAZE were negatively correlated with sapling counts. Sapling counts per plot were positively associated with the presence of small-diameter trees. As with the S0PRESENT outcome, TOPOPOSA was significant in single variable models, but not when fitted into the multivariate model.

TABLE 5-13. Poisson regression model for S123SEED outcome variable at location 4 (Sierra).

Factor	Rate ratio	95% confidence limits
ALTITUDE (ft)	.9961***	.9947 - .9975
SMALLTREES	2.191***	1.400 - 3.430
CUMGRAZE	.9976***	.9962 - .9991
SHRUBPRESENT	1.849*	.9038 - 3.785
OTHCANSPP	1.160	.9254 - 1.453

Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

Location 6 - Sequoia

The overall level of recruitment at this location was relatively low (Table 4-6, Figure 4-2). Therefore, a reduced set of predictor variables was considered for inclusion into the logistic regression model: TOPOPOS, INSOL12, SOILAWC, TOTCANOPY, OTHCANSPP, SHRUBPRESENT, GAPORCUT42, FIRE30YR, and CURRVERTBR. In addition, ALLRECR was the only outcome variable tested.

ALLRECR outcome. The number of plots with any form of recruitment was so low that only a few variables could be fitted into the model at a time. The final model contained only a single variable, CHRVERTBRA. Plots that were scored as having a high level of vertebrate browsing were significantly less likely to have any form of recruitment than plots with lower levels of chronic browsing pressure. Browsing at this site was caused by horses, mules, and deer.

TABLE 5-14. Logistic regression model for ALLRECR outcome variable at location 6 (Sequoia).

Factor	Odds ratio	95% confidence limits
CHRVERTBRA	.1557***	.05179 - .4682

Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

Location 7 - Dye Creek

The amount of recruitment at this location was similar to that seen at location 6, and a reduced set of predictor variables was considered for inclusion into the logistic regression model. Predictor variables considered in the model were: TOPOPOS, INSOL12, SOILAWC, TOTCANOPY, SHRUBPRESENT, GAPORCUT42, FIRE30YR, and CURRVERTBR. ALLRECR was the only outcome variable tested.

ALLRECR outcome. The overall fit of the model was fair. As at location 6, high levels of chronic vertebrate browsing pressure were associated with lower levels of recruitment. The magnitude of the effect of the CHRVERTBRA variable was almost identical to that calculated for location 6. Cattle were the primary browsers at this location, although deer are also present. SOILAWC was also significant in the logistic regression model. The odds ratio for this variable indicates that recruitment was more likely to occur in plots with higher levels of soil water-holding capacity.

TABLE 5-15. Logistic regression model for ALLRECR outcome variable at location 7 (Dye Creek).

Factor	Odds ratio	95% confidence limits
CHRVERTBRA	.1647***	.05488 - .4941
SOILAWC (in)	1.728**	1.044 - 2.858

Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

Location 15 - Jamestown

The following predictor variables were considered for inclusion into the logistic and Poisson regression models: TOPOPOS, INSOL12, SOILAWC, TOTCANOPY, OTHCANSPP, SMALLTREES, SHRUBPRESENT, SHRUBCOVER, GAPORCUT42, and CURRVERTBR. Altitude was not considered in the model for this location because the overall range in elevation at this site was rather small.

There were not enough plots with S0 seedlings at this location to construct a model for the S0PRESENT outcome. Since there was a relatively large number of sprout origin saplings at this location, a second Poisson model was constructed using the LIVESAPL outcome, which includes both seedling- and sprout-origin saplings. However, since 75% of the saplings at location 15 are sprout origin, this model primarily looks at effects on sprout origin saplings.

ALLRECR outcome. The fit of the final model was fair. In single variable models, all of the tested variables were significantly related to recruitment. However, most of the factors that were highly significant by themselves were not significant when combined with other variables, which indicates that many of these variables were highly interrelated. Three factors were included in the final model (Table 5-16). Plots with high levels of current vertebrate browsing (CURRVERTBRA) were less likely to have recruitment than those with lower levels of browsing. Recruitment was also much more likely to occur in plots that had shrubs than in those without. Furthermore, the probability of recruitment increased as the number of shrub species or the shrub cover increased. Plots with recent cutting or natural gaps were also more likely to have saplings than plots without, but the overall significance level of this variable was strongly affected by the other variables that were included in the model.

The final model correctly predicted the ALLRECR outcome in 81% of the plots with P(ALLRECR)≥0.5 as the criterion for predicting recruitment in a plot (Table 5-17). The model correctly classified 83% of the plots with recruitment and 80% of the plots that lacked recruitment. Plots with recruitment were somewhat clustered (Figure 5-4). In the northern part of the site, recruitment was found primarily in previously cut areas and along drainages. At the southern end of the site, many of the plots along a small creek and a north-facing slope had recruitment.

TABLE 5-16. Logistic regression model for ALLRECR outcome variable at location 15 (Jamestown).

Factor	Odds ratio	95% confidence limits
CURRVERTBRA	.2341**	.07145 - .7673
GAPORCUT42	3.063*	1.021 - 9.187
SHRUBPRESENT	6.450***	1.906 - 21.83

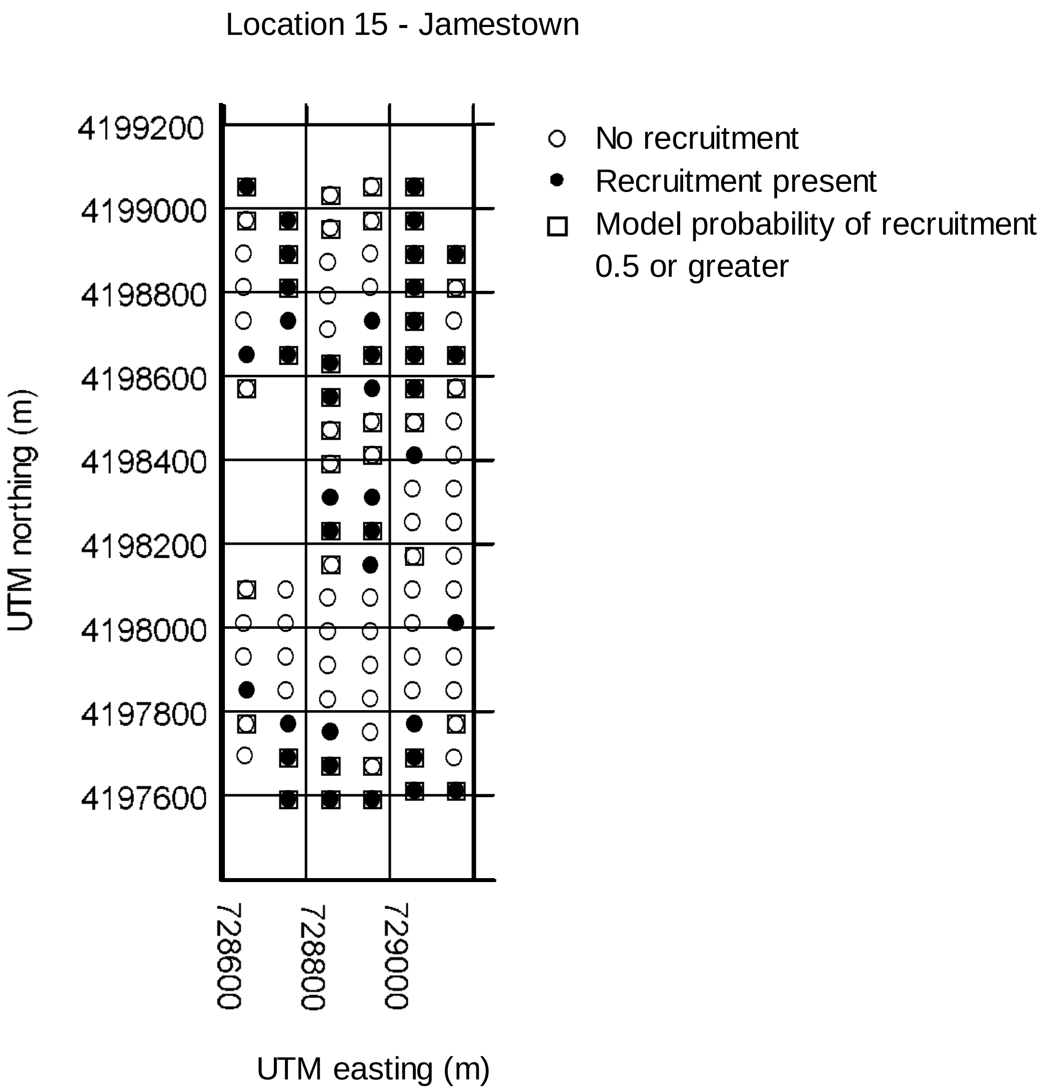
Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

TABLE 5-17. Counts of plots with observed recruitment (ALLRECR) versus recruitment predicted by logistic regression model for location 15 (Jamestown).

Observed	Predicted*		Totals
	No recruitment	Recruitment	
No recruitment	47	12	59
Recruitment	7	34	41
Totals	54	46	100

* Recruitment was considered to be predicted if the calculated probability of recruitment was ≥ 0.5.

FIGURE 5-4. Predicted and actual recruitment (ALLRECR) at location 15.



S123SEED outcome. The fit of the final model was fair. Plots with high levels of browsing damage (CURRVERTBRA) tended to have lower seedling-origin sapling counts per plot. Sapling counts were also generally higher in plots with moderate levels of plot canopy cover (>20% to 80%) than in plots with lower or higher levels of canopy cover. Although SHRUBPRESENT was significant in a single variable model, it was not significant in the multivariate model. However, the variable SHRUBCOVERA was highly significant in the multivariate model, indicating a positive association between sapling counts per plot and shrub cover. The variable GAPORCUT42 was also highly significant in a simple model. This variable was only marginally significant (P = .060) in the multivariate model prior to the addition of SHRUBCOVERA, and its significance level dropped to P= .200 in the final model.

TABLE 5-18. Poisson regression model for S123SEED outcome variable at location 15 (Jamestown).

Factor	Levels	Rate ratio	95% confidence limits
CURRVERTBRA		.3402**	.1233 - .9388
TOTCANOPYB	≤20% vs. >20% to 80%	5.498***	1.851 - 16.33
	≤20% vs. >80%	2.281	.6773 - 7.684
GAPORCUT42		1.671	.7615 - 3.666
SHRUBCOVERA		3.732***	1.463 - 9.523

Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

LIVESAPL outcome. The fit of this model was relatively poor. The overall effect of the predictor variable GAPORCUT42 was the same as seen in the models for the S123SEED and ALLRECR outcomes. A positive association was seen between the presence of shrubs (SHRUBPRESENT) and sapling counts per plot. However, this factor is partially confounded with cutting, since shrubby live oak resprouts were tallied as shrubs. TOPOPOSA was also significant in this model. Sapling counts per plot were likely to be lower on hilltops and high flats than on slopes and low-lying areas. The presence of other canopy species in the plot (OTHCANSPP) was negatively associated with the LIVESAPL outcome.

TOTCANOPYB was also significant in this model, but the direction of the effect was the reverse of that seen for S123SEED. For the LIVESAPL outcome, saplings were most numerous in plots with relatively low canopy. However, since a large proportion of the saplings at this location originated as stump sprouts (Figure 4-2), the effect of this variable is related to the fact that tree canopy is low in plots that have been cut recently.

CURRVERTBRA was also significant in the final model, with an effect that was opposite of its effect on the ALLRECR and S123SEED outcomes. This variable was not significant in a simple regression with the LIVESAPL outcome. The effect of this variable appears to be related to sprout-origin saplings, which were often browsed fairly heavily. The significance of the CURRVERTBRA variable in the multivariate model seems to reflect the fact that browsing damage was high in plots that had numerous sprout-origin saplings present. In this situation, high levels of browsing may be the result of the abundance of browse provided by sprout origin saplings, and does not indicate that browsing favors sapling recruitment.

TABLE 5-19. Poisson regression model for LIVESAPL outcome variable at location 15 (Jamestown).

Factor	Levels	Rate ratio	95% confidence limits
TOPOPOSA	hilltop vs. upper 1/3 slope	4.170*	.9633 - 18.05
	hilltop vs. lower 2/3 slope	8.674***	2.059 - 36.54
TOTCANOPYB	≤20% vs. >20% to 80%	.6249*	.3835 - 1.018
	≤20% vs. >80%	.4791**	.2326 - .9866
OTHCANSPP		.5154***	.3871 - .6863
GAPORCUT42		3.482***	1.613 - 7.521
SHRUBPRESENT		25.46***	10.18 - 63.67
CURRVERTBRA		2.043***	1.392 - 2.996

Significance level is denoted by asterisks: * P ≤ 0.10, ** P ≤ 0.05, ***P ≤ 0.01

Summary of within-location models

The table below summarizes the predictor variables that were significant (P≤ 0.10) in the final models. The predictor variables are arranged in groups of related variables to facilitate comparisons.

TABLE 5-20. Significant predictor variables (P≤ 0.10) for each of the tested outcome variables at each of the locations. The sign following the location number indicates whether the factor was positively (+) or negatively (−) associated with the outcome. Variables in shaded blocks were tested in models for only a single location.

Factor	Levels	Outcome variables			
		Allrecr	S0present	S123seed	LiveSapl
Environmental and soil variables					
ALTITUDE		1−	1−, 4−	1−,4−	
INSOL12		4+		3−	
SOILAWC		3+,7+	3+	1−,3+	
TOPOPOSA	hilltop vs upper 1/3 slope			1−,3+	15+
	hilltop vs lower 2/3 slope				15+
Management and history variables					
REBURN30		3−	3−	3−	
CUMGRAZE		4−	4−	4−	
CHRVERTBRA		6−,7−			
CURRVERTBRA		1+,15−		3+,15−	15+
CUT42YR		1+	1+	1+	
GAPORCUT42		4+,15+		3+	15+
Vegetation and stand variables					
OTHCANSPP		4+	4+	1−	15−
SHRUBCOVERA				15+	
SHRUBPRESENT		15+		1+, 3+,4+	15+
SMALLTREES		4+		4+	
STANDEDGEA		3−			
TOTCANOPYA	≤2.5% vs. >2.5 to 20%	3+			
	≤2.5% vs. >20%	3+	3+		
TOTCANOPYB	≤20% vs. >20% to 80%			15+	15−
	≤20% vs. >80%	4−	4−		15−

Between-location models

Although many of the predictor variables under study vary at the plot level, other variables, such as those related to climate, are fixed for the entire location. As noted earlier, it was not practical to build a logistic regression model using individual plot data for multiple locations, because of the difficulty inherent in modeling the within-location correlations. To analyze variables that were confounded with location, it was necessary to construct a data file in which the data for each location was reduced to a single value for each variable under study. This method reduces the total number of data points, so that relatively few variables can be considered at a time, and information on individual plots is lost in this analysis. Despite these drawbacks, multilocation models are useful because they allow us to consider factors that only vary between locations, and help us to evaluate factors at the landscape-level which may be related to the differences in the amount of recruitment between locations.

The outcome variables used for the between-location models, LOCALLRECR, LOCS123LIVE, and LOCS0PRESENT, are all based on the number of plots at each location that have recruitment of different types (Table 5-21). Since these outcomes are counts, data were fitted to Poisson regression models. We screened a large number of potential predictor variables in preliminary analyses to select variables which showed adequate levels of variation between the 15 locations. These selected variables were used to construct preliminary models using the LOCALLRECR outcome variable. We used information from these preliminary analyses and from the single-location models to select a final set of predictor variables. We used this final set of predictor variables to construct models for all three outcome variables. The predictor variables in the final set were AVGINSOL12, BADCANOPY, LOCCURRVERTBR, ETDEFICIT, LOCGAPORCUT, MAXCANOPYSPP, MINPPT2, ONEFIRE30, LOCSHRUBPRES, SOILAWC≥10CM. These variables are explained in Table 5-21. We did not consider the SMALLTREES variable for the between-location models due to the lack of data for this variable at locations 1 and 2.

TABLE 5-21. Variables used in models involving all locations.

Variable name	Type	Category	Description
LOCALLRECR	Count	Outcome	Number of plots at a location with any form of recruitment, including S0, and live or dead S1, S2, or S3 of either seedling or sprout origin (number of plots where ALLRECR=1)
LOCS0PRESENT	Count	Outcome	Number of plots at a location with S0 stage seedlings (number of plots where S0PRESENT = 1)
LOCS123LIVE	Count	Outcome	Number of plots at a location with live S1, S2, or S3 seedling-origin saplings (number of plots where S123SEED>0)
AVGINSOL12	Continuous	Site factor	Average December average-day insolation (INSOL12) for the location
BADCANOPY	Count	Site factor	Number of plots meeting one of the two following criteria: (1) plot canopy cover is >80%, or (2) plot blue oak canopy cover ≤2.5% and no recent cutting or gap in plot (GAPORCUT42=0)
LOCCURRVERTBR	Count	Site factor	Number of plots in which chronic vertebrate browsing intensity is rated as high (CURRVERTBRA=1)
ETDEFICIT	Continuous	Site factor	Difference between reference evapotranspiration (ETo) and 30-year average annual precipitation
LOCGAPORCUT	Count	Site/history factor	Number of plots in which either (1) tree cutting has occurred in the plot within the 42 years prior to 1992 or (2) a canopy gap has developed in the plot within the past 30 years (estimated) (GAPORCUT42=1)
MAXCANOPYSPP	Count	Site factor	The maximum number of canopy species found in any plot at the location
MINPPT2	Continuous	Site factor	Lowest two-year rainfall total for the location in 30 years prior to 1992
ONEFIRE30	Count	History factor	Number of plots that have been burned only one time in the 30 years prior to 1992
LOCSHRUBPRES	Count	Site factor	Number of plots containing shrubs (SHRUBPRESENT=1)
SOILAWC≥10CM	Count	Site factor	Number of plots in which the estimated soil available water-holding capacity is greater than 10 cm (SOILAWC>4 inches)

Overall model fit was similarly poor for the LOCALLRECR and LOCS123LIVE models, suggesting that these outcomes are related to additional factors which are not included in the model and that the Poisson model may not be the most appropriate model. However, the low number of data points (15) limits the number of factors that can be included in the model. Overall model fit was fairly good for the LOCS0PRESENT model.

The apparent direction of the effects of certain variables was reversed between the single variable and multivariate models for all outcomes, as shown in Table 5-22 and discussed below. This occurs when a predictor variable is correlated with other predictor variables in the model. In instances when this occurs, the net effect of correlated variables is correct as shown in the final model, but the effect of individual predictor variables cannot be inferred from the coefficient in the final model.

Insolation. We considered several insolation variables in preliminary analyses based on annual insolation, including an overall average and the number of plots falling within certain ranges (e.g. plots with average insolation ≥ 7250 MJ/m^2). AVGINSOL12 was used in the final model based on the significance of INSOL12 in several of the within-location models. AVGINSOL12 was negatively associated with both the LOCALLRECR and LOCS123LIVE outcome models (Table 5-22). Locations that had many plots with high December insolation, i.e., more xeric slope-aspect combinations, were less likely to have recruitment. AVGINSOL12 was not significantly associated with the LOCS0PRESENT outcome.

Evapotranspiration and precipitation. We considered a wide range of variables related to precipitation and evapotranspiration (Appendix 2). Some groups of variables were highly correlated, and only one variable from each of these groups was used in the analyses. The predictor variables MINPPT2 and ETDEFICIT were significant in the final models for the LOCALLRECR and LOCS123LIVE outcomes, but not in the LOCS0PRESENT model (Table 5-22). Locations which had experienced more severe droughts in the past 30 years (lower MINPPT2) tended to have lower levels of recruitment. Single variable models with the ETDEFICIT show that this factor is negatively correlated with the LOCALLRECR and LOCS123LIVE outcomes (rate ratios .9947, P=.05 and .9969, P>.10 respectively). However, in the multivariate model, the sign of the coefficient for this predictor variable was positive, which indicates that this variable is highly collinear with at least one other variable in the final model.

Soil available water-holding capacity. We selected SOILAWC≥10CM as the best variable for describing soil water conditions at the location level. This factor was significant in the models for both the LOCALLRECR and LOCS0PRESENT outcomes (Table 5-22). In single variable models for both outcomes, and in the multivariate model for LOCS0PRESENT, the presence of high soil AWHC values in a high proportion of plots (higher SOILAWC≥10CM) was negatively correlated with recruitment. In the multivariate model for LOCALLRECR, the apparent direction of this effect was reversed, presumably due to collinearity with other factors in the model.

Canopy cover. Total canopy cover was shown to be related to recruitment in a nonlinear fashion in the single location models. Moderate levels of canopy were positively related to recruitment, whereas very high and very low levels of canopy cover were negatively related to recruitment. Furthermore, since recruitment was positively related to the presence of recent canopy gaps, plots with low levels of canopy cover may have different probabilities of recruitment based on their history of tree cutting or natural mortality. Thus, overall averages of canopy cover are not useful for describing how prevalent favorable or unfavorable canopy cover levels are at a location.

We defined BADCANOPY (Table 5-21) as a summary variable that indicates whether plot canopy cover levels are unfavorable, based on the relationships discussed above. In simple regressions, BADCANOPY was negatively associated with each of the outcome variables (LOCALLRECR: Rate ratio .9482, P<.001; LOCS0PRESENT: Rate ratio .9353, P<.001; LOCS123LIVE: Rate ratio .9389, P<.001). However, in the multivariate models, the apparent direction of the BADCANOPY effect was reversed (rate ratios >1), and BADCANOPY was not significant in the final LOCALLRECR model (Table 5-22). This reversal indicates collinearity between BADCANOPY and other factors in the model, most likely GAPORCUT42, which is one of the criteria used to define BADCANOPY.

Canopy gaps and cutting. All of the recruitment outcomes were positively associated with the number of plots at a location that had been cut or had a recent canopy gap (LOCGAPORCUT, Table 5-22). This trend was the same as was observed in the within-location models (Table 5-20).

Browsing. In the within-location models, the browsing variables CURRVERTBRA and CHRVERTBRA are highly correlated with each other and with a number of the grazing history variables. Grazing history variables were not especially suited to the between-location analysis because it is difficult to select or develop a single variable that adequately describes the grazing history, particularly for those locations with multiple grazing histories (locations 4, 5, 6, 10, 11, 13, 14). Browsing variables are easier to summarize for an entire location. Browsing variables also integrate the effects of deer browsing, which was quite intense at some locations, whereas the grazing histories do not account for this factor. Based on preliminary analyses, we selected CURRVERTBRA in preference to CHRVERTBRA as the basis for the location summary variable LOCCURRVERTBR. All three outcome variables showed a negative association between the number of plots with high levels of vertebrate browsing (LOCCURRVERTBR) and recruitment (Table 5-22).

Fire. Selecting an appropriate variable for describing fire history for an entire location was also problematical. Based on the model for location 3, we decided not to lump single fires in the same category as repeated fires. Since few locations had repeated fires in the 30 year history period, we used the number of plots experiencing a single fire over the past 30 years as the predictor variable (ONEFIRE30YR). This factor showed a highly significant positive correlation with LOCALLRECR and a weaker positive association (P=.071) with LOCS123LIVE (Table 5-22).

Other woody species. There were large differences in the composition and density of the woody plant cover between locations, and it was again difficult to select a single variable that described the most relevant characteristic. Two of the predictor variables related to tree and shrub cover, MAXCANOPYSPP and LOCSHRUBPRES, were significant in the final between-location models (Table 5-22).

MAXCANOPYSPP was significant in all three models. In single variable models, MAXCANOPYSPP was positively correlated with each of the outcome variables. In the multivariate models, the direction of the effect was reversed for all outcomes. LOCSHRUBPRES was positively correlated with the LOCS0PRESENT outcome only in the final models, even though this factor was positively associated with sapling recruitment in most of the within-location models (Table 5-20). In single variable models, LOCSHRUBPRES showed significant positive correlations with the outcomes LOCALLRECR and LOCS0PRESENT.

TABLE 5-22. Poisson regression models for all outcome variables in the between-location models. Rate ratios in shaded cells show a reversal in the sign of the coefficient between single variable models and the final multivariate model.

Outcome:	LOCALLRECR		LOCS0PRESENT		LOCS123LIVE	
Factor	Rate ratio	95% confidence limits	Rate ratio	95% confidence limits	Rate ratio	95% confidence limits
AVGINSOL12	.7783***	.6782 - .8932			.7645***	.6299 - .9280
BADCANOPY			1.216***	1.140 - 1.297	1.059***	1.015 - 1.105
LOCCURRVERTBR	.9779***	.9696 - .9863	.9600***	.9424 - .9780	.9850***	.9756 - .9945
ETDEFICIT (cm)	1.128***	1.068 - 1.192			1.202***	1.115 - 1.297
LOCGAPORCUT	1.113***	1.076 - 1.151	1.144***	1.098 - 1.192	1.166***	1.105 - 1.230
MAXCANOPYSPP	.5701***	.4373 - .7432	.2137***	.1111 - .4113	.6537**	.4692 - .9109
MINPPT2 (cm)	1.228***	1.119 - 1.348			1.321***	1.166 - 1.496
ONEFIRE30YR	1.064***	1.038 - 1.090			1.012*	.9990 - 1.024
SOILAWC≥10CM	1.026***	1.015 - 1.037	.9838***	.9753 - .9924		
LOCSHRUBPRES			1.036***	1.016 - 1.057		

Significance level is denoted by asterisks: * P $\leq$ 0.10, ** P $\leq$ 0.05, ***P $\leq$ 0.01

6. DISCUSSION

The study locations varied widely with respect to the total numbers of saplings present and the percentage of plots which had saplings. Based on the number of plots with saplings, the study locations can be divided into four groups:

- four locations (1, 3, 4, 15) with at least moderate levels of sapling recruitment,
- four locations (6, 7, 9, 10) with low levels of sapling recruitment,
- three locations (8, 13, 14) with very low levels of sapling recruitment, and
- four locations (2, 5, 11, 12) with absolutely no saplings within the study area.

The range in the incidence of sapling recruitment observed in our study is probably representative of the range of variation that exists in blue oak woodlands. Based on our field observations, we believe that there are probably few locations where levels of sapling recruitment are significantly greater than observed at locations 1, 3, 4, and 15 in stands of comparable size. Since four locations had no saplings over the entire sampling grid area, our survey also included locations exhibiting the minimum level of sapling recruitment possible. This wide range in the abundance of sapling recruitment undoubtedly contributes to the diversity in opinions about the adequacy of blue oak regeneration. It is clear that there are stands in which blue oak saplings are common, but also many stands in which saplings are rare to nonexistent.

Even at locations where the incidence of recruitment was moderate, the distribution of saplings throughout the stand was not uniform. At locations with moderate levels of recruitment, plots with recruitment showed varying degrees of spatial clustering (Figures 5-1, 5-2, 5-3, 5-4). Clustering of saplings was also seen at a smaller spatial scale, based on the number of plots that had relatively high sapling counts (Figure 4-3). In looking at sapling distributions in plots ranging in size from about .01 to .56 ha, Harvey (1989) found that blue oak saplings were spatially clustered at two of four study areas in the Los Padres National Forest (near our location 9). Spatial clustering of blue oak sapling recruitment within stands has also been noted by others (Muick and Bartolome 1987). At least at the scale of observation used in our study, we believe that virtually all of the clustering can be explained by the spatially nonuniform distribution of factors associated with recruitment, such as tree cutting, fire, soil AWHC, topographic position, and canopy cover.

Tree mortality and regeneration

It is necessary to consider both recruitment and mortality in order to assess the adequacy of regeneration. As noted by Bartolome et al (1987) and Lang (1988), a lack of saplings per se may not indicate that regeneration is inadequate, since a fully-stocked stand with no mortality does not require recruitment to maintain stand density. These authors further contend that stand age structure data is needed to assess regeneration, but this concept implies that some past, existing, or "ideal" stand age structure is the standard for determining whether regeneration is successful. This concept seems to imply that regeneration is a goal-directed process (Oliver and Larson 1990) rather than the simple replacement of individuals lost from the population.

The balance between recruitment and mortality will influence the future age structure of the stand. Furthermore, certain stand age structures may be desirable from a management viewpoint. However, we do not believe that it is necessary to establish an arbitrary stand structure goal to describe the status of regeneration. Our assessment of regeneration describes the balance between mortality and recruitment at the plot level, and indicates whether sapling recruitment is capable of offsetting population and/or canopy cover losses due to tree mortality. This information indicates what type of stand age structures could develop over time, and resource managers can then decide whether these projected age structures are acceptable.

Natural tree mortality was observed in 30% of the 1,500 plots we surveyed, and dead trees were tallied at all 15 of the study locations (Table 4-12). Even after allowing for estimation errors due to the removal of dead trees, it is clear that mortality rates vary widely between locations as well as between plots within a location. In the current study, the maximum blue oak mortality rate at a single location was 5.4 deaths/100 trees/decade seen at location 12. In a previous study (Swiecki et al 1990), we reported an estimated natural mortality rate of 12.5 deaths/100 trees/decade for one location, although mortality rates at other locations in northern California varied from 0 to 7.8 deaths/100 trees/decade. These values (Swiecki et al 1990) were based on all oak species present, although most plots were dominated by blue oak and some were exclusively blue oak.

Several factors may contribute to the differences between the two studies. Our earlier study (Swiecki et al 1990) used the same plot layout as used by Bolsinger (1988), so that mortality estimates were based on data from clusters of five 0.08 ha plots distributed across 2 ha. In contrast, mortality estimates from the current study are based on 100 plots (0.08 ha each) spread over a minimum area of 61 ha. Maximum rates of mortality observed in relatively small areas are likely to exceed mortality rates estimated over larger areas, due to sampling error and the fact that oak mortality is often spatially clustered (Swiecki et al 1990). Mortality estimates in our earlier study were also based on trees that were estimated to have died in the past 10 years, rather than the 30-year span used in the current study. The 30-year time span is likely to underestimate mortality more than a 10-year span because the destruction or removal of dead material tends to increase with time.

In a study of valley oak (*Q. lobata*) mortality in Santa Barbara County (Brown and Davis 1991), an overall mortality rate of 20.8% over 51 years (approximately 4.2 deaths/100 trees/decade) was calculated. This study was based on analysis of historical aerial photographs and did not distinguish between natural mortality and tree removal. The study by Brown and Davis (1991) and a recent study by Tietje et al (1993) also indicate that oak mortality rates vary over time. In the latter study, 4% of the blue oaks in a set of sample plots in San Luis Obispo County died in the 4 years between 1988 and 1992, during California's most prolonged drought of the century. Taken in aggregate, these studies suggest that typical natural mortality rates in blue oak woodlands may be at least 2 to 4 deaths/100 trees/decade, and may be significantly higher in certain areas or over a given time interval.

At the scale of an individual plot, there may not be a current need for recruitment to replace dead trees in some cases. Regeneration may not be expected to occur in overstocked plots where mortality is due to self-thinning and all of the available growing space is occupied. All locations except location 11 had some mortality among suppressed trees in overstocked plots (Figure 4-7B), but most of the blue oak mortality we observed does not fall into that category. More commonly, plots that lost trees due to mortality were not overstocked, and mortality resulted in a loss of blue oak canopy cover within the plot.

Natural mortality of blue oak trees has occurred at all of our study locations within the past 30 years, yet sapling recruitment was observed at only 11 locations. Based on the balance between plots with density losses and plots with the potential for density gain, it appears that most locations are losing blue oak density at the stand level due to unreplaced mortality. The net balance between recruitment and mortality at the location or stand level is similar whether or not losses and potential gains in blue oak canopy are also considered (Figure 4-7). Only two locations among the 15 we studied have more plots with potential density and canopy gains than plots with recent density and canopy losses. These observations support the assertion that current recruitment is inadequate to maintain existing tree populations in at least some areas (Muick and Bartolome 1987).

In a few locations, patches of former woodland appeared to be thinning to the point that a type conversion to grassland appears imminent if the current lack of regeneration persists. Our observations and those of White (1966b) indicate that natural recolonization of open grasslands by blue oak is extremely slow at best. Therefore, the conversion of blue oak woodland to grassland is not likely to be easily reversed.

Predictor variables associated with sapling recruitment

There is no single characteristic that clearly differentiates locations with little or no recruitment from those with higher levels. However, a number of predictor variables that are significantly correlated with recruitment were identified in the statistical analysis. Of the tested predictor variables, variables related to topographic position, browsing intensity, recent canopy gaps or clearings, total canopy cover, and shrub cover were associated with sapling recruitment in the greatest number of locations. Other factors, including insolation, soil AWHC, repeated fires, and several vegetation-related variables were also significant at certain locations. The minimum two-year average precipitation and the ET deficit were the only two additional variables that were added to the overall list of significant predictor variables in the between-location models.

Taken in combination with our field observations, the statistical models show that some readily-observable site characteristics are correlated with sapling recruitment, but that these factors are often highly interrelated. In addition, it is apparent that the importance of a given factor can vary between locations, due to the relationship between the factor and other conditions at the location.

The correlations between predictor variables must be taken into account when interpreting the statistical models. As noted earlier, these correlations pose limits on the types of factors that can be considered simultaneously. For example, blue oak canopy cover was highly collinear with total tree canopy cover at most study locations. It was therefore not possible to consider both QDCANOPY and TOTCANOPY in a single model. Thus, while all variables which are significant in the final models are related to the recruitment outcomes, some variables which were excluded from the models may also be related to recruitment.

A second consideration is that collinearity between factors in a model can cause a reversal in the apparent direction of the effect of a factor, as was common in the between-location models (Table 5-22). This situation requires greater care in the interpretation of coefficients in the final models. It also points out a problem inherent in all correlative studies: observed relationships between variables can be confounded by other variables which have not been observed, or have not been included in the model. The effects of such underlying variables probably account for the fact that certain variables (e.g. CURRVERTBRA) have opposite relationships with recruitment at different locations.

Finally, the correlations between predictor variables stem from the fact that there are complex interactions between environmental, soil, management, and biotic factors. For instance, soil depth is often greater at the base of a slope than at the top, resulting in higher soil available water-holding capacity (AWHC) at these positions. Due to both elevated soil AWHC and additional water due to runoff, low topographic positions may support a wider diversity and greater cover of tree and shrub species. These densely vegetated areas may be favored by deer, resulting in high levels of browsing. Certain land managers may tend to preferentially cut or clear such areas, whereas others may not. Sapling recruitment may be correlated with a number of these factors, but it may not be possible to determine which factors are causal and which are merely related outcomes. Furthermore, due to the various types of feedback loops that can occur, distinguishing between cause and effect may simply become a "chicken and egg" exercise, with no obtainable answer.

Although the statistical models can help identify predictor variables that are related to various recruitment outcome variables, they do not provide a single definitive list of significant predictor variables. The models reported do not represent the only possible models, nor are they necessarily the best possible models. The derived models are subject to change based on the choice of variables tested, the coding of multiple levels for categorical variables, and even the method used to build the model. The main utility of these models is to identify those variables or clusters of related variables that show a clear relationship to sapling recruitment.

Individual factors associated with sapling recruitment are discussed in greater detail below.

Management and history variables

Grazing and browsing intensity, tree cutting, and fire were all shown to affect sapling recruitment. The apparent importance of these historical management variables on recruitment tends to complicate the process of deriving and applying models that predict blue oak recruitment probabilities. Historical data is often difficult or impossible to obtain, and the quality of this data is variable, but often poor. It is also difficult to translate management data into meaningful variables that can be used to build models. This is due in part to the lack of information about what aspects of complex processes, such as grazing or fire, are the most important ones to measure.

Grazing and browsing. Livestock grazing showed a clearly negative impact on sapling recruitment at location 4, the only location with both moderate levels of recruitment and clear differential grazing regimes. There is not enough information from this site to reliably distinguish between the effects of winter and summer grazing regimes. George and Hall (1991) showed greater impacts on blue oak seedlings from summer grazing than from winter grazing.

At the other locations, the vertebrate browsing ratings CHRVERTBRA and CURRVERTBRA were used to quantify the impact of browsing by livestock and wild herbivores, chiefly deer. Negative effects of browsing on sapling recruitment were seen for all outcomes in the between-location models (Table 5-22). In addition, in the locations where livestock were present (6, 7, and 15), high levels of vertebrate browsing were associated with a lower likelihood of seedling-origin sapling recruitment.

At locations 1 and 3, which have not been grazed by livestock for a number of years, browsing effects were either nonsignificant or showed a positive association with sapling recruitment. The association of higher sapling densities with high levels of recent deer browsing at these locations (CURRVERTBRA) could be due to suppression of sapling height growth. If chronic browsing by deer does not greatly elevate sapling mortality rates, the S1 sapling stage would tend to be prolonged where browsing pressure is intense. This could result in higher numbers of saplings per plot, since saplings would not be advancing to the tree stage in a timely fashion. Alternatively, high levels of browsing may sometimes occur where blue oak saplings are relatively dense if deer seek out blue oak saplings for browsing. We observed that blue oak was preferred over live oak as browse, and blue oak may be preferred over other possible browse species as well. Overall, the models suggest that blue oak sapling regeneration may be affected differently by deer browsing than by livestock grazing.

At many of our locations, it was obvious that livestock grazing and/or high deer populations had severely constrained blue oak sapling recruitment as well as regeneration of many other woody species. In many locations where grazing has been intense, blue oak saplings and juveniles of other woody species are limited to areas where grazing pressure is reduced, such as on steep slopes and among rock outcrops. In a few locations, less palatable species such as chamise, manzanita, and live oak were able to reproduce, even though blue oak reproduction was virtually eliminated by browsing. It has been demonstrated in many ecosystems that persistent high populations of either native browsing animals or livestock can profoundly affect the vegetative composition of forests and woodlands (Spurr and Barnes 1980, Oliver and Larson 1990). Such effects may include the elimination or suppression of woody species in the understory, or a shift in species composition to less palatable species.

The few saplings found in heavily grazed plots were usually confined to the S1 size class due to repeated browsing. Such browsing-stunted blue oak saplings may be many decades old (Harvey 1989, McClaran 1986, Mensing 1992), and the probability that these will be recruited to the tree stage may be poor. Most of the dead saplings we observed in open positions were S1 saplings stunted by repeated browsing. Saplings in this small size class remain susceptible to certain damaging agents, such as rodents, that would not be able to weaken or kill a larger tree.

Cutting and canopy gaps. Canopy gaps created by cutting or natural mortality were positively associated with recruitment in all of the between-location models (Table 5-22), and in the within-location models for all locations with moderate levels of recruitment (Table 5-20). Many of the recent canopy gaps at locations 1, 4, and 15 were due to cutting of the blue oak overstory, whereas at location 3, cutting was minimal and most gaps resulted from natural mortality of overstory trees. Both seedling- and sprout-origin saplings were seen in cut clearings at locations 4 and 15 (Tables 3-10, 3-15) but at location 1, almost all of the recruitment in cut areas was seedling origin.

An association between blue oak sapling recruitment and tree cutting has been noted by various researchers (Muick and Bartolome 1987, Swiecki et al 1990, Allen-Diaz et al 1990). Jepson (1910) also noted this phenomenon, and several other studies have shown that various second growth blue oak stands originated at a time when woodland clearing would have been going on (Vankat and Major 1978, McClaran 1986, White 1966a). As discussed below, such a pattern of recruitment could have resulted from the release of suppressed advance regeneration.

At many locations, saplings were found in recent canopy gaps, but blue oak saplings were seldom found in old cleared fields or other old clearings. In an old cleared field at the Hastings Reservation that was not subject to grazing, only S1-sized and seedling blue oaks were found 29 years after the field was abandoned, and these all occurred at the field edges in bare gullied soil or amid dense patches of *Erodium botrys* (White 1966b). These observations suggest that pioneer-type colonization of old gaps may be uncommon or very slow, at least under prevailing conditions.

Fire. Although fire was a significant predictor of recruitment in some models, the overall effects of fire on recruitment were mixed. ONEFIRE30YR showed a positive correlation with sapling recruitment in the between-location models. However, in the within-location models for locations 6 and 7, occurrence of a single fire within the past 30 years did not significantly affect sapling recruitment. A negative effect of repeated fires on sapling populations was shown for location 3 (Tables 5-6, 5-8, 5-9, 5-20). Locations 1 and 4 had significant amounts of recruitment and no recent fires, whereas locations 12 and 13 had recent fires but no significant recruitment. Previous studies involving direct observation of burned areas have not shown any positive effect of fire on blue oak seedling or sapling establishment or survival (Haggerty 1991a,b, Allen-Diaz et al 1990).

Data from McClaren and Bartolome (1989), Mensing (1992), and location 3 (Table 3-6) support the idea the fire temporally concentrates sapling ages. Most blue oak saplings resprout readily following topkill by fire (Haggerty 1991a, Allen-Diaz et al 1990). Since topkilled saplings are essentially returned to the seedling stage upon resprouting, fire may prolong the sapling stage of development. This could account for the positive relationship between ONEFIRE30Y and saplings seen in the between-location models. Alternatively, reduced competition following a fire and the opening of new gaps may allow the transition of existing seedlings to saplings.

Although the mortality rate of blue oak saplings following a single fire may be relatively low (Haggerty 1991a), repeated fires occurring within a few years of each other could greatly increase fire-related mortality rates. The repeated destruction of the shoot may stress many saplings beyond their capacity to recover, especially at a relatively harsh site such as location 3 (Pinnacles), and account for the negative effect of repeated fires on sapling populations seen there.

Vegetation and stand variables.

Several variables related to plot vegetation were significant predictors of recruitment. However, since sapling recruitment is simply one component of plot vegetation, correlations between sapling recruitment and vegetation characteristics do not imply that a causal relationship exists. Several of these variables, including those related to shrub cover and small-diameter blue oak trees, can probably be considered as outcomes that are favored by the same conditions that favor sapling recruitment, rather than as independent factors which directly influence sapling recruitment.

Canopy cover. Of the predictor variables related to vegetation and stand characteristics, the total canopy cover variables (TOTCANOPYA and TOTCANOPYB) were the most consistently related to sapling recruitment. The general tendency in all locations was that saplings were most likely to be found in plots with intermediate levels of canopy cover (20% to 80%) (Figure 4-5, Table 4-7). With the exception of canopy gaps created by recent clearing, plots with no canopy were apparently unfavorable for sapling recruitment, as were plots with nearly closed or closed canopies. This general relationship is further supported by the significance of the variable BADCANOPY in the between-location models (Table 5-22).

The lack of sapling recruitment in heavily canopied plots is consistent with what would be expected of an intolerant species. At several locations, saplings under the canopy were more likely to be dead or in decline than those found in the open (Table 4-11). Many of the saplings found under canopy appeared to have been overtopped by adjacent trees, and may have been recruited originally when the stand was more open.

Not all blue oak saplings were found under blue oak canopy. At several locations, blue oak saplings were sometimes located under foothill pine canopy. Foothill pine may provide an overstory that is compatible with blue oak sapling recruitment because it provides only light shade. Furthermore, the root distribution of foothill pine is likely to differ from blue oak, which may reduce root competition for soil moisture. If foothill pine canopy provides a favorable site for blue oak sapling recruitment, the loss of foothill pine from blue oak woodlands may have significant ramifications. We noted at a number of locations that no young foothill pines were present to replace those which had died.

Shrubs and other woody understory species. Shrub presence was positively associated with recruitment at all locations. Variables related to shrub cover (SHRUBPRESENT and SHRUBCOVERA) were included in final models for locations 1, 3, 4, and 15, but in almost all cases, the significance level of the shrub variables was much lower in multivariate models than in single variable models. LOCSHRUBPRESENT was also positively correlated with all of the between-location recruitment outcomes in single variable models, but was only included in the final model for LOCS0PRESENT. The reduced significance levels of the shrub presence variables in most multivariate models is most likely due to the correlations that exist between other predictor variables in the models and the presence of shrubs.

We observed an association between sapling presence and shrub presence in the field, but there was no evidence that there was a direct interaction between shrubs and blue oak saplings. Blue oak saplings were seldom found growing through or under shrubs, even though shrubs might occur in the same plots as saplings. In general, it appeared that conditions that favored sapling recruitment, such as low levels of browsing and the presence of recent canopy gaps, also favored the establishment and growth of shrub species. For example, at location 4, poison oak growth was rampant in recent clearings, but was poison oak was generally a minor element in undisturbed areas. In areas where poison oak growth was dense, it did not appear to be having any direct impact on blue oak sapling recruitment. At many locations, both shrubs and saplings were more likely to be found in areas with lower levels of livestock use.

At every location where we observed moderate numbers of blue oak saplings, regeneration of other woody species was also present. Conversely, with the exception of location 12, locations without blue oak recruitment or with only very low amounts of recruitment also had little or no regeneration of other woody species in the understory. Like the association with shrub presence, we believe that blue oak sapling recruitment and regeneration by other woody species in the understory are related outcomes.

At a few locations, mechanical clearing has been used to purge woody plants from the understory. Such clearing would almost certainly have destroyed any existing blue oaks in the S0 and S1 stages, and larger saplings may also have been eliminated. At many locations, persistent grazing and/or deer browsing pressure has kept the understory free of most woody plant regeneration. Whether by design or accident, past and current management in many of the study locations has selected against woody plants from the understory, including blue oak saplings.

Bolsinger (1988) also observed a positive association between increasing numbers of woody plants, trees, or shrubs in a plot and the presence of blue oaks less than 2.5 cm dbh (approximately the equivalent of our sapling and S0 seedling stages). He also noted that poison oak was more common on plots with blue oaks in this size class than in plots lacking blue oak in this size class.

Other canopy species. We included the variable OTHCANSPP in the analysis in order to assess whether recruitment was more likely to be found in pure stands of blue oak or in mixed stands. The presence of other canopy species in the plot was significantly related to recruitment at locations 1, 4, and 15. At location 4, sapling recruitment was positively associated with the presence of canopy species other than blue oak (Tables 5-10, 5-12). At location 15, a positive association was evident between seedling-origin recruitment and the presence of other canopy species (Table 3-16). OTHCANSPP was significant in the single variable model but not in the multivariate model for the S123SEED outcome at location 15. In contrast, OTHCANSPP was negatively associated with recruitment for the LIVESAPL outcome variable at location 15, which is due to the fact that many sprout origin saplings were found in plots which had been clear cut and had no tree canopy. The most common canopy species other than blue oak at locations 4 and 15 were interior live oak and foothill pine (Table 3-3).

OTHCANSPP was also negatively associated with recruitment at location 1. The most common canopy associates of blue oak at location 1 were coast live oak, California black oak, foothill pine, California bay, and California buckeye. High numbers of other canopy species were found along creeks and at higher elevations, and plots in these areas often had high levels of canopy cover. The combination of dense canopy cover and competition from other trees is probably responsible for the negative association between blue oak saplings and OTHCANSPP at location 1.

In the between-location models, MAXCANSPP was used as an indicator of overstory species diversity at each location. In single variable models, this factor was positively correlated with all three of the recruitment outcomes, but the apparent direction of the effect was reversed in the multivariate between-location models (Table 5-22). When the entire location is considered, a high level of canopy species diversity may be indicative of a mesic location that provides favorable conditions for sapling recruitment. However, once environmental variables are incorporated into the model, high numbers of canopy species are more likely to be associated with excessive levels of canopy and interspecific competition, and thus shows a net negative effect.

Stand edges and altitude gradients. ALTITUDE was significant at locations 1 and 4, but not at location 3, despite the fact that the elevational range was greater at location 3 than at location 4. At locations 1 and 4, fewer saplings occurred at higher altitudes, where blue oak was less dominant and was replaced by less drought-tolerant species. This was not the case at location 3, where the vegetation pattern was more of a mosaic which did not vary predictably with altitude within the study area.

At location 3, plots that were close to the vegetation type transition (STANDEDGEA>0) were less likely to have blue oak saplings. This appears to analogous to the effect of ALTITUDE at locations 1 and 4. Both variables are indicators of the proximity to the boundary between a cover type dominated by blue oak and one from which blue oak is absent or represents a minor component. The change in cover type may be the result of historically poor blue oak sapling establishment, which could be related to edaphic or microclimate differences, greater interspecific competition, or other factors that change along an altitude/cover type gradient. Alternatively, differences in sapling establishment rates may be related to successional changes in the vegetation associated with past disturbances.

Other researchers (Muick and Bartolome 1987, Bolsinger 1988) have suggested that less blue oak recruitment occurs at the lower elevations of its range. While this may be true, this effect is most likely due to factors that tend to vary along an elevational gradient, such as canopy cover, rainfall, and evapotranspiration. Altitude may therefore be a poorer predictor of recruitment than variables that measure these underlying factors more directly. ALTITUDE was not found to be a significant predictor in the preliminary screening of possible predictor variables for the between-location models.

Small trees. At several locations, notably locations 4, 7, and 9, most of the plots with some form of recruitment also had small diameter trees (SMALLTREES) (Figure 4-4). Furthermore, at locations 3, 4, and 15, most of the plots with small trees also had recruitment. In the within-location model for location 4, recruitment was positively correlated with the presence of small-diameter trees (SMALLTREES) in the plot. The relationship between SMALLTREES and recruitment is apparently due in at least some instances to the fact that small trees and saplings within a plot represent a single cohort of regeneration. Slow-growing individuals from the cohort were presumably suppressed by browsing, fire, and eventually competition from the developing overstory, and remained in the sapling size class while faster-growing individuals advanced to the small tree class. Harvey (1989) showed that some blue oaks remained in the equivalent of our S1 sapling size class for periods as long as 100 years in an area subjected to cattle grazing and periodic fires.

Several locations that had little or no recruitment also had few small-diameter trees, though this relationship did not hold for all locations (Figure 4-4). As noted in the location descriptions, many locations showed evidence of one or more episodes of past recruitment since settlement but little recent recruitment. This type of age structure has been documented in a number of widely separated blue oak stands (White 1966a, Vankat and Major 1978, Mensing 1992, McClaran 1986).

Environmental and soil variables

In general, microsite conditions that seem to favor blue oak sapling recruitment are those that support faster growth due to greater soil moisture availability and/or reduced evaporative demand. Northerly aspects, patches of deeper soil, and topographic positions that receive runoff, tend to be more likely to have blue oak saplings. However, the most mesic sites at relatively mesic locations may not be as favorable for sapling recruitment due to increased competition from other tree and shrub species and herbaceous vegetation.

Topographic position. Topographic position is often strongly correlated with the composition and productivity of woody vegetation, because soil characteristics and microclimate often vary predictably with topographic position, at least within a geographic region (Carvell and Tryon 1961, Spurr and Barnes 1980). In this study, topographic position (TOPOPOSA) was a significant predictor of recruitment at several locations, primarily in the Poisson regression models (Table 5-20). Hilltops were generally less favorable for recruitment than lower-lying topographic positions, but relationships between recruitment and topographic position varied between locations. For example, at location 1, which is relatively mesic, drainages supported a dense canopy of California bay, which virtually excluded blue oak. At location 7, a much more xeric location, drainages supported the greatest densities of blue oak and most of the blue oak recruitment.

The topography and geology within the range of blue oak are quite diverse. Consequently, plots in a given topographic position at different locations may not be equivalent to each other with respect to soil and microclimate characteristics that might influence recruitment. This variation within a topographic class is also seen within locations with complicated topography, and tends to reduce the efficiency of TOPOPOSA as a predictor. In a few cases, the opposite problem existed: TOPOPOSA was strongly correlated with other predictor variables, and therefore was not included in several multivariate models despite its significance in single variable models.

Soil available water-holding-holding capacity. Soil available water-holding capacity (SOILAWC) was a significant predictor of recruitment only at locations 3 and 7. At both locations recruitment was more likely to occur in plots with higher levels of SOILAWC. Among locations included in the analysis, locations 3 and 7 had the most droughty soils (Table 3-1), with estimated SOILAWC values of less than 5 cm (2 inches) in more than half of the plots at each location. At locations 1, 4, 6, and 15, soil AWHC values were higher overall and SOILAWC was nonsignificant. This suggests that recruitment may be limited by very low SOILAWC, but that SOILAWC is of little consequence in soils with at least moderate AWC.

The variable SOILAWC≥10CM was also significant in two of the between-location models, and generally indicated that higher levels of recruitment occurred in locations with low overall soil AWHC. The significance of this effect may be due in large part to the amount of recruitment at location 3, which had the lowest value of SOILAWC≥10CM. Based on the amount of recruitment at locations 1, 4, and 15, which had relatively high levels of SOILAWC≥10CM (Table 3-2), it does not appear that high soil AWHC directly limits recruitment. However, less droughty soils may support a wider range of woody species, which could limit blue oak recruitment through the effects of competition.

Insolation and climate variables. Potential average December insolation (INSOL12), a measure of combined slope and aspect effects, was generally a weak predictor of recruitment. However, based on preliminary analyses, INSOL12 was a better predictor than total potential annual insolation and potential average June insolation. One weakness of these calculated insolation variables is that they do not account for shading due to canopy cover or local terrain, and therefore overestimate actual insolation within the plot in many cases. Nonetheless, we believe insolation calculations are valuable for expressing the combined effects of slope and aspect. A similar methodology has been used by Borchert et al (1993) for describing slope/aspect effects on blue oak plant communities.

INSOL12 had apparently opposite effects on recruitment at locations 3 and 4. This difference can be explained largely by the difference in the distributions of plot insolations at the two locations (Appendix 4). Maximum insolation values were greater at location 3 than at location 4, and combined with the fact that location 3 is relatively xeric, it is logical that plots with high insolation (more xeric exposures) would be less favorable for sapling recruitment. At location 4, which is relatively mesic and supports a fairly diverse mix of canopy species, interspecific competition may be a much more significant factor affecting blue oak regeneration.

Due to their high level of drought tolerance, blue oak saplings may gain a competitive advantage at the most xeric sites (plots with higher INSOL12) in this otherwise mesic location.

In the between-location models, locations with predominantly xeric slope-aspects combinations (high AVGINSOL12) were less likely to have recruitment (Table 5-22). The rate ratios for the MINPPT2 and ETDEFICIT variables in the between-location models (Table 5-22) further indicate that xeric site conditions do not favor blue oak sapling recruitment. At some of our study locations, notably locations 2 and 9, existing blue oak stands are far denser on north-facing slopes than on southerly exposures. This pattern would tend to develop if regeneration is more successful on more mesic exposures. Borchert et al (1993) documented a pattern of greater blue oak density on northern exposures in San Luis Obispo County, and many others have noted this pattern as well.

The dominance of blue oak in many xeric habitats and the relatively high levels of recruitment seen at location 3 indicate that blue oak regeneration is certainly possible in xeric sites. The ability of blue oak to withstand drought is well documented (Griffin 1973, Baker et al 1981), and this species should have a competitive advantage at dry locations. However, the impact of other inhibitory factors, such as livestock grazing or repeated fires, may be of greater significance at xeric locations than at mesic locations, because of low saplings growth rates at dry sites. Although recruitment has occurred at location 3, where browsing pressure is low, regeneration is generally lacking at xeric locations that have been heavily grazed, such as locations 2, 8, and 11. Blue oak seedlings and saplings may have higher survival and growth rates in more mesic sites, leading to higher rates of recruitment even in the presence of grazing or high deer populations. This may help explain the relatively high rates of recruitment seen in grazed fields at locations 4 and 15.

Furthermore, Menke (undated) and Gordon et al (1991) demonstrated that cattle-grazed plots had lower levels of soil moisture during the growing season than ungrazed plots. Menke (undated) showed that cattle-grazed plots had increased soil compaction, depleted soil litter, and increased densities of herbaceous plants compared to ungrazed plots. By making site conditions more xeric, the impacts of grazing on seedling and sapling survival and growth are compounded at xeric locations. Due to these effects, blue oak regeneration may be inhibited more strongly by grazing at xeric locations and microsites than at more mesic locations and microsites.

Comparison of outcome variables.

In both within-location and between-location models, fewer factors were found to be correlated with S0 outcome variables than with the ALLRECR and S123SEED sapling variables. At least in part, this may be due to the lower numbers of plots which contained S0 recruitment relative to other types of recruitment. Few factors can be considered in models for outcomes that occur at low frequencies. It is also possible that the transition from the small seedling to the S0 seedling stage is subject to fewer constraints than is recruitment to the sapling stages. In a few locations, S0 seedlings were the only type of recruitment that we tallied. It may be noteworthy that S0 recruitment was only significantly related to gap-related variables at location 1, whereas sapling recruitment was correlated with gaps at locations 1, 3, 4, and 15 (Table 5-20). It may be that recruitment to the S0 stage is more likely to occur in the absence of a substantial canopy gap than is recruitment to the sapling stages. The distribution of plots with S0 seedlings by canopy class (Figure 4-5) suggests that S0 seedlings may be more shade tolerant than S1-S3 saplings. However, high levels of blue oak canopy cover (Table 4-8) do not appear to favor S0 recruitment.

Recruitment by size class

We did not attempt to tally seedlings smaller than the S0 class because such small seedlings often lose all of their foliage or their entire shoot by midsummer. Since our survey took place over an extended period (July through November), and the density of herbaceous vegetation varied widely between plots and locations, it would have been impossible to ensure that small seedlings were detected with equal efficiency in all plots. This limitation also applies to other past surveys which rated seedling densities (Muick and Bartolome 1987, Bolsinger 1988, Holzman 1993). Previous authors have not acknowledged this problem, possibly because the ability of small blue oak seedlings to survive despite mid to late season shoot necrosis (Swiecki et al 1990) was not appreciated at the time of these earlier surveys.

In general, S0 seedlings were most common in locations where seedling-origin saplings were also common, and often occurred in the same plots with saplings (Figure 4-1). While this in itself is not surprising, it does imply that many of the conditions that favor the transition from S0 to the sapling stages also favor the transition of small persistent seedlings to the S0 stage.

At most locations, S1 saplings were the most prevalent size class (Figure 4-2). This matches well with our observations that many saplings were stalled in the S1 size class due to browsing. Others have also reported high numbers of blue oak saplings that are shorter than the browse line (White 1966b, Borchert et al 1993, Muick and Bartolome 1987, Harvey 1989). The relative numbers of S2 and S3 saplings vary between locations, but in general, S3 saplings are slightly more prevalent than S2 saplings. We had expected to find fewer S2 saplings than S3 saplings, because a smaller growth increment is needed to grow from the S2 to S3 stage than from the S3 to the tree stage.

S2 and S3 saplings commonly occurred in the same plots as S1 saplings (Table 4-3). We believe that in many cases, all of the saplings in a single plot are members of the same cohort, but that individuals have grown at different rates. In some plots, sprout-origin saplings that originated from a single cutting event ranged in size from the S1 class to the S3 class and even included small-diameter trees.

Sprout origin saplings

We found that the overall proportion of saplings in the S2 and S3 size classes was higher among sprout-origin saplings (Table 4-5) than among seedling-origin saplings (Table 4-2). A plausible explanation for this difference is that sprout-origin saplings grow beyond the S1 stage more rapidly than do seedling-origin saplings. Due to the stored carbohydrate reserves in the parent tree's root system, blue oak stump sprouts can grow rapidly. This was documented in the study of McCreary et al (1991b), in which the longest shoots of unbrowsed blue oak stump sprouts averaged 85 cm after two years.

However, not all blue oak stumps produce sprout saplings. McCreary et al (1991b) showed variability in stump sprouting success between locations cut within the same year. Our data indicate that the success rate for sprout sapling establishment appears to vary between locations and between different years at a location. A number of factors may contribute to this variability. It has long been noted that stump sprouting in blue oak decreases with increasing tree age or size (Sudworth 1908, Jepson 1910, McCreary et al 1991b). Therefore, the success of resprouting following cutting depends on the age distribution of the existing stand.

Our field observations suggest that another cause of sprouting failure is rapid colonization of the stump by wood-decay fungi, especially those that decay the sapwood. Some of the effects of tree age on sprout success may actually be related to decay, because the presence of decay prior to cutting, and the overall susceptibility of a tree to decay, tends to increase with tree age. Resprouting failure due to stump decay can also be affected by a number of factors independent of the parent tree. The rate at which stumps become colonized by wood decay fungi may vary with the spatial distribution of particular decay fungi. Other factors that influence the infection process, such as season of cutting and weather conditions following cutting, may also contribute to variability in patterns and rates of stump decay and resprouting success.

As illustrated by the mortality among S1 sprout saplings (Table 4-5), not all stumps that send up shoots will give rise to trees. In many cases, mortality of stump-origin saplings probably results from the decline of the parent tree's root system, due to an inadequate supply of photosynthate from the sapling shoots. The declining roots and stump would be especially susceptible to decay by fungi that attack roots and the root crown. In addition, stump saplings are still subject to serious damage from livestock and wild vertebrates. We observed that severe browsing of the shoots by livestock and deer contributed to the mortality of both sprout- and seedling-origin saplings. McCreary et al (1991b) reported that the average shoot length of sprouts exposed to browsing was only half that of nonbrowsed sprouts. At one of their study locations (Hopland - location 5 in our study), browsing was so intense that sprout shoots were often chewed back to the parent trunk.

Since resprouting success is normally less than complete, stands regenerated from sprouts alone will always be of lower density than the original stand. Furthermore, in certain locations and years, stump sprouting may be minimal, and no significant sprout regeneration may occur after cutting. From a management perspective, stump sprouts may be an important supplemental source of blue oak regeneration in some areas that have been cut. However, stump sprouts are a risky source of regeneration, and in most cases, it would be unwise to rely exclusively on stump sprouts to restock cut stands. Seedling-origin saplings far outnumbered those of sprout origin in all but one of our study locations (Figure 4-2), and sprout-origin blue oak trees were in the minority at all study locations (Table 4-4).

Comparisons with past surveys

SMALLTREES was included as a plot variable in order to allow for comparisons between our data and that of the Forest Inventory and Analysis (FIA) Work Unit from the U.S. Forest Service Pacific Northwest Research Station (Bolsinger 1988). Our SMALLTREES size class is equivalent to the sapling size class in Bolsinger's (1988) report (Table 2-1). Bolsinger (1988) reported blue oak "saplings" (=SMALLTREES in this study) on 50% of the blue oak type sampled. In this study, 37% of the plots sampled in locations 3 through 15 had this size class present (Figure 4-4). As observed by Bolsinger (1988), trees in this size class do not necessarily represent recent recruitment.

The FIA "seedling" class corresponds fairly closely to the range of recruitment size classes represented by our ALLRECR variable, but may also include some seedlings smaller than our S0 class (Table 2-1). Bolsinger (1988) reported that 37% of the sampled blue oak type contained blue oak recruitment in this broad size class, compared with 18% of our plots which contained some form of comparably sized recruitment (ALLRECR). Bolsinger (1988) reports that only 13% of the blue oak type was moderately stocked or well stocked, i.e., at least 3 of 5 (60%) subplots within a plot had "seedlings". None of our locations had recruitment in 60% of the sample plots, although 2 locations (13%) had recruitment in more than 50% of the plots.

Due to differences in methods and definitions used, it is not possible to directly compare the FIA regeneration stocking levels with our sapling recruitment levels, but it appears that the FIA estimates for recruitment levels are generally higher than ours. Most of the differences between the FIA statewide data and our data can probably be attributed to differences in definitions and survey methodology. For example, we included plots within blue oak type which contained no trees if they were within 80 m of existing blue oaks, whereas the FIA survey did not include plots without trees. FIA surveyors also counted seedlings over 15 cm in height whereas our S0 seedlings were at least 25 cm tall. Finally, our 1500 plots are clustered in 15 discrete locations (Figure 2-1), whereas the approximately several hundred FIA plots containing blue oaks were randomly distributed across the range of blue oak.

Muick and Bartolome (1987) surveyed a subset of the FIA plots, and used different size class definitions (Table 2-1), and smaller subplots (0.01 ha) than used in our study. These differences limit our ability to directly compared our data with theirs. Muick and Bartolome's sapling size class roughly corresponds to the aggregate of our sapling and small tree classes (Table 2-1), and they found blue oaks in this size class in 29 of 41 plots (71%) which contained blue oak. Of the 13 locations where we tallied small trees, only locations 3, 4, and 6 have a similar incidence of plots with blue oaks in this size class range (Figure 4-4), although our percentages would be higher if plots without blue oak present were removed. A higher percentage of our saplings were scored as seedling origin (88%) compared to Muick and Bartolome's sample (72%). Muick and Bartolome (1987) did report that a high proportion of their "saplings" were browsed and that many were below 1.4 m height (our S1 size class). They also observed a wide variation in the density of "saplings" per plot, similar to what we observed.

Holzman (1993) surveyed 83 plots located in the vicinity of old U.S. Forest Service Vegetation Type Mapping (VTM) project plots. Plots used for recording tree data in her study had the same area as ours (0.08 ha), but were rectangular. Trees in the 3-13 cm dbh size class were found in 58% of the surveyed plots. Holzman (1993) reported that 63% of the plots had "seedlings" present, which were defined as blue oaks less than 30.5 cm tall. This size class would include what we considered to be small seedlings, S0 seedlings and small S1 saplings. Unfortunately, Holzman does not provide a separate tally of recruitment in her "small tree" size class (>30.5 cm tall, <2.54 cm dbh).

It is obvious that the diversity of methods and definitions used by different researchers precludes direct comparisons between different studies. This is due in part to the different objectives of these studies. To facilitate comparisons with existing research, blue oak researchers should consider using established size class definitions, at least for blue oaks shorter than 1.4 m. For recruitment taller than 1.4 m, comparisons with existing data will be easier to make if data are collected using narrow diameter classes or through direct measurement of diameter at 1.4 m (dbh).

Location of saplings relative to canopy

Several studies have shown that most blue oak seedlings establish under tree canopy. In a study of a field which had not been grazed for 28 years, White (1966) found seedlings at the edges of the field, near or under blue oak canopy. Muick and Bartolome (1987) reported that only 7% of the small blue oak seedlings they observed were found in the open, and that most (60%) were found directly under canopy. We found a similar distribution of blue oak seedlings relative to canopy in an earlier study (Swiecki et al 1990). Muick (1991) showed that initial survival of blue oak seedlings planted under shade cloth was greater than that of seedlings planted in full sun. Midday relative humidity and temperature are lower under blue oak canopy than in the open (Menke undated). The combination of a favorable microclimate under tree canopy and the relative lack of long-range acorn dispersal may account for the fact that most natural blue oak seedlings are found under or in close proximity to tree canopy.

The distribution of seedling-origin saplings relative to tree canopy which we observed does not correspond with the reported seedling distribution. We did not find an increase in the incidence of blue oak saplings with increasing blue oak canopy cover (Table 4-8), even though the probability of seedling presence should increase with increasing blue oak canopy. Furthermore, the distribution of saplings relative to canopy does not show that saplings are preferentially located under canopy (Figure 4-6), but approximates a random distribution of saplings relative to canopy. This shift in spatial distribution from the seedling to the sapling stage indicates that the canopy understory must be far less favorable for sapling recruitment than the open.

Reduced light levels and competition for soil moisture are the primary factors that limit the growth of trees in the understory (Spurr and Barnes 1980), although other factors may also be involved. Menke (undated) showed that despite the more favorable microclimate under tree canopy, water potentials of transplanted blue oak seedlings were lower under canopy than in the open in a grazed field. Although this effect was attributed to undocumented differences in herbaceous plant density, it may be more likely that soil moisture was depleted by the overstory blue oaks, and this intraspecific competition for soil moisture limits the recruitment of saplings from understory seedling. In an unpublished trial conducted in Ione, CA, (Mike Farmer, personal communication), small understory blue oak seedlings were recruited to the S0 stage by supplemental irrigation. Continued growth to the sapling stage has not occurred under canopy despite continued supplemental irrigation.

The loss of canopy through overstory tree removal or mortality eliminates shading and greatly reduces soil moisture competition. Established understory blue oak seedlings would be in the best position to exploit the additional soil and aerial growing space. Our field observations and the observed association between recent canopy gaps (GAPORCUT42) and sapling recruitment (Table 5-20) indicates that this process does occur. Canopy gaps provide the mechanism through which seedlings produced under tree canopy are transformed into saplings growing in the open.

Blue oak advance regeneration

One concept that has been lacking in most previous discussions of blue oak reproductive ecology has been that of advance regeneration. Advance regeneration (referred to as advance reproduction by some authors) typically refers to a bank of persistent seedlings or saplings, depending on the species, that is present in the forest or woodland understory (Grime 1979, Oliver and Larson 1990). Advance regeneration arises from seeds that germinate in the understory. Due to the suppressive effects of canopy shading and root competition for moisture and nutrients, advance regeneration remains in a small seedling or sapling growth stage for an extended period of time, ranging from a few years to more than a century, depending on the species involved (Oliver and Larson 1990).

For some species of oaks, advance regeneration grows very slowly, and may periodically die back to the ground and resprout from the root collar (Oliver and Larson 1990). Advance regeneration seedlings and saplings characteristically retain the ability to respond to a release from competition by showing relatively rapid growth, due to their established root systems and energy reserves. The release of advance regeneration usually involves the loss of canopy overstory through natural or human-caused disturbances. Tree mortality due to fire, disease or insect attack, windthrow, or overstory cutting can release the canopy competition that otherwise keeps advance regeneration suppressed.

Seedling advance regeneration, which consists of a bank of persistent seedlings, is a common source of regeneration in many species. A wide variety of temperate and tropical forest trees, as well as many other perennials, regenerate from a persistent seedling bank (Grime 1979, Oliver and Larson 1990). Regeneration from seedling advance regeneration is also common among many oak species (Oliver and Larson 1990). This type of regeneration mechanism is well-suited to species such as oaks which produce large seeds at irregular intervals, have relatively poor mechanisms for seed dispersal, and are capable of sprouting from the base following shoot loss. Although many oaks show relatively poor tolerance to the canopy understory when mature, advance regeneration of these same species is typically quite tolerant (Oliver and Larson 1990).

Based on data and observations of blue oak seedling survival and the distribution of sapling blue oaks, we previously proposed that small (mostly less than 15 cm tall) persistent seedlings of blue oak may function as advance regeneration (Swiecki 1990, Swiecki et al 1990). Our current study and other data from the literature provide further support for this concept and show that these small seedlings exhibit characteristics typical of advance regeneration. As discussed above, small seedlings show considerable tolerance of the understory and are most common under canopy. Small seedlings have the ability to resprout from the base following loss of the shoot due to desiccation or browsing (Griffin 1971, Swiecki et al 1990).

A number of different researchers (Griffin 1971, Swiecki et al 1990, Allen-Diaz and Bartolome 1992, Phillips 1993) have documented that natural blue oak seedlings are persistent and can survive in the understory for periods of at least 3 to 15 years despite repeated loss of their above-ground shoots. The maximum age that these persistent seedlings can attain has not been determined. In 1993, we resurveyed some of the natural seedling observation plots we established in 1988 (Swiecki et al 1990). Survival of blue oak seedling populations after five years of observation ranged between 6.5% and 83% at six locations in northern California (Swiecki and Bernhardt, unpublished data). The persistent seedlings in all of these studies are less than 25 cm tall, and are most are no taller than 15 cm.

Whereas blue oak seedlings appear to have all of the characteristics that typify advance regeneration, blue oak saplings do not. Saplings are more common in the open than in the understory (Table 4-9, Figure 4-6, Muick and Bartolome 1987). Mortality data (Table 4-11) also suggest that blue oak saplings are not particularly tolerant of understory conditions. Blue oak saplings are commonly recruited from seedling advance regeneration, but there is no evidence that saplings normally function as advance regeneration.

Regeneration mechanisms in blue oak

Some trees, known as tolerant species, are capable of continued growth and survival in the understory, whereas intolerant species perform poorly in the understory and eventually die if they remain overtopped. Within a given species, tolerance may vary with age, with seedlings and saplings showing greater tolerance than mature trees. In blue oak, only the small seedling stage shows a high degree of tolerance. Data from this study indicate that blue oak saplings are relatively intolerant of the understory. Previous field observations (Sudworth 1908, Tietje et al 1993) and survey data (Swiecki et al 1990, Muick and Bartolome 1987) indicate that mature blue oaks are intolerant of the understory, and our field observations from this study further support this conclusion.

Tree species vary in their ability to establish under different levels of canopy cover or following various types of disturbances, and several general patterns can be distinguished (Oliver and Larson 1990, Spurr and Barnes 1980). Species with windblown seeds and very poor understory tolerance, sometimes called pioneer species, establish readily and grow quickly following severe disturbances on sites lacking tree canopy and competing vegetation. Highly tolerant species establish readily even under dense canopy cover and are able to grow into the canopy layer despite heavy shading. Some species establish most readily in canopy gaps created by relatively minor disturbances, either from a dormant seed bank or a bank of suppressed understory seedlings or saplings, in a process that is sometimes referred to as gap-phase replacement. These different establishment patterns are not absolute or mutually exclusive, and some species may follow different patterns under different conditions.

Based on the results of this study, our previous study (Swiecki et al 1990), and information in the literature, it appears that most current recruitment can best be explained by a gap-phase mechanism. Many of the existing saplings are found in areas where canopy gaps have been created by moderate stand disturbances such as cutting and tree mortality. We believe that seedling advance regeneration in the understory serves as the primary source of the sapling recruitment in these gaps. Others have reported associations between overstory removal and sapling recruitment in blue oak (e.g. Jepson 1910, Allen-Diaz and Bartolome 1992, McClaran 1986), but most authors have presumed that saplings either originate in a direct fashion from recently-germinated acorns or as resprouts from existing saplings or trees.

We observed some seedling-origin saplings that did not appear to have arisen from advance regeneration. Saplings were sometimes found in areas away from canopy where no recent gap was obvious. It is possible that some of these saplings may have been recruited in gaps, but have remained suppressed in the sapling stage for so long that all evidence of the former overstory has disappeared. Harvey (1989) showed that many of the saplings less than 1.5 m tall at some of his study locations were between 40 and 100 years old.

In some cases, saplings not associated with recent gaps were probably recruited directly from seedlings that became established in the open from acorns transported by birds or mammals. We believe that blue oak is capable of colonizing open sites where plant competition and herbivory are limited. A common example of such colonization is along roadsides beyond pasture fences, where vertebrate browsing is minimal, herbaceous growth is often controlled with herbicides, and road runoff provides additional soil moisture. Artificial methods for establishing blue oak from seed are essentially based on producing such favorable microsites in the open through weed control and protective enclosures (McCreary et al 1991a). However, such "safe sites" appear to be relatively uncommon in California rangeland, due to grazing, herbaceous competition, and herbivory from high populations of rodents (Borchert et al 1989, Davis et al 1991, Hall and George 1991, Gordon et al 1991, Griffin 1971). This may explain why the rate of recolonization in old fields and other treeless areas is so low.

Our observations indicate that undisturbed, heavily canopied sites are unlikely to have sapling recruitment. We believe that saplings are most likely to be found under canopy when they become overtopped through the expansion of surrounding tree canopies. However, as noted above, the understory beneath foothill pine canopy may be favorable for blue oak sapling establishment. This raises the possibility that foothill pine may be an important component of successional processes in some blue oak woodlands.

Constraints to regeneration

If natural regeneration of blue oak depends primarily on advance regeneration, there are several ways that regeneration can be inhibited. Each of the following processes may be inhibited by unfavorable site and/or management factors:

1. Establishment of advance regeneration from seed
2. Persistence of established advance regeneration
3. The transition of seedling advance regeneration to the sapling size class
4. The transition of saplings to the tree size class

Our study focused on recruitment up to the sapling stage, and therefore measures the net effect of factors that influence any or all of the of the first three processes listed above. Some factors, such as the presence of browsing animals, may have similar effects on all four of these processes. Other factors may have opposing effects on the different processes. For example, the establishment of advance regeneration is apparently favored by higher levels of canopy cover than is favorable for the conversion of seedlings to saplings.

Factors which affect the processes leading to sapling recruitment in different ways probably contribute to the relatively poor fit seen in many of the statistical models. For example, a predictor variable that has a positive effect on seedling establishment may not appear to be a significant predictor if recruitment is subsequently inhibited by other factors. Manipulative studies could be designed to determine how each of the steps leading to sapling establishment are affected by different factors.

Since we do not know the past status of advance regeneration at any of our study locations, it is possible that some of the factors that were significant affected advance regeneration rather than sapling recruitment. Based on our seedling observation plots, it appears that the longevity of seedling advance regeneration at location 1 may be substantially greater than at location 2. If this pattern has been typical for the past few decades, it could help explain why there was no sapling recruitment at location 2, but a substantial amount of recruitment at location 1.

We found so few S2 and S3 saplings that we were not able to separately model the effects of factors affecting transition to these stages. It is obvious, however, that browsing and fire are both capable of retarding the transition of S1 saplings to larger size classes. High levels of canopy cover are also likely to inhibit the transition of saplings to the tree size class. A key question that remains unanswered is whether saplings that have been suppressed for extended periods of time are capable of accelerated growth once inhibitory factors have been removed. This question could be addressed through manipulative experiments.

We believe that our data and published studies are consistent with the hypothesis that blue oak sapling recruitment is a multistep process that may require many years to complete. The recruitment process is affected by various factors that inhibit or promote the advancement of seedlings and saplings into successively larger size classes. Saplings are most likely to be found in sites that are least affected by inhibitory factors, or where the effects of favorable factors (e.g. high soil moisture) overcome those of inhibitory factors (e.g. browsing).

At most of the locations we surveyed, it appeared that several factors were involved in limiting sapling recruitment. In these cases, the elimination of a single constraining factor will not necessarily increase the rate of recruitment. For example, eliminating a limiting factor such as livestock browsing may have little or no effect on sapling recruitment if canopy cover levels are unfavorably high or low. In addition, some factors that were previously present may have long residual effects that cannot be compensated for by current conditions. For example, if advance regeneration has been depleted or eliminated, factors that favor the recruitment of saplings from seedling advance regeneration, such as clearing, will not lead to sapling recruitment.

Based on our model of blue oak regeneration, we believe that much of the historical flush of blue oak regeneration that coincided with settlement in the late 1800's and early 1900's was due to the release of existing advance seedling regeneration due to widespread tree cutting, at a time when browsing pressure was not excessive. A major difference between present blue oak woodlands and pristine woodlands may be in the abundance and vigor of advance regeneration. We believe that long-term grazing, changes in the species composition of the woodland understory, and increased rodent populations may have greatly diminished populations of the seedling advance regeneration in many areas, greatly reducing the chance that saplings will be recruited in gaps created by mortality or clearing. If this view is correct, the extent of blue oak woodlands will continue to decrease due to unreplaced mortality if current management conditions continue.

7. CONCLUSIONS AND MANAGEMENT IMPLICATIONS

This study differs from previous surveys (Bolsinger 1988, Muick and Bartolome 1987, Holzman 1993) in that it examines stand dynamics at the landscape level through the use of a large number of plots at each study location. Because our study locations are distributed throughout the range of blue oak, we are confident that the trends we observed can be generalized over much of the range of blue oak.

Several important conclusions about blue oak sapling recruitment and regeneration can be drawn from this study. These conclusions apply to the current status of regeneration and projections are based on a continuation of current management practices. For the purposes of this discussion, the term "stand" should be considered to apply to a more or less contiguous block of woodland dominated by blue oak and at least 61 ha (150 acres) in extent (i.e. the minimum area we sampled at any study location).

1. In many stands, sapling blue oaks are absent or rare.

2. Natural mortality of blue oak trees can be found in most stands, and typical rates of natural mortality at the stand level may be at least 2 to 4 deaths/100 trees/decade.

3. In most stands, the percentage of the stand area which is likely to show a decrease in blue oak density and canopy cover is greater than the percentage that may show an increase in density and canopy cover.

4. In most stands where blue oak regeneration is poor, regeneration by woody overstory and understory associates is also low or lacking.

5. Sapling recruitment is often found in the same areas that contain shrubs, especially in stands with low levels of shrub cover.

6. Saplings are generally unlikely to be found in areas with high chronic levels of livestock browsing.

7. In areas that are subject to at least moderate browsing, the majority of all blue oak saplings are shorter than the browse line and show evidence of chronic browsing damage.

8. Frequent fires have a negative effect on sapling recruitment and growth. Infrequent fires appear to have either no effect or a slight positive effect on sapling recruitment.

9. Seedling-origin blue oak saplings are often found in relatively recent (30-40 years) canopy gaps.

10. Saplings tend to occur most frequently in areas with moderate amounts of canopy cover. Old cleared fields, areas with very low canopy cover, and areas with very dense canopy cover tend to have few or no saplings.

11. Saplings tend to be more likely to occur in mesic sites within xeric locations. In relatively mesic locations that have a diverse mix of canopy species, blue oak saplings may be more likely to be found in xeric sites.

A few of the major inferences we have drawn from this study and other published work that have implications for managing blue oak stands are as follows:

- Much of the existing blue oak sapling recruitment has probably arisen from seedling advance regeneration that was recruited following the opening of canopy gaps due to clearing, fire, or natural mortality.

• In areas where conditions have been unfavorable for the establishment and survival of seedling advance regeneration, canopy gaps are unlikely to favor sapling recruitment.

• Pioneer establishment of blue oak in treeless areas is uncommon under current range conditions, but sometimes occurs in favorable microsites.

• A number of factors may inhibit sapling recruitment, and the effects of these factors interact through a time interval that may span at least 30 or 40 years. Due to the importance of past conditions, there may be little relationship between the current management and stand conditions and the amount of sapling recruitment.

• Inhibitory factors, such as grazing and frequent fires, are likely to have a more pronounced effect on sapling recruitment in xeric locations than in mesic locations.

• The lack of regeneration in blue oak and the lack of regeneration by other woody species in hardwood rangelands are probably related outcomes that are the result of management practices which have selected against woody plants in the understory.

Based on the foregoing information and inferences, there are at least several tactics that could be used to promote blue oak regeneration.

• Understory clearing of shrubs should be minimized within blue oak stands.

• Alternative grazing regimes that reduce the duration and intensity of browsing pressure on woody vegetation may help to reduce the negative impact of browsing on regeneration.

• Fire may be of use as a tool to manipulate understory vegetation, but frequent burning is unlikely to promote blue oak regeneration.

• Cutting that involves extensive canopy removal should not be conducted in areas that have little or no advance regeneration. Overstory canopy cover should generally not be reduced below 20% cover within any 0.1 ha unit if regeneration is desired.

• Following cutting or other gap-creating events such as a wildfire, livestock use should be minimized until any recruited blue oak saplings have grown taller than browse line.

• Potentially adverse impacts should be especially minimized in areas that are near the limits of blue oak distribution at either the local or regional level.

Techniques such as those used in this study can be used to develop statistical models that describe the probability of sapling recruitment within stands, or possibly larger areas, subject to the limitations discussed earlier. However, good quality data on site history and management extending back at least 30 to 40 years is necessary for developing reasonable models. Due to the lack of adequate history data over large portions of the state, it is unlikely that a detailed statewide model for predicting recruitment could be developed. It may be possible to develop less detailed models at the statewide level that would indicate regions where recruitment is more likely or less likely to occur, but the predictive power of such models may be quite limited.

LITERATURE CITED

Allen, B. H.; Evett, R. R.; Holzman, B. A.; Martin, A. J. 1989. Report on rangeland cover type descriptions for California hardwood rangelands. Prepared for: California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program, Sacramento, CA.

Allen-Diaz, B. H.; Bartolome, J. W. 1992. Survival of *Quercus douglasii* (Fagaceae) seedlings under the influence of fire and grazing. Madrono 39:47-53.

Baker, G. A.; Rundel, P. W.; Parsons, D. J. 1981. Ecological relationships of *Quercus douglasii* (Fagaceae) in the foothill zone of Sequoia National Park, California. Madrono 28(1):1-12.

Bartolome, J. W.; Muick, P. C.; McClaren, M. P. 1987. Natural regeneration of California hardwoods. In: Plumb, T. R.; Pillsbury, N. H. tech. coord. Proceedings of the symposium 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. Dept. of Agriculture;

Begg, E. L. 1968. Soil survey of Glenn County California. Washington, D.C.: U.S. Dept. of Agriculture, Soil Conservation Service.

Bolsinger, C. 1988. The hardwoods of California's timberlands, woodlands, and savannas. Resource Bull. PNW-RB-148. Portland, OR: Pacific Northwest Research Station., Forest Service, U.S. Department of Agriculture.

Borchert, M. I.; Davis, F. W.; Michaelsen, J.; Oyler, L. D. 1989. Interactions of factors affecting seedling recruitment of blue oak in California. Ecology 70:389-404.

Borchert, M. I.; Cunha, N. D.; Krosse, P. C.; Lawrence, M. L. 1993. Blue oak plant communities of southern San Luis Obispo and northern Santa Barbara counties. Gen. Tech. Rep. PSW-GTR-139. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Dept. of Agriculture.

Bowers, W. O.; Snyder, R. L.; Southard, S. B.; Lanini, B. J. 1989. Water-holding characteristics of California soils. Leaflet 21463. Oakland, CA: Division of Agriculture and Natural Resources, Univ. of California

Brown, R. W.; Davis, F. W. 1991. Historical mortality of valley oak (*Quercus lobata* Nee) in the Santa Ynez Valley, Santa Barbara County, 1938-1989. In: Standiford, R. B., tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Dept. of Agriculture; p. 202-207.

Carvell, K. L.; Tryon, E. H. 1961. The effect of environmental factors on the abundance of oak regeneration beneath mature oak stands. Forest Science 7:98-105.

Cook, T. D. 1978. Soil survey of Monterey County, California. Washington, D.C.: U.S. Dept. of Agriculture, Soil Conservation Service.

Davis, F. W.; Borchert, M.; Harvey, L. E.; Michaelsen, J. C. 1991. Factors affecting seedling survivorship of blue oak (*Quercus douglasii* H. & A.) in Central California. In: Standiford, R. B., tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Dept. of Agriculture; p. 81-86.

Duffie, J. A.; Beckman, W. A. 1991. Solar engineering of thermal processes. Second edition. New York: John Wiley and Sons, Inc.

Frost, W. E.; McDougald, N. K.; Demment, M. W. 1991. Blue oak canopy effect on seasonal forage production and quality. In: Standiford, R. B., tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Dept. of Agriculture; p. 307-311.

Gordon, D. R.; Welker, J. M.; Menke, J. W.; Rice, K. J. 1989. Competition for soil water between annual plants and blue oak (*Quercus douglasii*) seedlings. Oecologia 79:533-541.

Gordon, D. R.; Rice, K. J.; Welker, J. M. 1991. Soil water effects on blue oak seedling establishment. In: Standiford, R. B., tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Dept. of Agriculture; p. 307-311.

Gowans, K. D. 1967. Soil Survey of Tehama County, California. Washington, D.C.: U.S. Dept. of Agriculture, Soil Conservation Service.

Griffin, J. R. 1971. Oak regeneration in the upper Carmel Valley, California. Ecology 52:862-868.

Griffin, J. R. 1973. Xylem sap tension in three woodland oaks of central California. Ecology 54:152-159.

Griffin, J. R.; Critchfield, W. B. 1976. The distribution of forest trees in California. Res. Paper PSW-82. Berkeley, CA: U.S. Dept. Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

Grime, J. P. 1979. Plant strategies and vegetation processes. New York: John Wiley and Sons, Inc.

Haggerty, P. K. 1991a. Fire effects in blue oak (*Quercus douglasii*) woodland in the southern Sierra Nevada, California. M.S. Thesis, University of California, Davis.

Haggerty, P. K. 1991b. Fire effects in blue oak woodland. In: Standiford, R. B., tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Dept. of Agriculture; p. 342-344.

Hall, L. M.; George, M. R. 1991. Grazing compatible with blue oak regeneration. Prepared for: California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program, Sacramento, CA.

Harvey, L. E. 1989. Spatial and temporal dynamics of a blue oak woodland. Ph.D. Thesis. University of California, Santa Barbara.

Herbert, F. W., Jr. ; Begg, E. L. 1969. Soils of the Yuba Area, California. Davis, CA: Univ. of California.

Hickman, J. C. (ed.) 1993. The Jepson manual: higher plants of California. Berkeley, CA: Univ. of California Press.

Holland, V. L. 1976. In defense of blue oaks. Fremontia 4(1): 3-8.

Holzman, B. A. 1993. Vegetation change in California's blue oak (*Quercus douglasii*) woodlands 1932-1992. M. S. Thesis. University of California, Berkeley.

Howard, R. F.; Bowman, R. H. 1991. Soil survey of Mendocino County, Eastern part, and Trinity County, Southwestern part, California. Washington, D.C.: U.S. Dept. of Agriculture, Soil Conservation Service.

Isgrig, D. 1969. Soil Survey, San Benito County, California. Washington, D.C.: U.S. Dept. of Agriculture, Soil Conservation Service.

Jepson, W. L. 1910. The silva of California. Memoirs Univ. of Calif., vol 2. Berkeley, CA: Univ. of Calif. Press.

Lambert, G.; Kashiwagi, J. 1978. Soil Survey of Napa County, California. Washington, D.C.: U.S. Dept. of Agriculture, Soil Conservation Service.

Lang, F. J. 1988. Oak regeneration assessment - a problem analysis. (JSA 86-72.) Prepared for: California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program, Sacramento, CA.

Lindsey, W. C. 1974. Soil Survey of the eastern Santa Clara Area, California. Washington, D.C.: U.S. Dept. of Agriculture, Soil Conservation Service.

McClaran, M. P. 1986. Age structure of *Quercus douglasii* in relation to livestock grazing and fire. Ph.D. Dissertation, Univ. of California, Berkeley.

McClaran, M. P.; Bartolome, J. W. 1989. Fire related recruitment in stagnant *Quercus douglasii* populations. Canadian J. For. Res. 19:580-585.

McCreary, D. D.; Adams; T.; Schmidt, R.; Scott, T.; Tietje, W. 1991a. Selected techniques for restocking hardwood rangelands in California with native oaks. Prepared for: California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program, Sacramento, CA.

McCreary, D. D.; Tietje, W. D.; Schmidt, R. H.; Gross, R.; Weitkamp, W. H.; Willoughby, R. L.; Bell, F. L. 1991b. Stump sprouting of blue oaks in California. In: Standiford, R. B., tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Dept. of Agriculture; p. 64-69.

Menke, J. W. undated. Forage and oak sapling responses to canopy removal and defoliation. Prepared for: California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program, Sacramento, CA.

Mensing, S. A. 1992. The impact of European settlement on blue oak (*Quercus douglasii*) regeneration and recruitment in the Tehachapi Mountains, California. Madrono 39 (1): 36-46.

Muick, P. C.; Bartolome, J. R. 1987. An assessment of natural regeneration of oaks in California. Prepared for: Calif. Dept. of Forestry, Sacramento, CA.

Muick, P. C. 1991. Effects of shade on blue oak and coast live oak regeneration in California annual grasslands. In: Standiford, R. B., tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Dept. of Agriculture; p. 21-24.

Oliver, C. D.; Larson, B. L. 1990. Forest stand dynamics. New York: McGraw-Hill, Inc.

Phillips, R. L. 1993. Aging blue oak seedlings. Oaks 'n' Folks 93(March):4.

Pruitt, W. O.; Fereres, E.; Kaita, K.; Snyder, R. L. 1987. Reference evapotranspiration (ETo) for California. Oakland, CA: Univ. of California Division of Agriculture and Natural Resources Bulletin 1922.

Sketchley, H. R. 1965. Soil survey of the Amador area, California. Washington, D.C.: U.S. Dept. of Agriculture, Soil Conservation Service.

Smith, B. F.; DeLapp, J. A.; Stone, C. O.; 1977. Soil-vegetation map, Sonora quadrangle (northwest quarter), Calaveras and Tuolomne Counties, California. Map 78B-2. Pacific Southwest Forest and Range Expt. Station; Div. of Agr. Sciences, Univ. of California; Division of Forestry, Calif. Dept of Conservation.

Spurr, S. H.; Barnes, B. V. 1980. Forest Ecology. New York: John Wiley & Sons, Inc.

Standiford, R. B.; Tinnin, P. J. (Ed.) 1992. Integrated Hardwood Range Management Program, fifth progress report, July 1991 - December 1992. University of California and State of California.

Stephas, F. G.; Waterman, L. W.; Broderson, W. D.; Jahnke, J. J. 1982. Soil survey of Tulare County, California, Central part. Washington, D.C.: U.S. Dept. of Agriculture, Soil Conservation Service.

Stromberg, L. K.; Huntington, G. L.; Begg, E. L.; Smith, G. K. 1962. Soil survey of the Madera area, California. Washington, D.C.: U.S. Dept. of Agriculture, Soil Conservation Service.

Swiecki, T. J. 1990. Oak diseases and insects: a delicate balance. Fremontia 18: 58-63.

Swiecki, T. J; Bernhardt, E. A. 1991. Minimum input techniques for restoring valley oaks on hardwood rangeland. Prepared for: California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program, Sacramento, CA.

Swiecki, T. J; Bernhardt, E. A.; Arnold, R. A. 1990. Impacts of diseases and arthropods on California's rangeland oaks. Prepared for: California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program, Sacramento, CA.

Sudworth, G. B. 1908. Forest trees of the Pacific Slope. Washington, D.C: U.S. Department of Agriculture.

Tietje, W., Weitkamp, W, Jensen, W., and Garcia, S. 1993. Drought take toll on central coast's native oaks. California Agriculture 47:4-6.

Vankat, J. L.; Major, J. 1978. Vegetation changes in Sequoia National Park, California. Journal of Biogeography 5:377-402.

USDA Forest Service, Los Padres National Forest. Preliminary soil survey.

Welch, L. E. 1977. Soil survey of Contra Costa County, California. Washington, D.C.: U.S. Dept. of Agriculture, Soil Conservation Service.

White, K. L. 1966a. Structure and composition of foothill woodland in central coastal California. Ecology 47:229-237.

White, K. L. 1966b. Old-field succession on Hastings Reservation, California. Ecology 47:865-868.

APPENDIX 1. SAMPLING AND PLOT SELECTION RULES

Sampling grid characteristics

1. Plots are located along a series of 10 parallel transects spaced 100 m apart.
2. There are 20 plots along each transect. Plot centers along the transects are 80 m apart.
3. The entire sampling grid shows the locations of 200 plot centers, of which the first 100 eligible plots, starting from the origin, will be sampled.

Eligibility of sampling areas and plots

Areas are eligible for sampling if they are oak woodland (>10% canopy cover) or oak savannah (< 10% canopy cover but with at least 1.6 trees/ha) in which blue oak is a dominant canopy species.

Plots are considered to be eligible for sampling if they meet one of the following criteria:

1. Blue oak is present in the canopy or understory.
2. The plot is within 80 m of a blue oak tree or sapling.
3. The plot has been cleared of blue oaks within the last 30 years but is not intentionally maintained free of trees (e.g. through cultivation).

Placement of the sampling grid

Step 1. A random number table is used to select random x and y coordinates that fall within the eligible area on a base map.

Step 2. Plot 101 on the sampling grid (transect 1, plot 1) is placed over the random starting point with the transects oriented northward from the starting point.

Step 3. If 100 eligible plots which can be accessed by foot are located within the grid this orientation is selected.

Step 4. If there is an insufficient number of eligible plots, the grid is rotated to the cardinal directions proceeding in a clockwise direction. The first of these orientations which fulfills the conditions noted in step 3 is the selected orientation.

Step 5. If none of the four orientations fulfills the conditions noted in step 3, a new random point is selected, and the selection process is repeated.

Offsetting plots in the field

If the plot falls across fence lines, roads, or other sources of interference, the plot center is offset the shortest possible distance that will avoid the interference.

APPENDIX 2. PREDICTOR AND OUTCOME VARIABLE DEFINITIONS

This appendix lists the variables that were measured or assessed in field plots, as well as variables that were compiled from history data or calculated from other variables. Location average variables, which were only used in the between-location models, are also listed. The variables are arranged by category, and each entry lists the variable name as used in this report, the type of variable, and a description of how the variable was assessed or computed. Variable types include binary (0 - factor absent / 1 - factor present), categorical (numerical or alphanumeric categories), and continuous (variable may assume any value in a range).

Note: This is not a complete listing of all fields in the database which was converted to ARC/INFO format and delivered to CDF. In addition, the names of some variables used in the report have been changed from those used in the CDF database.

Plot topographic variables

UTM-X
Continuous. Universal Transverse Mercator (UTM) X coordinate of plot position in meters easting determined from map positions and GPS readings. Absolute distances are from UTM zone meridians.

UTM-Y
Continuous. Universal Transverse Mercator (UTM) Y coordinate of plot position in meters northing. Absolute distances are from the equator.

ALTITUDE
Continuous. Plot altitude in feet, based on USGS map elevations.

SLOPE
Continuous. Plot slope measured by clinometer in percent slope.

ASPECT
Continuous. Plot aspect measured by compass (corrected for declination) in degrees (0-359).
Not applicable if slope = 0

TOPOPOS
Categorical. Topographic position of plot. Codes adapted from USFS-FIA methods.

1- Flat ridgetop or peak > 40 m wide
2- Convex ridgetop or peak < 40 m wide
3- Sidehill upper third
4- Sidehill middle third
5- Sidehill lower third
6- Concave canyon bottom < 200 m wide
7- Flat bench, terrace, or alluvial flat > 200 m wide

TOPOPOSA
Categorical. Topographic position of plot recoded to 3 classes:

TopoPos	TopoPosA
1, 2	1
3	2
4, 5, 6, 7	3

Stand and tree canopy variables

STANDEDGE
Categorical. Number of noneligible plots (not considered to be within the stand) that border the plot (0-4).

STANDEDGEA.
Binary. Indicates (1), one or more of the adjacent plots on the sampling grid falls outside of the blue oak stand or (0), all of the adjacent plots contain blue oaks.

TOTCANOPY
Categorical. Overall estimate of total tree canopy cover in the plot, rated using the following 0-6 scale:

Category	Range	Central value
0	0	0
1	>0 and ≤2.5%	1.25%
2	>2.5% and ≤20%	11.25%
3	>20% and ≤50%	35%
4	>50% and ≤80%	65%
5	>80% and ≤97.5%	88.75%
6	>97.5%	98.75%

TOTCANOPYA
Categorical. Total canopy in plot recoded to three classes:

TOTCANOPYA	TOTCANOPY	Range
1	0, 1	≤2.5%
2	2	>2.5% and ≤20%,
3	3, 4, 5, 6	>20%

TOTCANOPYB
Categorical. Total canopy in plot recoded to three classes:

TOTCANOPYB	TOTCANOPY	Range
1	0, 1, 2	≤20%
2	3, 4	>20% and ≤80%,
3	5, 6	>80%

TOTCANPCT
Continuous. Same as TOTCANOPY, but numbers reported are the central values of the categorical ranges.

CANSPPTOT
Count. Total number of canopy species in plot.

OTHCANSPP
Count. Total number of canopy species other than blue oak in plot.

MAXCANOPYSPP
Count. The maximum number of canopy species found in any plot at each location.

CANSPPOTH

Categorical. A list of tree species other than blue oak present in the plot. Taxonomy follows Hickman (1993).

Tree species	Common name
Acer macrophyllum Pursh	Big-leaf maple
Aesculus californica (Spach) Nutt.	California buckeye
Alnus rhombifolia Nutt.	White alder
Arbutus menzesii Pursh	Madrone
Arctostaphylos manzanita C. Parry	
Arctostaphylos viscida C. Parry	
Fraxinus dipetala Hook. & Arn.	California ash
Fraxinus latifolia Benth.	Oregon ash
Fremontodendron californicum (Torrey) Cov.	Flannelbush
Pinus ponderosa Laws.	Ponderosa pine
Pinus sabiniana Douglas	Foothill pine
Platanus racemosa Nutt.	California sycamore
Quercus × alvordiana Eastw. *(Q. douglasii × Q. john-tuckeri).*	
Quercus agrifolia Nee	Coast live oak
Quercus douglasii Hook. & Arn.	Blue oak
Quercus garryana Hook.	Oregon oak
Quercus john-tuckeri K. Nixon & C.H. Muller	Tucker's oak
Quercus kelloggii Newb.	California black oak
Quercus lobata Nee	Valley oak
Quercus × morehus Kellogg *(Q. kelloggii × Q. wislizenii)*	Oracle oak
Quercus wislizenii A.DC.	Interior live oak
Salix spp.	Willow
Umbellularia californica (Hook. & Arn.) Nutt.	California bay

BADCANOPY

Count. Location summary variable. Number of plots at each location meeting one of the two following criteria:
1) plot canopy cover greater than 80%, or
2) plot blue oak canopy cover less than or equal to 2.5%, **and** no recent cutting or gap in plot (GAPORCUT42=0).

QDCAN

Categorical. Overall estimate of total canopy cover by blue oak in the plot, rated using the 0-6 scale listed under TOTCANOPY.

QDCANPCT

Continuous. Same as QDCAN, but numbers reported are the central values of the categorical ranges.

QDCANDECR

Binary. 1 (Yes) / 0 (No) Evaluation of whether the cover of blue oak in the plot has decreased due to tree removal, mortality, or severe dieback or failure in the last 30 years (since 1962).

QDLIVEALL
Count. The number of all live blue oak trees in the plot.

QDDEADALL
Count. The number of all dead blue oak trees in the plot.

QDDEADPLOT
Binary. 1 (Yes) / 0 (No) Indicates whether dead blue oak trees occur in the plot.

QDMORT
Count. The number of all dead blue oak trees in the plot plus the number of visible blue oak stumps.

QDMORT42
Count. The number of all dead blue oak trees in the plot plus STUMP42 (the number of visible blue oak stumps in plots where tree cutting has occurred in the past 42 years). This variable is a better estimate of mortality occurring in the past 42 years only.

QDLIVE
Count. The number of apparent seedling origin live blue oak trees in the plot.

QDDEAD
Count. The number of apparent seedling origin dead blue oak trees in the plot.

QDSPLIVE
Count. The number of live blue oak stump resprout trees in the plot. Trees were assigned to the stump sprout class if they had a visible stump or stump scar or multiple trunks arising at or slightly above ground level. In general, trees of questionable origin were assigned to the seedling origin class (QDLIVE).

QDSPDEAD
Count. The number of dead blue oak stump resprout trees in the plot.

STUMPS
Count. Number of blue oak stumps in the plot.

STUMP42
Count. Number of blue oak stumps in the plot, but only in plots where cutting in the past 42 years is reported. This variable differs from STUMPS in that stumps from very old clearing events are omitted.

NEWGAP
Binary. 1 (Yes) / 0 (No) Evaluation of whether mortality or removal of any canopy species has formed a new gap in the plot within the last 30 years. This variable is related to opportunities for recruitment under a gap recruitment model.

GAPORCUT42
Binary. 1 (Yes) / 0 (No) Plot has been scored positive for NEWGAP or for tree cutting within the past 42 years (CUT42YR = 1). This is an adjustment of the variable NEWGAP.

LOCGAPORCUT
Count. Location summary variable. The number of plots at each location in which tree cutting has occurred in the plot within the 42 years prior to 1992 or a canopy gap due to other factors has occurred within the past 30 years (i.e. plots where GAPORCUT42 = 1).

PASTRECR
Binary. 1 (Yes) / 0 (No) Assessment of whether recruitment appears to have occurred in the plot within the past 150(±) years.

SMALLTREES
Binary. Trees in the 3 to 13 cm (1 to 5 inch) dbh class present (1) or absent (0) in the plot. This is included to provide data comparable to the sapling size class in the FIA (Bolsinger) survey. This variable was added after sampling was completed at the first two locations.

Understory variables

BARECOVER
Categorical. The percentage of the plot area occupied by bare ground and rocks, estimated using the 0 - 6 scale listed under TOTCANOPY.

BUNCHCOVER
Categorical. The percentage of the plot area occupied by native bunchgrasses or other native perennial grasses, estimated using the 0 - 6 scale listed under TOTCANOPY.

HERBCOVER
Categorical. The percentage of the plot area occupied by herbaceous plants, estimated using the 0 - 6 scale listed under TOTCANOPY.

SHRUBCOVER
Categorical. The percentage of the plot area occupied by shrubs, estimated using the 0 - 6 scale listed under TOTCANOPY. Shrubs are generally defined as woody plants less than 3.7 m (12 ft) tall.

SHRUBCOVERA
Binary. Indicates the presence (1) or absence (0) of more than 2.5% shrub cover in the plot.

BAREPCT, BUNCHPCT, HERBPCT, SHRUBPCT
Continuous. Same as the four understory cover estimate variables listed above, but numbers reported are the central values of the categorical ranges listed under TOTCANOPY.

SHRUBSPTOT
Count. Total number of shrub species present in the plot.

SHRUBPRESENT
Binary. Indicates presence (1) or absence (0) or any shrub species present in the plot.

LOCSHRUBPRESENT
Count. Location summary variable. Number of plots at a location containing shrubs.

POISONOAK
Binary. Poison oak (*Toxicodendron diversiloba*) present (1) or not present (0) in the plot.

RHAMNUSCROCEA
Binary. *Rhamnus crocea* present (1) or not present (0) in the plot.

ARCTOSTAPHYLOS
Binary. Any species of manzanita (*Arctostaphlos* spp.) present (1) or not present (0) in the plot.

SHRUBSPP

Categorical. The shrub species present in the plot. Shrubs are woody plants less than 3.7 m high. Taxonomy follows Hickman (1993).

Shrub species	Common name
Adenostoma fasciculatum Hook. & Arn.	Chamise
Arctostaphylos glandulosa Eastw.	Manzanita
Arctostaphylos glauca Lindley	Manzanita
Arctostaphylos manzanita C. Parry	Manzanita
Arctostaphylos sp.	Manzanita
Arctostaphylos standfordiana C. Parry	Manzanita
Arctostaphylos viscida C. Parry	Manzanita
Artemisia californica Less.	California Sagebrush
Baccharis sp.	
Ceanothus cuneatus var. *cuneatus* (Hook.) Nutt.	Buck brush
Ceanothus sp.	
Cephalanthus occidentalis var. *californicus* Benth.	California button willow
Cercis occidentalis Torrey	Western redbud
Cercocarpus betuloides var. *betuloides* Torrey & A. Gray	Birch-leaf mountain-mahogany
Ericameria linearifolia (DC.) Urb. & J. Wussow	Interior goldenbush
Eriodictyon californicum (Hook. & Arn.) Torrey	
Eriodictyon tomentosum Benth.	
Eriogonum fasciculatum Benth.	California buckwheat
Fraxinus dipetala Hook. & Arn.	California ash
Haplopappus sp. (*sensu* Munz and Keck 1968)	
Heteromeles arbutifolia (Lindley) Roemer	Toyon
Juniperus californica Carriere	California juniper
Lonicera sp.	Honeysuckle
Lupinus sp.	Lupine
Mimulus sp.	Monkey flower
Prunus ilicifolia	Holly-leafed cherry
Quercus berberidifolia Liebm.	Scrub oak
Quercus durata Jepson	Leather oak
Quercus john-tuckeri K. Nixon & C.H. Muller	Tucker's oak
Rhamnus californica Eschsch.	California coffeeberry
Rhamnus ilicifolia Kellogg	Holly-leaf redberry
Ribes sp.	Gooseberry
Rubus sp.	Blackberry
Salvia mellifera E. Greene	Black sage
Toxicodendron diversiloba (Torrey & A. Gray) E. Greene	Poison oak
Vitis californica Benth.	California wild grape

O - (coded OU*n* on data sheets) other unidentified shrubs with *n* being the number of unidentified species in the plot

Soil variables

SOILCODE
Categorical. Alphanumeric code indexed to each discrete soil type classified within a site. Each plot is assigned a code based on soil survey data and field observations. Location code letters are listed below.

Location/ID	Code
1 / Wantrup	W
2 / Black Butte	BB
3 / Pinnacles	P
4 / Sierra FS	S
5 / Hopland	H
6 / Sequoia	SP
7 / Dye Creek	DC
8 / Pardee	PR

Location/ID	Code
9 / Pozo	SR
10 / San Antonio	SA
11 / Hensley Lake	HG
12 / Henry Coe	HC
13 / Mt. Diablo	M
14 / Ca Hot Springs	BR
15 / Jamestown	J

SOILTYPE
Categorical. Soil type within plot. Determined from SCS Soil Surveys and from field observations.
C=clay
Co=coarse
G=gravelly
L=loam
R=rocky
S=sandy/sand
Si=silty/silt
V=very (as in very rocky)
These codes may be used in combination (GSiCL=gravelly silty clay loam)

SOILDEPTH
Categorical. Visual evaluation of soil depth in plot, based on herbaceous growth and other visual indicators. These ratings are location-specific, not general across all locations (e.g. soils rated as moderate at one location might be the same depth as those rated as deep at another location)
1=shallow
2=moderate
3=deep

SOILROCKYA
Categorical. Rockiness of soil in plot.
0=soil not obviously rocky
1=soil rocky (rocks intermixed in soil)
2=soil rocky with significant rock outcrops

SOILAWC
Continuous. An estimate of the soil available water-holding capacity (AWHC) of the soil profile in the plot. Calculated based on SCS soil survey information on AWHC and depth for given

soil types, estimated soil texture, depth, and rockiness as noted in the field. The following steps were followed to develop this estimate:

1. The overall range of AWHC for each SOILCODE was determined from published data or estimated from soil texture.

2. The overall range of soil depths reported for each SOILCODE was determined from published data or estimated based on field observations.

3. An AWHC value (inches water/inch soil) was assigned for each combination of SOILCODE, SOILTYPE, and SOILROCKYA based on the range in step 1 above as adjusted for surface soil texture and soil rockiness. The adjustment for soil rockiness is based on the method of Bowers et al (1989).

4. A depth value (inches) for each combination of SOILCODE and SOILDEPTH was assigned based on the range in step 2 above and plot depth ratings. SOILDEPTH ratings of 1, 2, and 3 were typically assigned to the minimum, average, and maximum depth values reported for the SOILCODE.

5. The estimated SOILAWC (inches water) for the soil profile in each plot was obtained by multiplying the AWHC value from step 3 by the depth value in step 4.

WHCCLASS
Categorical. Ranking of the soil available water-holding capacity of the soil profile in the plot, based on SOILAWC value.
1 = less than 2 inches
2 = 2 to 3.99 inches
3 = 4 to 7.99 inches
4 = 8 inches or greater

SOILAWC≥10CM
Count. Location summary variable. Number of plots at a location in which the estimated SOILAWC is 10 cm or greater.

Environmental variables

INSOL6
Continuous. Calculated total daily solar insolation (MJ/m^2) for the plot on the average day in June (June 11) for the plot. Insolation values are based on plot slope, aspect, latitude, and altitude using a program provided by Tom Rumsey (Dept. Biol. and Agr. Engr., U. C. Davis) based on the Hottel estimation model in Duffie and Beckman (1991). Values are based on integrated values calculated at 0.5 hr intervals. Calculations include both direct beam and sky diffuse radiation, but do not account for topographic effects that would shorten day length. Ground reflectance is also set to zero.

INSOL12
Continuous. Calculated total daily solar insolation (MJ/m^2) for the plot on the average day in December (December 10). See notes under INSOL6 for other details.

INSOLANN
Continuous. Calculated total annual solar insolation (MJ/m^2) for the plot, based on the sum of daily values calculated for each day of the year. See notes under INSOL6 for other details.

AVGINSOL12
Continuous. Location summary variable. Average December average-day (INSOL12) for the location.

AVGPPT
Continuous. Historical average annual precipitation at the location in cm.

AVG30PPT
Continuous. Calculated or estimated average seasonal (12 month) precipitation at the location over the past 30 years in cm. Rainfall seasons are standardized to be from July 1 to June 30 for all locations.

MINPPT1
Continuous. Minimum seasonal precipitation at the location over the past 30 years in cm.

MINPPT2
Continuous. Minimum average seasonal precipitation in any 2 year interval at the location over the past 30 years in cm.

MAXPPT1
Continuous. Maximum seasonal precipitation at the location over the past 30 years in cm.

MAXPPT2
Continuous. Maximum average seasonal precipitation in any 2 year interval at the location over the past 30 years in cm.

ETO
Continuous. Estimated annual reference evapotranspiration (ETo) for the location in cm, based on data published by the California Department of Water Resources.

ETDEFICIT
Continuous. Difference between estimated annual reference evapotranspiration (ETo) and average annual precipitation (30 year) for the location in cm.

SUMMERPPT
Continuous. Number of years out of the past 30 years with at least 1.3 cm (0.5 inch) of precipitation recorded in the months of June through August at the location.

Animal variables

CHRVERTBR
Categorical. Severity of chronic (long-term) vertebrate browsing on vegetation below the browse line in the plot, rated on a 0 - 3 scale, based on the percentage of vegetation in the plot showing evidence of repeated browsing and definite stunting.
0 = none
1 = <20%
2 = 20-80%
3 = > 80%

CHRVERTBRA
Binary. Indicates presence (1) or absence (0) of a chronic vertebrate browsing rating of 3 in the plot.

CURRVERTUSE
Categorical. Current livestock use of the plot as indicated by the presence of trampling, bare soil, and droppings, measured by a 0 - 3 scale.
0 = no apparent use
1 = low use
2 = medium use
3 = high use

CURRVERTBR
Categorical. Severity of current season and recent vertebrate browsing on vegetation below the browse line in the plot, measured on a 0 - 3 scale.
0 = no browsing
1 = little browsing
2 = moderate browsing
3 = heavy browsing

CURRVERTBRA
Binary. Indicates presence (1) or absence (0) of a current vertebrate browsing rating of 3 for the plot.

LOCCURRVERTBR
Count. Location summary variable. Number of plots at a location in which CURRVERTBRA = 1.

RODIMP
Categorical. Relative abundance of rodent activity in the plot. This variable was added after the first 2 locations.
0 = no signs of rodent activity
1 = rodent signs present, not abundant
2 = high levels of rodent activity in plot

RODTYPE
Categorical. Type of rodent signs in the plot. This variable was added after the first 2 locations.
MS = mouse
GS = ground squirrel
R = Rabbit/jackrabbit
G = gopher or mole

Grazing history

GRAZHIST
Categorical. A location-specific alphanumeric code that designates an individual grazing history based on information from the land manager or other sources. These codes are used to cross-index individual histories with the associated grazing variables, and use the same location code letters as listed under SOILCODE.

GRCONT30
Binary. Indicates whether the plot has been grazed continuously (i.e. every year) over the past 30 years, 1=Yes, 0=No

GRLAST
Continuous. Continuous number of years (before 1992) that the plot has been free of grazing animals. Value equals 0 for currently-grazed areas.

GRYEARS30
Continuous. Number of years the plot has been grazed between 1962 and 1992. Maximum value is 30 for continuously-grazed areas.

GRBREAK30
Continuous. Longest period of years the plot has **not** been grazed between 1962 and 1992. Maximum value is 30 for nongrazed areas, minimum is 0 for continuously-grazed areas.

GRALLYR30
Count. The number of years with year-round grazing in plot during the past 30 years (1962-1992).

GRANIMAL30
Categorical. Grazing animals that have used the plot over the past 30 years. Concurrent use is noted by two or more letters in combination. Sequential use by different animals is indicated by a slash (/).

Code	Animal
C	Cattle
H	Horses and/or mules
S	Sheep
N	None - used only for permanently discontinued or nongrazed areas

GRSEASON30
Categorical. Normal grazing season for the plot for the majority of the 30 years from 1962-1992. For plots where grazing was discontinued, this variable indicates the season for the majority of the grazed years.

Code	Grazing season
N	Nongrazed
Y	Year round (either continuous or intermittent during year)
R	Rainy season (winter and/or spring)
D	Dry season (summer and/or fall)

MAXGRDUR
Continuous. The longest grazing season in months (0-12) for plot for any period of at least 3 years during the past 30 years (1962-1992) = greater of MAXGRDUR15-30 and MAXGRDUR0-15.

MAXGRDUR15-30
Continuous. The longest grazing season in months (0-12) for plot for any period of at least 3 years during the interval from 15 to 30 years before 1992 (1962-1976).

MAXGRDUR0-15
Continuous. The longest grazing season in months (0-12) for plot for any period of at least 3 years during the last 15 years before 1992 (1977-1992).

MAXSTOCK
Categorical. The highest relative stocking rate (0 [none] - 3 [high] scale, with half ranks and including averaged ranks) for plot for any period of at least 3 years during the past 30 years (1962-1992) = greater of MAXSTOCK0-15 and MAXSTOCK15-30.

MAXSTOCK15-30
Categorical. The highest relative stocking rate (0 [none] - 3 [high] scale, with half ranks and including averaged ranks) for plot for any period of at least 3 years during the interval from 15 to 30 years before 1992 (1962-1976).

MAXSTOCK0-15
Categorical. The highest relative stocking rate (0 [none] - 3 [high] scale, with half ranks and including averaged ranks) for plot for any period of at least 3 years during the last 15 years before 1992 (1977-1992).

CUMGRAZE & WTDCUMGRAZE
Continuous. These are cumulative grazing scores for each grazing treatment in the plot, calculated as the sum of yearly grazing scores for the past 30 years. Individual year grazing scores are calculated as:

Grazing Score = months × stock rating × season factor × animal factor

where:

months = number of months of grazing during the year

stock rating = relative stocking rate (0 [none] - 3 [high] scale, with half ranks)

season factor = weighting factor for season of grazing, set to 1 for wet season (winter-spring) grazing and 2 for dry season (summer) or year-round grazing. These weights are based on data from George and Hall (1991).

animal factor = weighting factor for type of animal, based on potential for browsing blue oak. For CUMGRAZE, this factor is set to 1 for all animals (i.e. unweighted). For WTDCUMGRAZE, factors used are 1 for cow, .8 for horse, 1.5 for sheep. These weighting factors are empirical estimates. No published data were found for establishing these weights.

GRALLYR30
Count. The number of years with year-round grazing in plot during the past 30 years (1962-1992).

Clearing history

CLEARHIST
Categorical. History of tree removal in each plot as determined from historical aerial photos, field observations, and other sources of information. Location codes are as in SOILCODE.

CUT30YR
Binary. Assessment of whether tree(s) have been cut from plot within the past 30 years, based on plot observations, aerial photos, and history reports.
0 = no known cutting in past 30 years or possible tree cutting for trail construction/maintenance only
1 = Tree cutting in plot within 30 years

CUT42YR
Binary. Assessment of whether tree(s) have been cut from the plot within the past 42 years, based on plot observations, aerial photos, and history reports. This variable was substituted for CUT30YR because we were unable to determine precisely when a number of the plots at location 1 were cut.
0 = No known cutting in past 42 years or possible tree cutting for trail construction/maintenance only
1 = Tree cutting in plot within 42 years

NUMCUT30
Count. Number of times plot has been cut in past 30 years. Coded as 0 in plots with trail clearing only.

BRUSHCLR30
Binary. 1 (Yes) / 0 (No) - Assessment of whether brush has been cleared from the plot within the past 30 years, based on plot observations, aerial photos, and history reports.

NUMBRUSH30
Count. Number of times brush in the plot has been cleared in past 30 years.

Fire history

FIRESCAR
Binary. Field observations indicating whether fire-scarred trees, charred wood, or other signs of past fire are present (1) or not (0) within the plot.

FIREHIST
Categorical. Fire history in the plot over the last 30 years as related by the land manager or compiled from other sources. Location codes are as in SOILCODE.

FIRE15-30
Continuous. Number of fires occurring in the interval from 15 to 30 years before 1992 (1962-1976) within the plot.

FIRE0-15
Continuous. Number of fires occurring in the past 15 year interval (1977-1992) within the plot.

NUMFIRES
Continuous. Number of fires occurring in the past 30 year interval (1962-1992) within the plot.

FIRE30YR
Binary. Denotes presence (1) or absence (0) of 1 or more fires occurring in the past 30 year interval (1962-1992) within the plot area.

REBURN30
Binary. Indicates plot has (1) or has not (0) burned at least two times in the past 30 years.

MULTBURN10
Continuous. Maximum number of fires occurring in the plot within any 10 year interval in the past 30 years.

ONEFIRE30
Count. Location summary variable. Number of plots at the location which have burned only one time in the 30 years prior to 1992.

Sapling variables

Data for sapling classes S1-S3 are presented as counts of saplings in each size, origin, and condition class by their position relative to the canopy. **For the S0 class only**, data are estimated counts of live seedlings, using the following count classes:

0 = 0
1 = 1 to 10
2 = 11 to 20

3 = 21 to 30
4 = 31 to 40

Size classes:

S0- Large seedling. <1 cm basal diameter, but at least 25 cm (10 inches) tall
S1- Saplings≥1 cm bd, <140 cm tall
S2- Saplings ≥140 cm tall, dbh < 1 cm
S3- Saplings dbh 1-3 cm

-Sprouts from a stump > 8 cm are coded as sprout origin (Sprs1-3)
-Position relative to the canopy (open grown, edge of canopy, or under the canopy) are coded as open, edge, and can
-Whether the sapling is live or dead is coded as l or d.

There are 36 total combinations for scoring sapling recruitment. The individual variable names are listed in the table below.

Seedling origin		Open	Edge	Canopy
S1	live	S1OPEN_L	S1EDGE_L	S1CAN_L
	dead	S1OPEN_D	S1EDGE_D	S1CAN_D
S2	live	S2OPEN_L	S2EDGE_L	S2CAN_L
	dead	S2OPEN_D	S2EDGE_D	S2CAN_D
S3	live	S3OPEN_L	S3EDGE_L	S3CAN_L
	dead	S3OPEN_D	S3EDGE_D	S3CAN_D
Sprout origin				
S1	live	SPRS1OPEN_L	SPRS1EDGE_L	SPRS1CAN_L
	dead	SPRS1OPEN_D	SPRS1EDGE_D	SPRS1CAN_D
S2	live	SPRS2OPEN_L	SPRS2EDGE_L	SPRS2CAN_L
	dead	SPRS2OPEN_D	SPRS2EDGE_D	SPRS2CAN_D
S3	live	SPRS3OPEN_L	SPRS3EDGE_L	SPRS3CAN_L
	dead	SPRS3OPEN_D	SPRS3EDGE_D	SPRS3CAN_D

Sapling summary variables

To reduce the total number of dependent variables in the analysis, the following summaries were made from sapling counts.

S123SEED
Count. Sum of live and dead S1, S2, and S3 seedling-origin saplings in the plot.

LIVESAPL
Count. Total count of all seedling-origin and sprout-origin live saplings of stages S1-S3 in the plot.

S123LOGIC
Binary. Indicates the presence (1) or absence (0) of any live seedling-origin saplings (S1 through S3) in the plot.

S0123LIVE
Binary. Indicates the presence (1) or absence (0) of any live seedling-origin recruitment (S0-S3) in the plot.

S0PRESENT
Binary. Indicates the presence (1) or absence (0) of any S0 seedlings in the plot.

ALLRECR
Binary. Indicates presence (1) or absence (0) of any live or dead, sprout- or seedling-origin saplings or S0 seedlings in the plot.

LOCS123LIVE
Count. Location summary variable. Number of plots at a location where S123LIVE =1.

LOCS0PRESENT
Count. Location summary variable. Number of plots at a location where S0PRESENT =1.

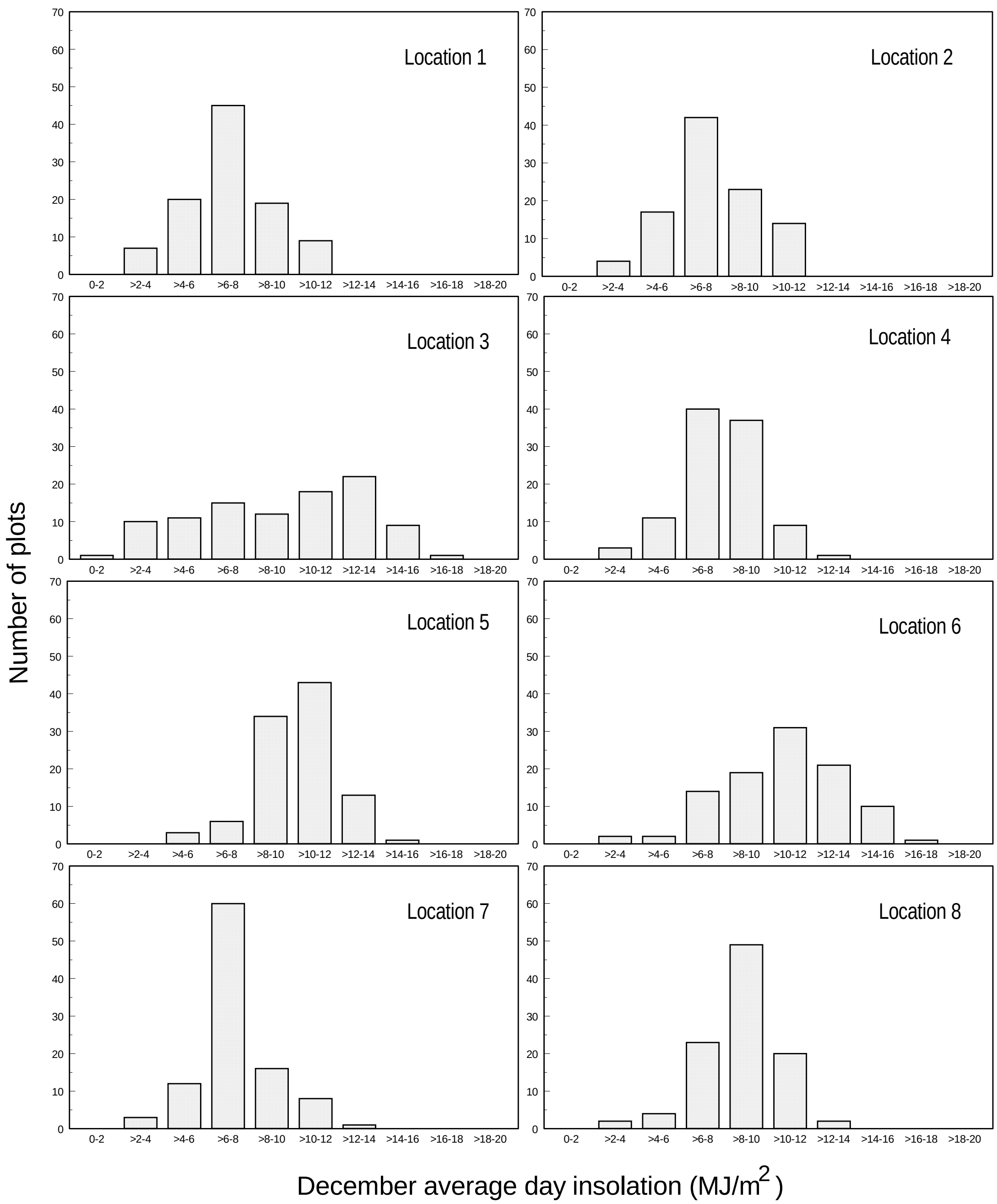
LOCALLRECR
Count. Location summary variable. Number of plots at a location where ALLRECR =1.

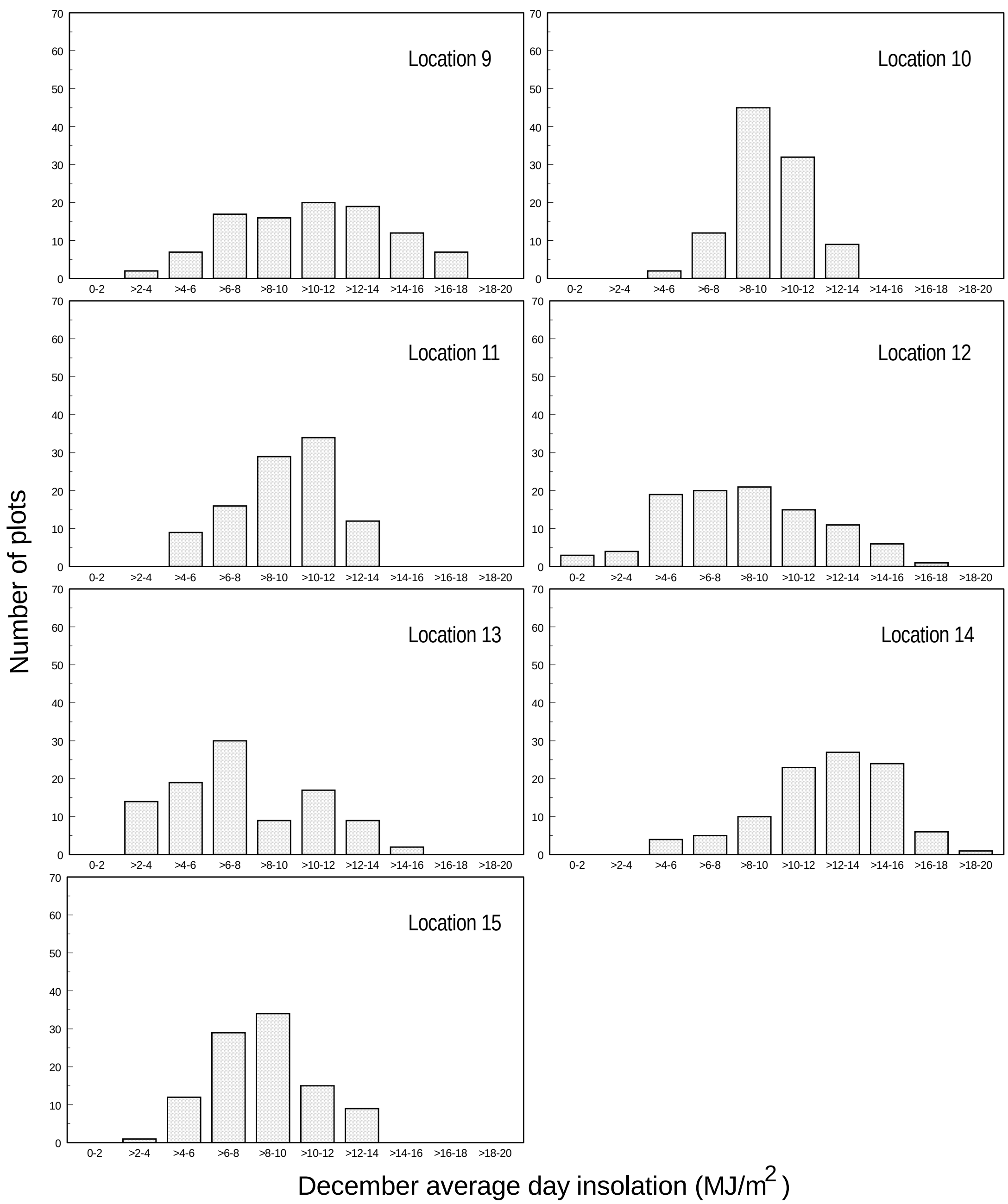
APPENDIX 3. Soil types mapped at each study location

Location	Soil-code	Number of plots	Number of plots with Allrecr >0	Soil subgroup	Soil great group	Soil series	Depth (inches)	Reference
1	W1	99	37	Ultic-Typic	Haploxeralfs	Bressa-Dibble complex silt loam-silty clay loam	51-102	Lambert and Kashiwagi 1978
	W2	1	1	Typic	Haploxeralfs	Tehama sandy loam	91-152	
2	BB1	100	0	Typic	Palexeralfs	Newville gravelly loam	20-121	Begg 1968
3	P1	72	36			Igneous rock land	25-61	Isgrig 1969
	P2	27	16	Pachic	Haploxerolls	Sheridan coarse sandy loam	61-91	
4	S1	6	4	Typic	Rhodoxeralfs	Las Posas gravelly loam	51-102	Herbert and Begg 1969
	S2	5	2	Ruptic-Lithic Typic Mollic	Xerochrepts Rhodoxeralfs Haploxeralfs	Auburn- Las Posas- Argonaut gravelly loam	25-102	
	S3	10	7	Mollic	Haploxeralfs	Sobrante gravelly loam	41-89	
	S4	45	20	Ruptic-Lithic Typic Mollic	Xerochrepts Rhodoxeralfs Haploxeralfs	Auburn- Las Posas- Argonaut rocky loam	25-102	
	S6	33	18	Mollic Typic	Haploxeralfs Rhodoxeralfs	Sobrante- Las Posas rocky loam	41-102	
	S7	1	1	Ruptic-Lithic Mollic	Xerochrepts Haploxeralfs	Auburn- Sobrante very rocky loam	25-89	
	S8	1	0	Mollic Typic	Haploxeralfs Rhodoxeralfs	Sobrante- Las Posas very rocky loam	41-89	
5	H1	18	0	Typic Ultic Mollic	Argixerolls Argixerolls Haploxeralfs	Yorkville- Yorktree- Squawrock loam	53-152	Howard and Bowman 1991
	H2	25	0	Typic Ultic Lithic	Argixerolls Argixerolls Xerochrepts	Yorkville- Squawrock- Witherell loam/sandy loam	30-152	
	H3	17	0	Ultic Typic Dystric	Argixerolls Haploxeralfs Xerochrepts	Yorktree- Hopland- Woodin complex loam/gravelly sandy loam	58-102	
	H4	40	0	Dystric-Lithic Lithic Dystric	Xerochrepts Xerorthents Xerochrepts	Maymen- Etsel- Mayacama complex sandy/gravelly loam	18-61	
6	SP1	37	4	Typic	Xerorthents	Cieneba-Rock outcrop coarse sandy loam	25-51	Stephas, Waterman, Broderson, and Jahnke 1982, NPS
	SP2	63	18	Typic	Xerochrepts	Vista-Rock outcrop coarse sandy loam	51-102	
7	DC1	79	14	Lithic	Xerorthents	Toomes very rocky loam	20-38	Gowans 1967
	DC2	9	1	Lithic	Xerorthents	Toomes extremely rocky loam	8-20	
	DC3	12	5	Lithic	Xerorthents	Toomes very rocky loam, deep N slopes	30-91	
8	PR1	100	3	Ruptic-Lithic	Xerochrepts	Auburn silt loam/very rocky silt loam	30-56	Sketchley 1965

Location	Soil-code	Number of plots	Number of plots with Allrecr >0	Soil subgroup	Soil great group	Soil series	Depth (cm)	Reference
9	SR1	11	9	Mollic Lithic	Haploxeralfs Xerochrepts	Modesto- Rincon- Millsholm loam	41-152	USDA Forest Service
	SR2	63	4	Typic Calcic	Argixerolls Haploxerolls	Los Osos- Nacimiento complex clay loam	51-102	
	SR3	26	2	Calcic	Haploxerolls	Nacimiento calcareous clay loam /sandy loam	51-102	
10	SA1	41	3	Xeric	Torriorthents	Shedd silty clay loam	51-76	Cook 1978
	SA2	58	12	Calcic Pachic	Haploxerolls	Linne silty clay loam	61-102	
	SA3	1	0	Calcic Pachic	Haploxerolls	Salinas clay loam	152-191	
11	HG1	100	0	Mollic Typic	Haploxeralfs Xerochrepts	Ahwahnee and Vista coarse sandy /rocky coarse sandy loam	91-152	Stromberg, Huntington, Begg and Smith 1962
12	HC1	90	1	Ultic	Haploxeralfs	Parrish gravelly clay loam	61-107	Lindsey 1974
	HC2	10	0	Lithic	Xerorthents	Gaviota loam	41-48	
13	M1	55	1	Lithic	Haploxerolls	Lodo clay loam	25-51	Welch 1977
	M2	7	1	Lithic	Haploxerolls	Lodo gravelly clay loam/ rocky clay loam	25-51	
	M3	24	1	Typic	Argixerolls	Los Osos clay loam	61-102	
	M4	5	0	Typic	Argixerolls	Los Osos clay loam-clay	61-102	
	M5	1	0		Xerorthents	Rock outcrop-Xerorthents- loam	10-25	
	M6	5	1	Typic	Argixerolls	Gilroy clay loam	51-102	
	M7	2	0	Typic	Argixerolls	Gilroy gravelly clay loam	51-102	
	M8	1	0	Lithic	Xerorthents	Gaviota sandy loam	25-51	
14	BR1	100	7	Typic	Haploxeralfs	Blasingame -/+ rock silt loam	51-102	Stephas, Waterman, Broderson, and Jahnke 1977
15	J1	33	10	Mollic	Haploxeralfs	Argonaut gravelly loam	51-91	Smith, DeLapp, and Stone 1977
	J2	8	0	Lithic	Xerochrepts	Auburn silt loam	25-71	
	J3	59	31	Mollic	Haploxeralfs	Sobrante silt loam	51-91	

APPENDIX 4. Distributions of plot December average day insolation at each study location.




Location 9
Location 10
Location 11
Location 12
Location 13
Location 14
Location 15
Number of plots
0-2
>2-4
>4-6
>6-8
>8-10
>10-12
>12-14
>14-16
>16-18
>18-20
December average day insolation (MJ/m2)

APPENDIX 5. DATA SHEETS

LOCATION

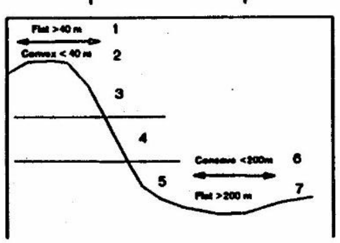
DATE

SHEET

BY:

PLOT_NO								
STAND EDGE: 0-4								
SLOPE								
ASPECT								
TOPO_POS: 1-7								
SOIL_TYPE								
SOIL DEPTH:1/S-3/D								
SOIL ROCKY								
TOT CANOPY: 0-6								
QD CANOPY: 0-6								
PAST RECRUITMENT								
CANOPY_SPP								
UNDER_BARE: 0-6								
UNDER_BUNCH: 0-6								
UNDER_HERB: 0-6								
UNDER_SHRUB: 0-6								
SHRUB SPP								
RODENT:0-2/type								
GRAZ_HIST								
CHR VERT_BR: 1-3								
CURR USE/BR:1-3								
FIRE_HIST								
FIRE_SCAR: +/-								
RIMP_HIST								
VERTCNTRL_HIST								
CLEAR_HIST								
Mistletoe								

Topo_pos



0-6 Scale

0 - not seen
1 - <2.5%
2 - 2.5 to < 20%
3 - 20 to < 50%
4 - 50 to < 80%
5 - 80 to < 97.5%
6 - >= 97.5%

LOCATION SHEET BY:

DATE

PLOT NO								
OFFSET								
GPS X COORD								
GPS Y COORD								
GPS ALTITUDE								
QD TREES LIVE/DEAD								
# CUT STUMPS								
QD CVR DECR? Y/N								
30 YEAR GAP Y/N								
Trees < 5" dbh								
S0: <10, 10-20, etc								
S1_O LIVE/DEAD								
S1_E LIVE/DEAD								
S1_C LIVE/DEAD								
S2_O LIVE/DEAD								
S2_E LIVE/DEAD								
S2_C LIVE/DEAD								
S3_O LIVE/DEAD								
S3_E LIVE/DEAD								
S3_C LIVE/DEAD								

CIRCLE SEEDLINGS OF SPROUT ORIGIN