FACTORS INFLUENCING THE PROBABILITY OF OAK REGENERATION ON SOUTHERN SIERRA NEVADA WOODLANDS IN CALIFORNIA

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ABSTRACT

Regeneration of oaks on California's 3.0 million hectares of hardwood rangelands has been identified as a critical factor affecting the sustainability of this important source of biological diversity in the state. A survey of oak seedling and sapling regeneration was carried out in the southern Sierra Nevada region of the state on 192 sample plots. Logit regression analysis was carried out on vegetation and site factors to predict the probability of finding any seedling (trees less than 0.3 m in height) or sapling (trees between 0.3 and 3.0 m in height) oak regeneration on sample plots. Oak regeneration probability relationships were derived for *Quercus douglasii* Hook. & Arn. (blue oak), *Q. wislizeni* A. DC. (interior live oak) and *Q. crysolepis* Liebm. (canyon live oak), and *Q. kelloggii* Newb. (black oak). Tree cover was found to be positively correlated with the probability of seedling and sapling regeneration for all three species groups. Grazing was negatively correlated with *Q. douglasii* seedling probability, and nonsignificant with *Q. douglasii* saplings or the other species evaluated. Solar radiation levels derived from site slope and aspect were significant factors for *Q. kelloggii*, *Q. wislizeni*, and *Q. crysolepis* seedlings. Elevation was positively related to the probability of finding *Q. douglasii* seedlings. These relationships can be used by managers of hardwood rangelands to prioritize restoration efforts, grazing management, and other site treatments to ensure the long-term sustainability of the hardwood rangeland resource.

California's oak woodlands, also known as hardwood rangelands, occupy an estimated 3.0 million hectares (Bolsinger 1988). These oak woodland areas are characterized by an overstory canopy of at least ten percent hardwood tree species, predominantly in the genus *Quercus*, with an understory of annual grasses and occasional native perennial grasses. Griffin (1978), Bartolome (1987), Holmes (1990), and Allen et al. (1991) provide good ecological descriptions of these areas.

Since European settlement of California, oak woodlands have been managed primarily for livestock production (Huntsinger and Fortmann 1990). These areas have taken on a new importance because of the recognition that they have the richest wildlife species abundance of any habitat in the state, with 331 vertebrate species relying at least partly on oak woodlands (Verner 1980; Barrett 1980). Other public values obtained from these areas include water quantity and quality, outdoor recreation, and aesthetics. California's oak woodlands are somewhat unique for western wildlands, with over 80% in private ownership (Bolsinger 1988).

Because of the significant ecological values supplied by hardwood rangelands, sustainability of these oak dominated habitats has great importance. To maintain stands at current canopy density, sufficient oak regeneration must be present to replace mature trees lost to mortality. Maintenance of remaining oak stands is especially critical, since the total area of oak woodlands has decreased by about 485,000 ha since 1945 (Bolsinger 1988) due to clearing for urbanization and intensive agricultural production.

Concern about the lack of regeneration for some oak species has been evident in the literature. Sudworth's (1908) early description of California's trees noted the apparent poor natural regeneration of several oak species, especially *Q. douglasii* Hook. & Arn. (blue oak). White (1966) documented the lack of trees in the sapling size class in oak woodlands on California's central coast and raised concerns about the long-term sustainability of these areas. Griffin (1977) noted a lack of young oak seedlings and hypothesized that this might be due to livestock grazing, rodent herbivory, and the introduction of annual exotic plants into the understory. Gordon et al. (1989) evaluated *Q. douglasii* seedling moisture competition with exotic annual grasses and perennial native grasses and demonstrated that current conditions are more xeric than presettlement times. Allen-Diaz and Bartolome (1992) evaluated natural *Q. douglasii* seedling establishment, survival, and growth in north coastal California oak woodlands and concluded that *Q. douglasii* has a successful strategy for seedling establishment. However, their research was not able to determine the factors which prevented recruitment of seedlings to the sapling size class. Fire and sheep grazing were eliminated as factors inhibiting sapling recruitment. Borchert et al. (1989) found very low seedling recruitment in *Q. douglasii* woodlands on the central coast of California due to herbivory from a variety of rodents and ungulates.

Recent statewide surveys of California's oak woodlands carried out by Bolsinger (1988) and Muick and Bartolome (1987) also confirm that the absence of oak saplings, especially *Q. douglasii* and *Q. lobata* Nee (valley oak), may make sustainability of the resource difficult in some areas.

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OBJECTIVE

Managers of hardwood rangelands must be able to assess the likely occurrence of seedlings or saplings on a given site to assess sustainability of the resource. For example, if very low occurrence of oak seedlings was observed on a site with high mortality of mature overstory oaks, then it would be important for managers to design artificial oak regeneration plans to maintain oak cover over time. If there was a high probability of oak seedlings being present on a site, but a low probability for saplings, then managers would need to design regeneration strategies to protect seedlings from factors which impede recruitment to the sapling size class.

The objective of this study was to develop models to predict the probability of oak regeneration on specific hardwood rangeland areas. Particular emphasis was given to evaluating the factors which contribute to the presence or absence of oak regeneration on a given site.

The information presented will help provide an initial assessment of potential sustainability of the hardwood range resource and help guide managers in identifying critical hardwood range habitat where intervention may be necessary to ensure that regeneration occurs.

STUDY AREA

A four-county area in the western foothills of the southern Sierra Nevada range in California was chosen for this study. This region, consisting of Madera, Fresno, Tulare, and Kern counties has almost 620,000 ha of hardwood rangelands, which is about 20% of the total hardwood rangeland area in the state. The northern extent of the sample area was at a latitude of 37°12′N, northeast of the city of Fresno. The southern extent of the sample area was at a latitude of 35°30′N, east of the city of Bakersfield.

There are five principal oak species found in the southern Sierra Nevada hardwood rangelands. *Quercus kelloggii* Newb. (black oak) is found from higher elevation mixed-conifer forest sites down to moister sites in the hardwood range region. *Quercus lobata* is found in riparian zones, in deep alluvial soils, and on moist hillsides. *Quercus wislizeni* A.DC. (interior live oak) and *Q. crysolepis* Liebm. (canyon live oak) grow in dense clusters on moist sites. *Quercus douglasii* is found at the lower edge of the hardwood range land area before it becomes open grassland, quite probably due to moisture limitations, and also in mixed-woodland stands with the other *Quercus* species listed above. Other principal associated tree species present include *Pinus sabiniana* Douglas (foothill pine) and *Aesculus californica* (Spach) Nutt. (California buckeye).

METHODS

A series of ten major oak regeneration transects was established on both private rangeland and USDA Forest Service lands, beginning at an elevation with sufficient rainfall to support open *Q. douglasii* savanna cover, about 180 m in the northern part of the sample area and 485 m in the most southern part of the sample area. The upper elevation for the sample transects was the transition zone between oak woodlands and mixed conifer forest, which occurred at about 920 m elevation in the northern region of the study area and 1525 m in the southern part.

A total of 192 survey plots were randomly located 60 m to the north or south of the main elevational transects. Random plot locations were checked to ensure that they occurred in the oak woodland vegetation type. If a plot was not in oak woodlands, then another location was randomly selected.

At each sample location, a strip transect, 30.5 m long and 3.7 m wide was laid out (0.011 ha) in a randomly chosen direction. Data were collected during the months of July and August in 1987, 1988, and 1989. The diameter at breast height (DBH), 1.4 m above the ground, and total height were taken for each overstory tree in the plot, defined as trees with DBH over 2.5 cm. This was used to calculate overstory basal area, number of trees, and volume per ha. Tree and shrub crown cover by species was recorded at each plot using a line intercept sampling method. Herbaceous plant residual dry matter was estimated as high, medium, or low (greater than 800, 550, and less than 400 kg/ha respectively) using visual comparisons with known standards (Clawson et al. 1982). Slope, aspect, elevation, and whether there was livestock grazing were recorded for each site. Species, height, and root collar diameter were recorded for all oak under 3 m in height. Oak trees less than 0.3 m in height were classed as seedlings, and trees from 0.3 m to 3 m in height were classed as saplings.

To assess oak seedling and sapling regeneration probability, a dummy variable, STOCK, was set to zero if there was no oak regeneration on the site, that is, the plot was unstocked. The site was considered to be stocked with seedlings or saplings if there was at least one tree in either of these classes on the sample plot, representing at least 90 seedlings or saplings per hectare. The value of STOCK for stocked sites was set to one. Species type was considered in assigning the value to STOCK. For example, if a mixed stand had an overstory with both *Q. douglasii* and *Q. kelloggii*, and seedlings of *Q. kelloggii* were present but seedlings of *Q. douglasii* were not, then the value of STOCK would be set to one for *Q. kelloggii* and to zero for *Q. douglasii*.

This measure of regeneration, i.e., present or absent, is somewhat crude. It merely serves as a preliminary estimate of whether seedlings or saplings are likely to be present or absent from a site. This information would need to be combined with observations of overstory mortality as well as a quantitative account of the distribution of trees by size class to determine if there is a regeneration problem for a given site. This first cut at evaluating the site factors will help managers to evaluate where to concentrate efforts, and to evaluate where more detailed stand structure data collection should be emphasized.

This study hypothesized that sample plot regeneration stocking was a function of abiotic site factors such as rainfall and solar insolation, vegetation characteristics such as competition from overstory trees, shrubs, grasses, and forbs, and management factors such as grazing history or fire frequency. The predicted value of the dependent variable, STOCK, can be interpreted as the probability of a site being stocked.

(1) STOCK = f(abiotic site factors, vegetation, management).

Since the dependent variable, STOCK, is a discontinuous variable having a value of either 0 or 1, normal regression procedures to evaluate hypothesized explanatory variables could not be used. For such data, the assumptions implicit in ordinary least squares solution of linear regression are violated, and it is possible that a resulting predictive equation could give a value for the dependent variable outside the 0 to 1 range. The common practice in this situation is to transform the dependent variable using the logistic function, a process known as *logit* regression. This procedure utilizes a maximum likelihood estimation process to estimate the coefficients for the independent variables in the prediction equation shown in (2). A complete discussion of the assumptions of logit regression are given in Wonnacott and Wonnacott (1979).

$$(2)\quad \text{STOCK} = \frac{1}{1 + e^{-(x'\beta)}}$$

β = vector of logit regression coefficients

x = vector of independent variables.

Separate logit analyses were carried out on the probability of a site being stocked with seedlings and saplings for each oak species in the study. The independent variables evaluated are described below. Independence of variables was ensured through observation of the correlation matrix of the variables.

Solar radiation—The site factors of slope and aspect were combined into a single variable for the amount of solar radiation reaching the site, expressed in calories per day per square centimeter following the procedure in Buffo et al. (1972). June 22nd was selected as the date for calculating solar radiation since day length is longest and the sun is at its highest on that date, representing the maximum evaporative demand on the site.

TABLE 1. SUMMARY OF 192 OAK REGENERATION PLOTS IN SOUTHERN SIERRA NEVADA SAMPLE.

Quercus species	Regeneration category	Percentage of stocked plots
Q. douglasii	Seedling	64
	Sapling	31
Q. kelloggii	Seedling	83
	Sapling	25
Q. wislizeni and *Q. crysolepis*	Seedling	75
	Sapling	48

Elevation in meters—Rainfall in the southern Sierra Nevada increases with elevation (Standiford et al. 1991), and this factor is a proxy for the annual rainfall at the site.

Grazing—A dummy variable for the presence (grazing = 1) or absence (grazing = 0) of grazing.

Number of woody species on site—The diversity of woody species at the site is affected by a variety of abiotic and biotic factors. In general, the diversity of woody species increases as the amount of available moisture at the site increases due to rainfall and soil characteristics.

Shrub crown cover percent—Individual cover by species was collected and combined to give total shrub cover on the site.

Tree cover—Total crown cover for all trees was evaluated, as well as the cover of individual *Quercus* species.

Forage residual dry matter—A dummy variable with 3 = high, 2 = medium, 1 = low.

RESULTS

Table 1 summarizes the information collected from sample plots. On the 192 survey plots, *Q. douglasii* was the most common species in these southern Sierra Nevada oak woodlands, occurring on 131 plots. *Q. kelloggii*, *Q. wislizeni*, and *Q. crysolepis* cover were present on about one-third of the plots sampled. Seedlings were fairly commonly found for all *Quercus* species. About 64% of the plots with *Q. douglasii* overstory cover were stocked with *Q. douglasii* seedlings, which meant there was at least one seedling present in the plot. *Q. kelloggii* seedlings were found on 83% of the plots with *Q. kelloggii* cover, while 75% of the plots with either *Q. wislizeni* or *Q. crysolepis* cover had seedlings for these species. A smaller percentage of plots were stocked with sapling oaks, ranging from 25% stocking for *Q. kelloggii* to 48% stocking for *Q. wislizeni* or *Q. crysolepis* plots.

Table 2 shows results of the logit regression of the independent variables on probability of oak seedling or sapling stocking. All coefficients shown were significant at the 0.10 level using a t-test. The significance of the entire equation was evaluated using the Chi-square statistic to test the hypothesis that

$$b_0 = b_1 = b_2 = \ldots = b_i = \ldots = b_n = 0 \tag{3}$$

where b_i = logit coefficient.

This hypothesis was rejected at the 0.05 level of significance for the six equations in Table 2. The percentage of plots correctly classified with the logit regression equations as to the presence or absence of oak regeneration are also shown. Prediction success ranged from 61% of the *Q. wislizeni* and *Q. crysolepis* sites correctly classified as stocked or unstocked with saplings, to 83% of the *Q. kelloggii* sites classified as stocked or unstocked with seedlings.

An example of use of the logit coefficients in Table 2 to predict the probability of *Q. douglasii* seedlings on an area with 30% total overstory tree cover, elevation of 900 m, and livestock grazing is

$$\text{STOCK} = \frac{1}{1 + e^{-[-0.789+0.00156(900)-1.487(1)+0.0232(30)]}} \tag{4}$$

$$= 0.456.$$

This means that for these site factors, there is about a 46% probability that the area will be stocked with *Q. douglasii* seedlings.

DISCUSSION

Seedling and sapling stocking in this study were compared with similar data from Bolsinger's (1988) statewide oak regeneration survey. In general, this southern Sierra area had a higher probability of seedling regeneration and lower probability of sapling regeneration than the statewide averages in Bolsinger (1988). The individual species are discussed below.

QUERCUS DOUGLASII. *Quercus douglasii* is the most widespread oak woodland cover type in the California. In this study, elevation, livestock grazing, and tree canopy cover were significant independent variables to predict *Q. douglasii* seedling stocking. The effects of grazing, elevation, and tree canopy cover on *Q. douglasii* seedling regeneration probability is shown in Figures 1 and 2 derived from the logit regression analyses. On dry, low elevation sites, and also on oak savannas with low canopy cover, there is a low probability

TABLE 2. LOGIT COEFFICIENTS FOR ESTIMATING THE PROBABILITY OF *Q. DOUGLASII, Q. KELLOGGII, Q. WISLIZENI* AND *Q. CRYSOLEPIS* SEEDLING AND SAPLING STOCKING. Numbers in parentheses are t-values for the coefficient. Significance of t-values are ***—significant at $P < 0.01$; **—significant at $P < 0.05$; *—significant at $P < 0.10$.

Variable	*Q. douglasii*		*Q. kelloggii*		*Q. wislizeni* and *Q. crysolepis*	
	Seedling	Sapling	Seedling	Sapling	Seedling	Sapling
Constant	−0.789 [−1.42]*	−2.189 [−3.52]***	7.8902 [1.34]*	−3.0194 [1.88]**	−6.108 [−2.53]***	−0.8699 [−2.27]**
Elevation	0.00156 [2.97]***			−0.00425 [−1.41]*		
Solar radiation			−0.0109 [−1.43]*		0.0077 [2.43]***	
Graze	−1.487 [−2.98]***					
Total tree cover	0.0232 [2.64]***					
Q. douglasii cover	0.0173 [1.80]**					
Q. kelloggii cover			0.0516 [2.93]***	0.0316 [2.70]***		
Live oak cover[1]					0.0256 [1.47]*	0.0325 [2.62]***
Non-target tree cover					0.0429 [2.19]**	
No. woody species		0.315 [2.19]**				
Equation significance	***	**	***	***	***	***
Pct. right predictions	0.748	0.718	0.828	0.756	0.803	0.607

[1] Includes *Q. wislizeni* and *Q. crysolepis*.

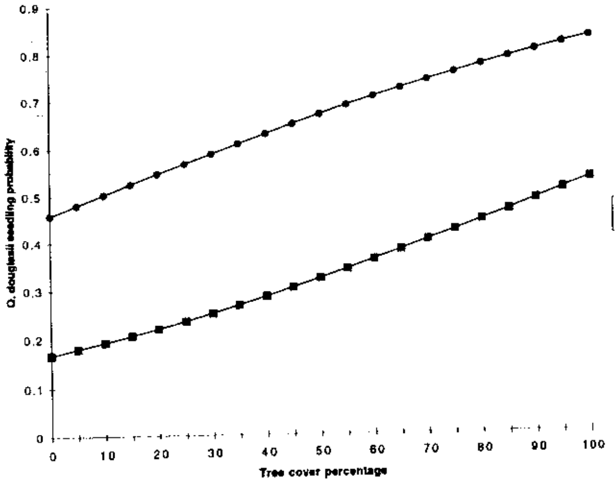

FIG. 1. Probability of *Q. douglasii* seedling regeneration in southern Sierra Nevada oak woodlands at 900 m elevation with varying overstory tree cover.

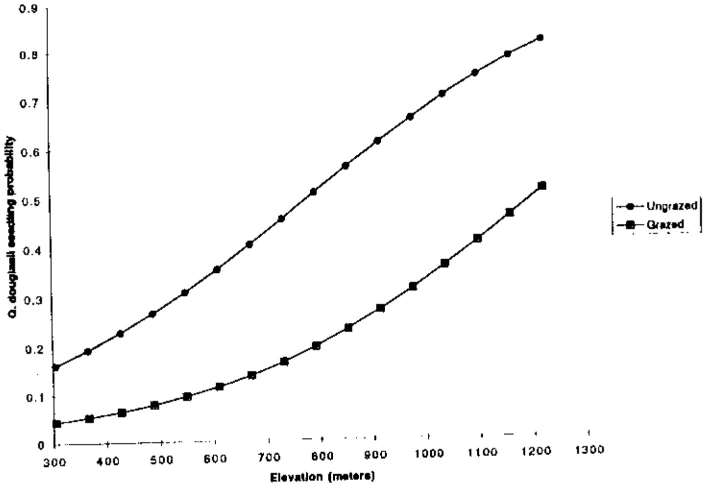

FIG. 2. Probability of *Q. douglasii* seedling regeneration in southern Sierra Nevada oak woodlands with 35% tree cover with varying elevation.

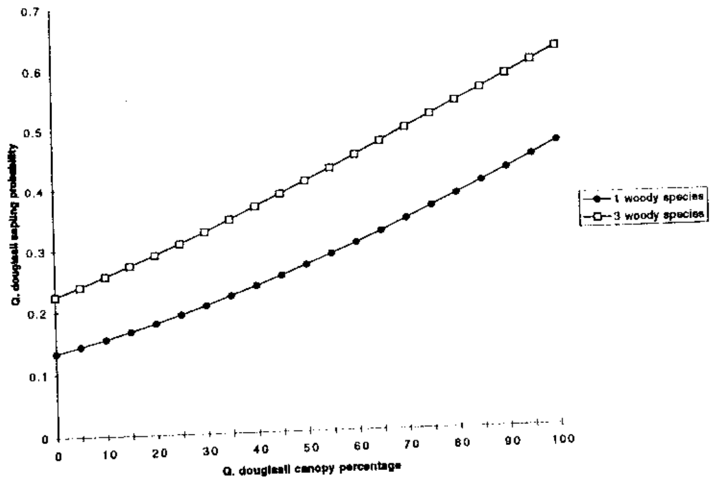

FIG. 3. Probability of *Q. douglasii* saplings in southern Sierra Nevada oak woodlands by *Q. douglasii* canopy cover and the number of woody species on the site.

of stocking with *Q. douglasii* seedlings. A negative grazing effect on seedling probability is also demonstrated. Hall et al. (1992) have shown how livestock season of use and grazing intensity influences *Q. douglasii* seedling herbivory and suggest grazing strategies to minimize these losses. Borchert et al. (1989) also demonstrated lower *Q. douglasii* seedling recruitment in grazed areas. This can be contrasted with the results by Allen-Diaz and Bartolome (1992), which showed that typical sheep grazing in coastal *Q. douglasii* woodlands had no effect on seedling establishment or mortality when compared to ungrazed areas.

In general, there were a low number of *Q. douglasii* saplings in this survey. The probability of *Q. douglasii* saplings on a site increases as *Q. douglasii* cover and the number of woody species present increases. Bolsinger (1988) also found a high correlation with *Q. douglasii* regeneration and the number of woody species on a site. Figure 3 graphically shows the *Q. douglasii* sapling probability curve for tree cover and woody species present. On pure *Q. douglasii* stands with low canopy cover, sapling stocking probability is low. As woody species diversity increases, the probability of saplings increases.

Given these relationships, it is clear that managers will often need to implement practices designed to increase recruitment into the sapling size class to ensure sustainability of *Q. douglasii* cover types.

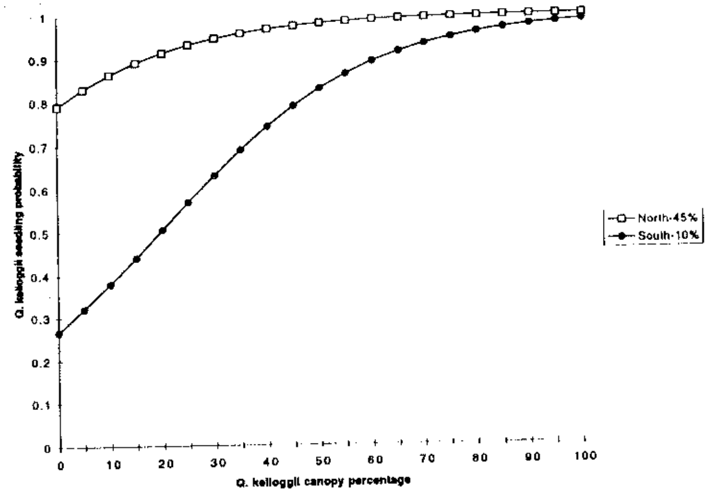

FIG. 4. Probability of *Q. kelloggii* seedling regeneration in southern Sierra Nevada oak woodlands for two slopes and aspect classes with varying *Q. kelloggii* cover.

This is most pronounced on low elevation savanna sites where *Q. douglasii* is the only woody species present.

QUERCUS KELLOGGII. To date, there has not been much concern expressed about *Q. kelloggii* regeneration in the state, as *Q. kelloggii* cover has increased in recent years (Bolsinger 1988). Much of this increase has taken place due to conversion of conifer forest lands as a result of silvicultural practices that favor conifer harvest over *Q. kelloggii* harvest. Little study has been made of oak woodlands with a *Q. kelloggii* component. The southern Sierra Nevada is a major area where *Q. kelloggii* occurs in woodlands. This study showed a very high probability of *Q. kelloggii* seedling stocking influenced by the amount of solar radiation (combination of slope and aspect) and the amount of *Q. kelloggii* tree cover. As solar radiation increases, *Q. kelloggii* seedling probability decreases. This may indicate that *Q. kelloggii* is not tolerant of the high evapotranspiration resulting from high solar insolation. Figure 4 shows seedling probability for different *Q. kelloggii* cover percentages at two solar radiation levels. Dry south slopes with low *Q. kelloggii* canopy cover have the lowest probability for seedlings.

This study shows a very low sapling component in *Q. kelloggii* stands, with only 25% of the plots having saplings. This is consistent with the classification of *Q. kelloggii* as a shade-intolerant species

(Burns and Honkala 1990). The relatively high canopy cover for stands with a *Q. kelloggii* component in this study (67%) may result in poor recruitment of seedlings to saplings due to competition with overstory trees for light and moisture. This study shows that managers need to carefully assess the rate of mortality for mature *Q. kelloggii* trees, as the low sapling probability on some sites may lead to an eventual decline in cover. It may be necessary to develop management practices to enhance seedling recruitment into the sapling class.

QUERCUS WISLIZENI AND *Q. CRYSOLEPIS.* This study showed that *Q. wislizeni* and *Q. crysolepis* seedlings and saplings have a fairly high probability of occurring, with 75% of the *Q. wislizeni* and *Q. crysolepis* plots having seedlings and 48% having saplings. Regeneration probability was not shown to be significantly related to grazing or elevation. The lack of significance of elevation is probably because *Q. wislizeni* and *Q. crysolepis* occurred over a relatively narrower range than either *Q. douglasii* or *Q. kelloggii*. Solar radiation had a significant positive relationship with the probability of seedling stocking. *Q. wislizeni* and *Q. crysolepis* with their sclerophyllous leaf anatomy is more drought tolerant than *Q. douglasii*, and might be predicted to dominate on sites with higher solar radiation.

CONCLUSIONS

Our study identified factors associated with the probability of *Q. douglassii*, *Q. kelloggii*, *Q. wislizeni*, and *Q. crysolepis* regeneration in southern Sierra Nevada oak woodlands. In general, there was a relatively high probability of oak seedling stocking in most areas. However, oak seedlings may not persist in the landscape for the long term. Allen-Diaz and Bartolome (1992) have shown that annual mortality of natural *Q. douglasii* seedlings is about 50% per year for several years. Relatively low probability of sapling stocking in this study suggests there may be a problem in having adequate recruitment of oaks to replace mortality of mature trees. Oaks in the sapling height class are usually well established, and have a high probability for remaining in the landscape to replace mature trees lost to mortality, so it is the probability of saplings that has the greatest effect in oak woodland sustainability.

In our study, a significant grazing effect was detected only for *Q. douglasii* seedlings. Future work can perhaps determine if grazing strategies, such as those suggested by Hall et al. (1992), can increase *Q. douglasii* sapling recruitment from the relatively more abundant seedlings found in this study.

In areas with low seedling and sapling probability, it may be necessary to intervene with management practices, such as preparation of a seed bed with fire or weed control, protection against insect or rodent herbivory, or modification of season and intensity of livestock grazing, to ensure recruitment of seedlings into the sapling class. The probability relationships derived in this study can be used to help identify and concentrate management and protection efforts needed. In particular, seedling and sapling probability curves can be used to guide decisions about the need for artificial oak regeneration. Planting oak seedlings or direct seedling of acorns can be concentrated on those areas with the lowest probability for natural regeneration.

Overstory tree cover was positively correlated with the probability of oak seedlings and saplings. This suggests that in very open oak savannas, where the probability of seedlings and saplings is lower than in dense woodland stands, overstory thinning may result in a stand with an inadequate number of saplings to replace thinned trees. There is insufficient information in this study about the cause-effect relationship between oak canopy and regeneration to determine if thinning in denser stands might release seedlings or saplings for recruitment into larger size classes. Our study found a range of tree covers from 0 to 100%, with a mean of 54%.

The relationships developed in our study can be coupled with mortality estimates (Swiecki et al. 1991) and tree growth estimates (Standiford and Howitt 1988) to assess current management practices, and the likelihood that oak stands can be sustained and continue to provide ecological benefits for future generations.

LITERATURE CITED

ALLEN, B. H., B. A. HOLZMAN, and R. R. EVETT. 1991. A classification system for California's hardwood rangelands. Hilgardia 59(2):1–45.

ALLEN-DIAZ, B. H. and J. W. BARTOLOME. 1992. Survival of *Quercus douglasii* (Fagaceae) seedlings under the influence of fire and grazing. Madroño 39:47–53.

BARRETT, R. H. 1980. Mammals of California oak habitats—management implications. Pp. 275–291 *in* Proceedings of the Symposium on the Ecology, Management, and Utilization of California Oaks, June 26–28, 1979. USDA Forest Service General Technical Report PSW-44.

BARTOLOME, J. W. 1987. California annual grassland and oak savannah. Rangelands 9:122–125.

BOLSINGER, C. L. 1988. The hardwoods of California's timberlands, woodlands, and savannas. USDA Forest Service General Resource Bulletin PNW-RB-148.

BORCHERT, M. I., F. W. DAVIS, J. MICHAELSEN, and L. D. OYLER. 1989. Interactions of factors affecting seedling recruitment of blue oak (*Quercus douglasii*) in California. Ecology 70:389–404.

BUFFO, J. P., L. J. FRITSCHEN, and J. L. MURPHY. 1972. Direct solar radiation on various slopes from 0 to 60 percent—north latitude. USDA Forest Service Research Paper PNW-142. 74 pp.

BURNS, R. M. and B. H. HONKALA (tech. coord.). 1990. Silvics of North America—Volume 2, hardwoods. USDA Forest Service Agricultural Handbook 654.

CLAWSON, W. J., N. K. MCDOUGALD, and D. A. DUNCAN. 1982. Guidelines for residue management on annual range. University of California Division of Agricultural Sciences leaflet 21327. 4 pp.

GORDON, D. R., J. M. WELKER, J. W. MENKE, and K. J. RICE. 1989. Competition for soil water between annual plants and blue oak (*Quercus douglasii*) seedlings. Oecologia 79:533–541.

GRIFFIN, J. R. 1978. Oak woodland. Pp. 383–416 *in* M. G. Barbour and J. Major (eds.), Terrestrial vegetation of California. University of California, Davis. John Wiley and Son, New York.

HALL, L. M., M. R. GEORGE, D. D. MCCREARY, and T. E. ADAMS. 1992. Effects of cattle grazing on blue oak seedling damage and survival. Journal of Range Management. Journal of Range Management 45(5):503–506.

HOLMES, T. H. 1990. Botanical trends in northern California oak woodland. Rangelands 12:3–7.

HUNTSINGER, L. and L. P. FORTMANN. 1990. California's privately owned oak woodlands: owners, use, and management. Journal of Range Management 43(2):147–152.

MUICK P. C. and J. W. BARTOLOME. 1987. Factors associated with oak regeneration in California. Pp. 86–91 *in* Proceedings of the Symposium on Multiple Use of California's Hardwood Resources. USDA Forest Service General Technical Report PSW-100.

STANDIFORD, R. B. and R. HOWITT. 1988. Oak stand growth on California's hardwood rangelands. California Agriculture 42(4):23–24.

STANDIFORD, R. B., N. K. MCDOUGALD, R. PHILLIPS, and A. NELSON. 1991. South Sierra oak regeneration survey. California Agriculture 45(2):12–14.

SUDWORTH, G. B. 1908. Forest trees of the Pacific slope. USDA Forest Service. 441 p.

SWIECKI, T. J., E. A. BERNHARDT, and R. A. ARNOLD. 1991. Monitoring insect and disease impacts in rangeland oaks in California. Pp. 208–213 *in* Proceedings of the Oak Woodlands and Hardwood Rangeland Management Research Symposium, Davis, CA. USDA Forest Service General Technical Report PSW-126.

VERNER, J. 1980. Birds of California oak habitats—management implications. Pp. 246–264 *in* Proceedings of the Symposium on the Ecology, Management, and Utilization of California Oaks, June 26–28, 1979. USDA Forest Service General Technical Report PSW-44.

WHITE, R. L. 1966. Structure and composition of foothill woodland in central coastal California. Ecology 47:229–237.

WONNACOTT, R. J. and T. H. WONNACOTT. 1979. Econometrics. John Wiley and Sons, New York.