Bren School of Environmental Science and Management
University of California, Santa Barbara

# Ecology and Management of Oak Woodlands on Tejon Ranch

*Recommendations for Conserving a Valuable California Ecosystem*

**2011 Group Project Final Report**

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**June 10, 2011**

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***Recommendations for Conserving a Valuable California Ecosystem***

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a three academic quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

____________________________________
FRANK W. DAVIS, PH.D.
June 2011

## ACKNOWLEDGEMENTS

We would like to thank the following individuals for their support and guidance throughout the duration of our project.

Dr. Frank Davis – Faculty Advisor, Bren School of Environmental Science and Management
Dr. Mike White – Client, Conservation Science Director, Tejon Ranch Conservancy
Tom Maloney – Client, Executive Director, Tejon Ranch Conservancy
Dr. Trish Holden – Bren School of Environmental Science and Management, UCSB
Dr. Lee Hannah – Bren School of Environmental Science and Management, UCSB
Dr. Bruce Kendall – Bren School of Environmental Science and Management, UCSB
Dr. Maki Ikegami – Bren School of Environmental Science and Management, UCSB
Dr. Claudia Tyler – Assistant Research Biologist, ICESS, UCSB
Soapy Mulholland – Executive Director, Sequoia Riverlands Trust
Hilary Dustin – Conservation Director, Sequoia Riverlands Trust
Nicole Molinari – PhD Candidate, EEMB, UCSB
Karen Stalhler – PhD Candidate, EEMB, UCSB
Thomas Reed – PhD Candidate, EE, UCSB
Rusty Brown – UCSB Library Imagery Specialist
Deborah Lupo – UCSB Library Imagery Specialist
Dan Gira – More Mesa Preservation Coalition
Dr. Heather Scheck – Santa Barbara County Plant Pathologist
Bob Stafford – Wildlife Biologist, Chimineas Ranch and California Department of Fish & Game
David Clendenen – Resource Ecologist, Wind Wolves Preserve, The Wildlands Conservancy
Sheri Spiegal – PhD Candidate, Range Ecology Lab, UC Berkeley
Jennifer Browne – Operations Manager, Tejon Ranch Conservancy
Chris A. Niemela – Conservation Scientist, Tejon Ranch Conservancy
Rob Peterson – Senior Director of Land and Resource Planning, Tejon Ranch Company
Biogeography Lab – Bren School of Environmental Science and Management, UCSB

# Abstract

In 2008 the Tejon Ranch Company and a group of conservation organizations signed the landmark Tejon Ranch Conservation and Land Use Agreement which permanently protected 178,000 ecologically valuable acres on the Ranch, and created the Tejon Ranch Conservancy whose mission is to "preserve, enhance, and restore the native biodiversity and ecosystem values of the Tejon Ranch and the Tehachapi Range for the benefit of California's future generations". One of the Conservancy's primary tasks is the creation of a Ranch-Wide Management Plan (RWMP) which will support the Conservancy's mission. The goal of this project was to study oak woodlands on the ranch and make oak woodland management recommendations to be included in the RWMP. Through a combination of field work, data analyses, and modeling we characterized the ranch's oak woodlands, compared their structure to other California oak woodlands, quantified oak woodland population growth rates, and modeled how climate change will influence future distribution of oak woodlands. We found that blue, valley, and black oak populations are slowly declining and predicted that climate change will result in significant shifts in suitable habitats for blue, valley and black oaks. Given these threats we recommend that the Conservancy employ protective cages around seedlings and saplings in areas that are likely to remain climatically suitable over the next 50 years.

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# EXECUTIVE SUMMARY

Tejon Ranch is the largest contiguous private property in California and encompasses 270,000 acres at the convergence of four major ecoregions: the Mojave Desert, the Central Valley, the Sierra Nevada, and the Transverse Ranges. The ranch is home to rare and endemic species and a variety of vegetation communities including extensive foothill and montane oak woodlands, all located within 100 miles of Los Angeles.

In 2008, the Tejon Ranch Company, owner of Tejon Ranch, and a coalition of conservation organizations signed the landmark Tejon Ranch Conservation and Land Use Agreement (the Agreement). Under the Agreement, the Tejon Ranch Company may develop 30,000 acres of Tejon Ranch uncontested by the conservation organizations while 178,000 acres of the ranch are committed to permanent conservation. In March of 2011 an additional 62,000 conservation acres were secured. The Agreement also established the non-profit Tejon Ranch Conservancy (the Conservancy) whose mission is to "preserve, enhance, and restore the native biodiversity and ecological values of Tejon Ranch and the Tehachapi Range for the benefit of California's future generations". In pursuit of this mission the Conservancy is charged with developing a Ranch-Wide Management Plan (RWMP) that will employ an adaptive management strategy in order to enhance conservation values on the Ranch and maintain current land uses permitted under the Agreement such as hunting, cattle grazing, and filming. The goal of our project is to assess the ecological condition of oak woodlands on Tejon Ranch and make management recommendations for the RWMP.

Our research included three months of field data collection during the summer of 2010. Group members A. Krieger and S. Moy collected tree, understory, and soil data in 105 blue, valley, and black oak woodland plots. These data were used to characterize Tejon's oak woodlands and were used in other modeling exercises and analyses. Table *i* below lists the primary methods that this project employed and their associated purposes:

**Table i - Overview of the methods and analyses done in this study.**

| *Method/Analysis* | *Purpose* |
|---|---|
| Timber Survey Map Validation | Quantify map uncertainty and the degree to which the Timber Survey Map accurately classifies the distribution of oaks on the Ranch |
| Mutual Information Analysis (MIA) | Stratified random sampling for selection of oak woodland plots |
| Species Environmental Gradient Modeling: HyperNiche | Modeled species distributions by using species importance values calculated from relative basal area and relative species abundance |
| MaxEnt Modeling | Climate suitability forecasting for three focal species |
| Historical Photo Analysis | Quantify change over time (i.e. population growth rate) |
| Comparative Analysis | Statewide and management comparisons |

To learn how to best manage oak woodlands on Tejon Ranch, we addressed five guiding questions:

***What are the current extent, distribution, and condition of the oak woodlands on Tejon Ranch?***

According to a 1980 timber survey map that has the best information available regarding oak distribution on Tejon Ranch, 6% of the ranch is covered by blue oak woodland, 7% is covered by valley oak woodland, and 2% is covered by black oak woodland. Our plot level characterization of primary vegetation agreed with the much larger timber survey polygons 57.7% of the time. Blue, valley, and black oaks occupy distinct environmental locations on the ranch. Blue oak woodlands are most dominant at lower elevations between 500 meters and 1000 meters of elevation while black oaks dominate woodlands at elevations above 1200 meters. Valley oaks at Tejon Ranch exhibit a bi-modal elevational distribution, reaching maximum abundance between 400 to 600 meters and 1400 to 1800 meters of elevation. Tejon Ranch is within the southern extent of the ranges of blue, valley, and black oak woodlands. As a result oak woodlands on the ranch occupy higher elevations than others throughout California. Blue oak and valley oak woodland understories are dominated by grasses while black oak woodland understory is composed of a mixture of grass and shrubs.

***How do the structures of oak woodlands on Tejon Ranch compare to those in the rest of California?***

We compared stand basal area and tree diameter at breast height (DBH) in our plots to those recorded in a statewide sample of U.S. Forest Service Inventory and Analysis (FIA) plots and data reported by Allen-Diaz et al. in chapter 12 of Terrestrial Vegetation of California (Bolsinger 1988). Tejon's oak woodlands, particularly valley oak and black oak woodlands are better stocked than those throughout California. Tejon Ranch's blue, valley, and black oak trees also have larger DBHs than those throughout the state.

***How are the oak woodlands on Tejon Ranch changing over time and is there a regeneration problem?***

We compared archival air photos from 1952 and 2009 to determine how the oak populations were changing over time. The estimated annual population growth rate for blue oaks ranged from 0.996 to 0.999. Population growth rate ranged from 0.997 to 1.000 for valley and 0.998 to 1.000 for black oaks. While these growth rates are only slightly below one, oak populations will see a decrease of about 9% over the next 50 years at the current rate of decline.

***How do we expect the oak woodlands of Tejon Ranch to be impacted by climate change?***

Many plant communities are predicted to shift in response to climate change and oak woodlands are expected to lose habitat in future climates (Kueppers et al. 2005). We modeled future oak distribution on the ranch with species distribution models using a moderate-high (A2) carbon emission scenario and two general circulation models. These climate change models assume a continued increase in $CO_2$ emissions throughout the 21$^{st}$ century, and predict a 2.5° C to 4.5° C increase in temperature over the same time period (Cubasch et al. 2001, Cayan et al. 2008). For the state of California, one model predicts a slightly wetter future (+ 8% change in annual precipitation), and one predicts a slightly drier future (- 28% change in annual precipitation) (Cayan et al. 2008). We found a general decline in climatic suitability for oaks on Tejon Ranch between now and mid-century and further reductions by the end of the century. The overall trend is movement upslope and toward north facing aspects. Our results showed similar conclusions for both models and for all species. Of the three species modeled, blue oaks showed the most significant loss of climatically suitable habitat: 71%-80% reduction by mid-century, and 92%-93% reduction by the end of the century. For black oak the models predict a reduction in suitable habitat of 61%-78% by mid-century, and 90%-100% by the end of the century. Valley oaks are predicted to lose 19%-56% of their suitable habitat on the Ranch by mid-century, and 78%-94% by the end of the century. Despite these drastic reductions in climatically suitable habitat, the abundance of varied topography and microclimates on the ranch may provide habitat refugia for oak species, effectively buffering these populations from severe habitat loss due to climate change.

***How are current land management practices affecting Tejon's oak woodlands?***

Hunting, fire management, and grazing impact oak woodlands on the ranch. Depending on the intensity, duration and seasonality of grazing, livestock can influence seedling recruitment, both directly by way of browsing and indirectly by reducing the competition from annual grasses. Grazing can also alter soil properties including bulk density and infiltration rates. Fire influences oak woodlands by altering fuel loads, understory assemblage and composition, and soil properties. Hunting impacts oak woodlands by affecting deer, elk, and feral pig populations, and the understory community. While our research did not quantify the impact of grazing, fire and hunting on Tejon oak woodlands, we recommend the Conservancy establish experimental plots in order to determine how different management regimes impact Tejon Ranch's oak woodlands.

***Management Recommendations***

Blue, valley, and black oak populations on Tejon Ranch are all undergoing a slow but significant decline, threatening losses of about 9% over the next 50 years. The most cost effective way to stabilize oak populations is to deploy small, circular cages around naturally occurring saplings and seedlings in order to exclude browsing ungulates. This protection should allow seedlings and saplings to escape the browse layer within roughly five years. If current demographic rates persist, this process will need to be repeated every five years to stabilize oak populations.

Given that climate change is predicted to influence future oak distribution, we recommend that the Conservancy target its restoration efforts in areas where suitable oak habitat is projected to be stable over the next 50 years. Because of uncertainties about whether future climate on Tejon Ranch will be wetter or dryer, we recommend that managers target restoration efforts in areas where both the 'warmer-wetter' climate model and 'warmer-drier' climate model used in this study predict to be stable climatically suitable habitat over the next 50 years.

In order to stabilize oak populations, we calculated that managers will have to protect blue oak seedlings or saplings at a density of 8.49 trees/ha within the blue oak target area, 0.21 trees/ha within the valley oak target area, and 1.62 within the black oak target area.

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES



## LIST OF BOXES

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# PROJECT SIGNIFICANCE

Oaks cover extensive areas of the California landscape from coastal shrubs to foothill woodlands to montane forests, but in the past 200 years oak cover has been drastically reduced due to human development, including more than 1 million acres of oaks lost in the past 50 years (Brussard et al. 2004, Giusti et al. 2005). Today 20 oak species still cover about 17 million acres of the California landscape (Giusti et al. 2005).

California's oak woodlands face a variety of threats. Perhaps the most well studied threat to oak woodlands is commonly referred to as the oak "regeneration problem" (Tyler et al. 2006, Griffin 1971, 1976, Bolsinger 1988, Brown & Davis 1991, Whipple et al. 2010). A widespread lack of oak regeneration has been well documented in California (Tyler et al. 2006). However, some research suggests that no regeneration problem exists (Tyler et al. 2006). The extensive use of oak woodlands for cattle grazing has frequently been cited as the cause of the regeneration problem (Giusti et al. 2005). Cattle browse oak seedlings, eat acorns, and compact the soil, making it difficult for seedlings to germinate. According to Mahall et al. (2005) grazing is the most pervasive anthropogenic disturbance in oak woodlands, savannas, and grasslands in California. Another threat to oak woodlands is sudden oak death (*Phytopthora ramorum*). Sudden oak death was first detected in the San Francisco Bay area in the 1990s and has since spread as far south as Big Sur and as far north as Mendocino County. While the pathogen has not been detected on Tejon Ranch, California Bay Laurel (*Umbellularia californica)* is a known carrier of the disease and is present on the Ranch, heightening concerns. Development has historically been a threat to oak woodlands. From 1945 to 1988 it was estimated that 1.2 million acres of hardwoods, primarily blue and valley oak woodlands, were lost in California (Bolsinger 1988). Many oak woodlands exist on private lands that are well suited for housing or agriculture. In the San Joaquin Valley it is estimated that 95% of riparian oak woodlands have been converted to agricultural use in the last 100 to 150 years (Kelly et al. 2005).

Threats to oak woodlands are currently being addressed by a variety of organizations employing a range of strategies. Most sweeping is the California Oak Conservation Act, a state law that protects oaks from development by requiring their replacement if oaks are removed for development. In addition, 41 counties in California have their own oak protection ordinances. Private conservancies and land trusts have also played an important role in oak conservation. Additionally, the University of California operates the Integrated Hardwood Range Management Program whose goal is to conserve hardwood forests in California including oak woodlands.

The Tejon Ranch Conservancy has a unique opportunity to sustainably manage a large, contiguous block of some of the most scenic and ecologically valuable oak woodlands in California. The Ranch supports roughly 82,000 acres of blue oak, valley oak, and black oak, canyon oak, interior live oak, white oak, and mixed oak woodlands (Appelbaum et al. 2010, US Fish & Wildlife Service 2009) that are permanently protected under the Tejon Ranch Conservation and Land Use Agreement. Tejon Ranch's oak woodlands are particularly valuable because of their location at the crossroads of the southern Sierra Nevada Mountains and the

California Transverse Ranges making them a waypoint for wildlife migrating between these two regions. This connectivity also has significant climate change adaptation implications as it will allow animal species to migrate and vegetation communities to shift northward in response to a warmer climate.

# BACKGROUND

## OAK WOODLAND DIVERSITY AND ECOLOGY

### *Diversity and Distribution*

Oaks (*Quercus spp.*) dominate California's landscape and play an important role in the culture, history, and ecology of the state (Pavlik 1991, FRAP 2002, Giusti et al. 2005, Kelly et al. 2005). California is home to 20 of the 89 known species of oak in the US, 7 of which are endemic to the state (Nixon 2002). FRAP (2002) estimates that oaks cover at least one-sixth of the state (>17 million acres), in mostly privately owned, low elevation foothill woodlands. Oak woodland cover has sharply declined over the last century due to the expansion of agriculture, rangelands, and urban and rural development (Bolsinger 1988).

### *Basic Biology*

The oak species in California are generally long-lived species; some documented to be over 600 years old (Pavlik 1991). Seed germination generally occurs in response to fall or winter rains and, once established, many species can take between 20 and 30 years to develop their flowering and reproductive capacities (Giusti et al. 2005). Oaks are wind-pollinated and flower in the early spring when the new leaves are forming. Depending on the species, acorns will mature in the Fall of the same year (e.g., valley oak, blue oak) or the Fall of the second year (e.g., black oak). Acorn crops are thought to be quasi-cyclical, and timing of mast years varies by species (Giusti et al. 2005). Oak stands in California vary considerably in terms of tree density and canopy cover. Oak woodlands, with 10-60% tree canopy cover and grassy ground cover (FRAP 2002, Barbour et al. 2007), grow on a variety of soil types and climates and typically occur in elevational bands below montane forests (Pavlik 1991).

### *Oaks and Wildlife*

Oak woodlands provide some of the richest wildlife habitat of all of California's vegetation types (Pavlik 1991, Brussard et al. 2004). Of the 632 species of terrestrial vertebrates found in the state, over half of them use oak woodlands for cover, reproduction, or forage (Giusti et al. 2005). The structural diversity of oak woodlands provides diversity in wildlife habitats, and the asynchronous production of acorns across individuals and species provides a food source that can last for over four months in the fall when grasses and other forage are in short supply (Pavlik 1991, Giusti et al. 2005, Koenig et al. 2009). Studies show that the timing of a mast crop of oak trees is directly correlated to reproductive success of a multitude of species of birds (Pavlik 1991, Koenig et al. 2009). Other studies have shown that in October, a single mule deer may eat as many as 300 acorns per day (Pavlik 1991).

### *Oak Woodlands of Tejon Ranch*

There are 10 species and two recognized inter-specific hybrids of oak found on Tejon Ranch (Tejon Ranch Conservancy 2010):

*Q. agrifolia* – coast live oak
*Q. berberidifolia* – scrub oak
*Q. chrysolepis* – canyon live oak

*Q. douglasii* – blue oak
*Q. garryana* var. *breweri* – brewer oak
*Q. john-tuckeri* – tucker's oak
*Q. kelloggii* – black oak
*Q. lobata* – valley oak
*Q. wislizeni* var. *frutescens* – interior scrub oak
*Q. wislizeni* var. *wislizeni* – interior live oak
*Q.* x *alvordiana* – alvord oak
*Q.* x *morehus* – oracle oak

Oak communities studied for this report are often referred to as "hardwood rangelands." The term "rangeland" indicates that livestock grazing is the dominant current or historical land use. Hardwood rangelands encompass all communities of hardwood species ranging from sparsely populated savannahs to densely populated forests. However, for simplicity we will refer to the communities studied as "oak woodlands" for the rest of this report. The critical ecological role that these woodlands play in the ecosystem makes their management a top priority. Blue, valley and black oak biology and ecology is summarized below:

### *Blue Oak Woodlands*

Blue oaks (*Q. douglasii*) are endemic to California, and dominate over half of the state's woodlands (Pavlik 1991). They generally grow 30 – 40 feet tall with a diameter at breast height (DBH) of 10 – 25 inches (Giusti et al. 2005). Blue oaks are found up to 4,000 feet in elevation and are the most common woodland oak species in California. These trees are winter deciduous but are also facultatively drought-deciduous, meaning that they can drop their leaves mid-growing season if drought conditions become too stressful (Pavlik 1991). This unique adaptation has allowed them to occupy some of the hottest and driest, non-desert climates in the state. They are adapted to poor soils and are common in foothills bordering interior valleys. Blue oaks often form mono-specific woodland stands with sparse, grassy understories (annual bromegrass, wild oats, fiddleneck, and foxtail). Associations with trees and shrubs such as foothill pine, canyon and interior live oak, juniper, white-leaf manzanita, coffeeberry, poison oak, ceanothus, buckbrush, and California buckeye are not uncommon (Borchert et al. 1991, Pavlik 1991, Brussard et al. 2004).

### *Valley Oak Woodlands*

Also endemic to California, valley oaks (*Q. lobata*) are arguably the largest of all the oaks in the United States. They have been known to grow over 100 feet tall, with a DBH of up to 7 feet (Pavlik 1991). They typically grow below 2,000 feet in elevation, but they have been found up to 6,000 feet when deep soils and available water tables allow (Giusti et al. 2005). Valley oaks are phreatophytic, meaning that they get their water from belowground sources and are not directly dependent on precipitation and other surface water sources. They do, however, require fairly deep and rich soils, and are found in riparian areas and floodplains, alluvial fans and flats, and upland terraces and plateaus (Giusti et al. 2005). Valley oaks most commonly have very open understories composed of annual and perennial grasses, but occasionally may include shrubs such as poison oak, toyon, and coffeeberry (Brussard et al. 2004). Valley oaks were once widely distributed throughout much of California, but their extent has been greatly reduced due to displacement by agriculture and urban and rural development on prime lowland real estate (Pavlik 1991, Appelbaum et al. 2010), and given population and climate change predications, their range is anticipated to decrease even more over the next century (Grivet et al. 2008).

### *Black Oak Woodlands*

Unlike valley and blue oaks, black oaks (*Q. kelloggii*) are more of an upland species. They are generally found on well-drained soils between 2,000 feet and 6,000 feet in elevation. They typically grow 70 – 80 feet tall, with a DBH of 24 – 48 inches (Giusti et al. 2005). They are extensive in the state's northern ranges and in the Sierra Nevada. Although they are found from Oregon to Mexico (Pavlik 1991), the population in the Tehachapi Mountains is one of a handful of scattered southern populations (Giusti et al. 2005). Black oaks are esteemed for their beauty, nutritious acorns, wildlife browse capacity, and high quality wood.

## *Climate Change*

Blue oaks are found in the foothills of the Coastal Ranges and western Sierra Nevada Mountains and valley oaks are found in the Central Valley. Using regional and global climate models, Kueppers et al. (2005) found that future climate change will likely reduce the area of California habitat with climates similar to those in which blue and valley oaks are now found. They predicted climate related habitat loss to be upwards of 59% for blue oaks and 54% for valley oaks if measures are not taken to reduce temperature changes due to greenhouse gas induced climate change. While reductions in climatically suitable habitat have been predicted throughout the range of valley oak, Sork et al. (2010) found that genetic variation at local and regional scales can have a large impact on the magnitude and impact of these climate effects. This highlights the value of local-scale analyses as a means to better understand the spatial variation of species responses to climate change. Though no specific studies could be found that focused directly on the effects of climate change on black oaks, it is reasonable to assume that a changing climate would have similar effects on black oaks as has been predicted for blue and valley oaks.

## *Oak Regeneration*

Regeneration in oak savannas and woodlands is an issue that has been studied for decades (Griffin 1971, 1976, Bolsinger 1988, Brown & Davis 1991, Whipple et al. 2010). Through field experiments, historical records, and spatial analyses, researchers have identified reduced recruitment and skewed size distributions in valley oak, blue oak, and others (Bolsinger 1988, Giusti et al. 2005, Tyler et al. 2006, 2008, Whipple et al. 2010). On Tejon Ranch, aerial photography as well as size class studies indicate that regeneration of valley oak is a concern (Appelbaum et al. 2010).

The primary controls on recruitment are the ability of an acorn to successfully germinate, and then survive and grow beyond the browse height of ungulate herbivores. At the seed stage, acorns must survive infection, desiccation, and predation and then become planted deep enough in the soil and in a climatically favorable location to allow for germination (Callaway 1992a, Giusti et al. 2005, Tyler et al. 2008). Once emerged, seedlings are exposed to herbivory by insects, rodents and ungulates, competition for resources with non-native annual grasses, and climatic stressors such as drought and sub-optimal light conditions (Callaway 1992b, Gordon & Rice 2000, Giusti et al. 2005, Tyler et al. 2008).

Explanations for the regeneration problem have focused on seedling competition with non-native Mediterranean annual grasses, and the browsing of seedlings and saplings by livestock (Giusti et al. 2005). However, oak sapling exclosure experiments have indicated that livestock browsing may not be the primary factor (Tyler et al. 2006). These exclosure experiments and others on oak regeneration are limited in their spatial and temporal scope and most have examined oak stand structure (size class) and not stand demography. Evidence suggests that valley oaks are in fact experiencing increased mortality and declines in population (Brown & Davis 1991, Giusti et al. 2005, Tyler et al. 2006, Whipple et al. 2010).

## POLICY

***California Oak Woodlands Laws and Ordinances Applicable to Tejon Ranch***

In response to growing concerns about the future of oaks in California, governments at the state and local levels have responded with laws and ordinances targeted at slowing and ultimately reversing the trend of rapid oak woodland conversion. The California Oak Woodlands Conservation Act of 2001 established the Oak Woodlands Conservation Fund whose funds are used to incentivize private landowners to conserve oak woodlands. Under the Act, counties can receive funds from the state to create and implement voluntary oak woodlands management plans. These plans are particularly focused on promoting cattle grazing practices consistent with healthy oak woodlands (McCreary 2004). In 2004 the state passed Senate Bill 1334 which created specific guidelines for the mitigation of oak woodland conversion under the California Environmental Quality Act (CEQA). Mitigation options include purchase of oak woodland conservation easements, planting and maintenance of oak trees for 7 years, and monetary donations to the state Oak Woodlands Conservation Fund.

Many California counties have oak ordinances of some sort (IHRMP 2010). County oak ordinances have a range of conservation strategies including protecting old large individuals, known as heritage trees, requiring that a certain proportion of oak woodland canopy remain intact, requiring extensive information gathering, and requiring mitigation of any oak woodland conversion (Giusti et al. 2005). Kern County, which contains the majority of Tejon Ranch, has an oak ordinance that defines oak woodlands as stands of oak with at least 10% canopy cover. Any development of oak woodlands must leave 30% of existing oak canopy cover untouched. Development within the drip-line of oaks is restricted. The ordinance also includes measures to protect oak trees that may not comprise oak woodlands, but have a DBH of 12 inches or greater. Developers may remove these trees, but they must first provide evidence that leaving the tree intact would impose a significant hardship. The County of Los Angeles – in which a small sliver of the southern portion of Tejon Ranch is located – has an Oak Tree Ordinance that focuses on individual oak trees with diameters at breast height of at least 8 inches. The ordinance requires a permit from the County for any project that will prune, trim or remove any oak tree of adequate size. The ordinance requires permit applications and highly detailed reports for development projects involving oak removal. Presumably many developers would rather find a way to work around existing oaks rather than invest time and money into a lengthy permitting process. The Los Angeles County oak ordinance requires offsite mitigation for removal of oaks or payment into the county's Oak Forests Special Fund. For every acre of oak woodland removed, two acres of comparable oak woodland are required for mitigation. This mitigation requirement will be critical for the Centennial Development on Tejon Ranch, which lies entirely in Los Angeles County.

***Federal and State Laws Relevant to Tejon Ranch and the Ranch-Wide Management Plan***

A number of other federal and state laws directly affect the development and management of Tejon Ranch. One class of laws protects wildlife on the Ranch. These laws include the Federal Endangered Species Act, the California Endangered Species Act, the Bald and Golden Eagle Protection Act, the Federal Migratory Bird Treaty Act, and the California Native Plant Protection Act. A number of other laws govern surface waters and hydrology on the Ranch. The Federal Clean Water Act protects wetlands, the California Fish and Game Code Section 1600-

1616 protects natural flows of surface waters on the Ranch, and the California Porter-Cologne Act protects surface waters on a state level.

Tejon Ranch provides foraging habitat to the endangered California condor. In order to move forward with their development plans, the Tejon Ranch Company had to apply for an Incidental Take Permit (ITP) issued by the US Fish and Wildlife Service (FWS) under section 10 of the Endangered Species Act. In order to qualify for the ITP Tejon Ranch Company was required to negotiate a Multiple Species Habitat Conservation Plan (MSHCP) under which the permanent protection of the conserved lands on the Ranch would count as mitigation for the incidental take of endangered species due to development (US Fish & Wildlife Service 2009). In addition to the California condor, 26 other listed and non-listed species deemed important to the FWS were included in the MSHCP. In addition, the granting of an ITP by the FWS requires an Environmental Impact Statement (EIS) under the National Environmental Policy Act (NEPA).

Tejon Ranch also participates in the California Williamson Act Program. The Williamson Act of 1965 established incentives for private landowners to continue open space land use such as farming and grazing rather than selling their land to developers. Under the Act, private landowners can enter into contracts with local governments under which they will enjoy lower property taxes if landowners agree to continue open space land use.

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# PROJECT INTRODUCTION

Tejon Ranch is the largest contiguous private property in California. Located in Kern County, the ranch encompasses 270,000 acres at the convergence of four major ecological regions: the Mojave Desert, the Central Valley, the Sierra Nevada, and the Transverse Ranges (Figure *i*). Tejon Ranch is home to rare and endemic species and a wide variety of vegetation communities ranging from San Joaquin grasslands, to foothill oak woodlands, montane oak and conifer forest, mixed conifer forest, chaparral, Joshua tree woodland, desert scrub, and desert grasslands, all located less than 100 miles from Los Angeles.


**Figure i- Location of Tejon Ranch at the intersection of four of California's major ecoregions: the Mojave Desert, the Sierra Nevada Mountains, the Central Valley, and the Coastal Ranges.**

In 2008 the Tejon Ranch Company, owner of Tejon Ranch, and a coalition of conservation organizations signed the landmark "Tejon Ranch Conservation and Land Use Agreement" (the Agreement). Under the Agreement the Tejon Ranch Company can develop 30,000 acres of Tejon Ranch, uncontested by the conservation organizations, while 178,000 acres are be committed to permanent conservation. In March of 2011 an additional 62,000 were secured for conservation (Figure *ii*). The Agreement also established the non-profit Tejon Ranch Conservancy (the Conservancy) whose mission is to "preserve, enhance, and restore the native biodiversity and ecological values of Tejon Ranch and the Tehachapi Range for the benefit of California's future generations". In pursuit of this mission the Conservancy must develop a Ranch-Wide Management Plan (RWMP) that will employ an adaptive management strategy with the goal of "restoring and enhancing the natural values of the conserved lands" (Tejon Ranch Company 2009a). This project aims to assess the condition of oak woodlands on the Ranch and make recommendations for the management of these systems for the Ranch-Wide Management Plan.

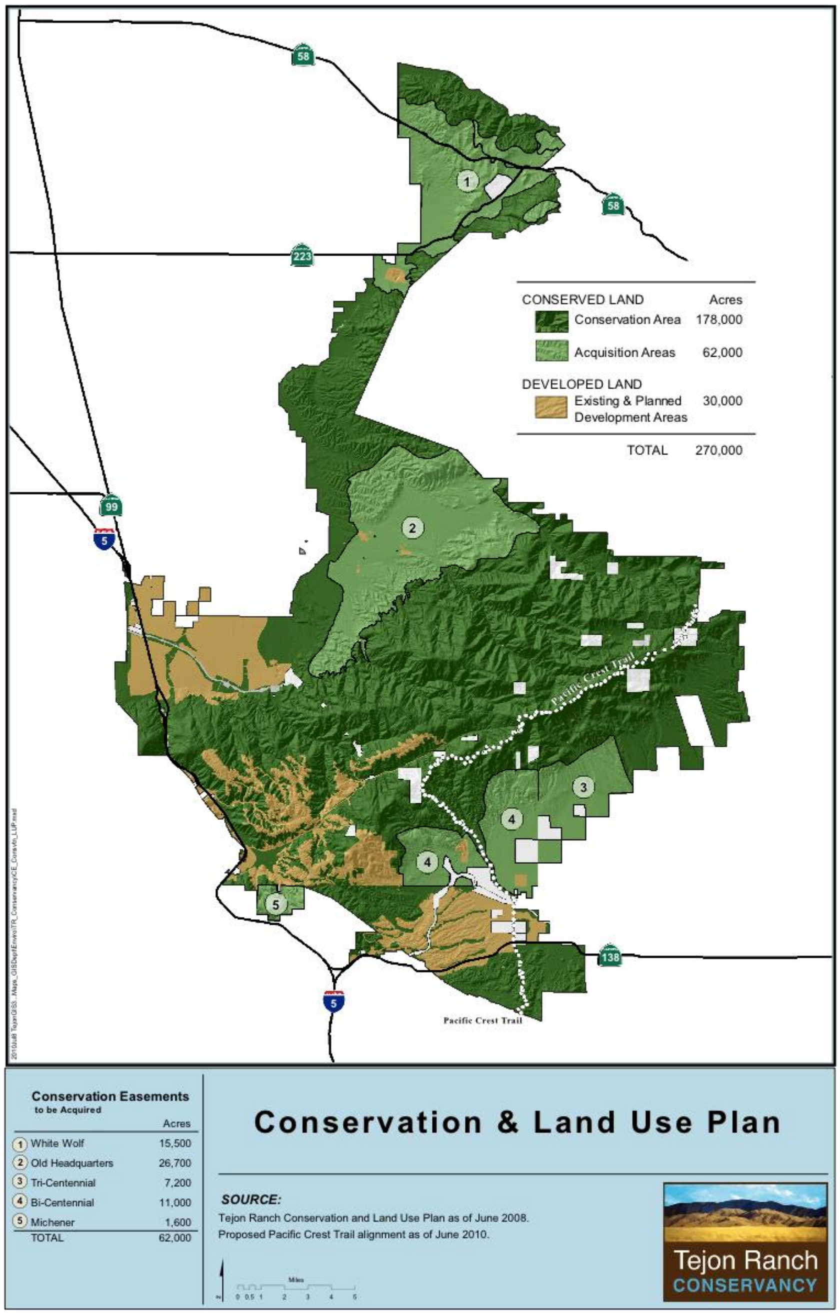


**Figure ii - Map of Tejon Ranch showing land allocations as determined by the Tejon Ranch Conservation and Land Use Agreement.**

Tejon Ranch's extensive foothill and montane oak woodlands include blue oak, valley oak, black oak, interior live oak, canyon live oak, and brewers oak. Our research focused on blue, valley, and black oak woodlands because their understories are heavily utilized by ranch's cattle grazing operations.

The goal of this project was to assess the ecological condition of the oak woodlands on Tejon Ranch and make management recommendations to the Tejon Ranch Conservancy. To do this we addressed five guiding questions:

- **Chapter 1:** What are the current extent, distribution, and condition of oak woodlands on Tejon Ranch?
- **Chapter 2:** How does the structure of oak woodlands on Tejon Ranch compare to the structure of oak woodlands in the rest of California?
- **Chapter 3:** How are oak woodlands on Tejon Ranch changing over time, and is there a regeneration problem?
- **Chapter 4:** How do we expect oak woodlands on Tejon Ranch to be impacted by climate change?
- **Chapter 5:** How are current land management practices affecting Tejon's oak woodlands?

Project methods included literature review, field data collection in 105 oak woodland vegetation plots, computer modeling, historical air photo analysis, and various comparative analyses.

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# Q1: What is the current extent, distribution and ecological condition of oak woodlands on Tejon Ranch?

## Data Collection and Map Validation

The best available data regarding the extent and distribution of blue, valley, and black oaks on Tejon Ranch is a timber survey conducted in 1980. The timber survey indicates that 6% of the Ranch is covered by blue oaks, 7% is covered by valley oaks, and 2% is covered by black oaks (Table 1.1). Using the timber survey map and a stratified random sampling scheme, we selected oak woodland sampling locations for plot-based surveys of current woodland structure and composition (Figure 1.1). For more information on how plot locations were selected see Appendix I.

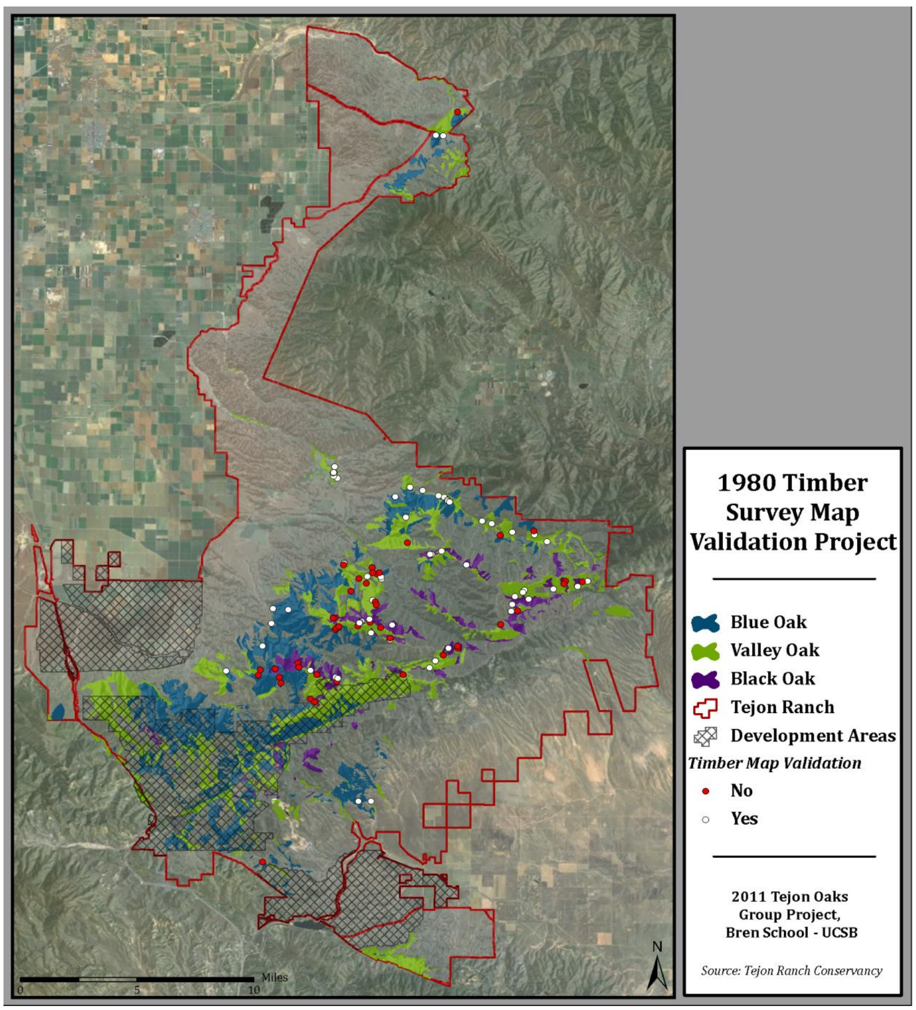


**Figure 1.1 - Map of Tejon Ranch showing the locations of 105 vegetation plots. White dots represent plots validating the timber survey map; red dots represent plots invalidating the timber survey map. Also shown are polygons from the 1980 timber survey maps indicating the locations of blue, black, and valley oak woodlands.**

**Table 1.1 - Total coverage of blue, black, and valley oak on Tejon Ranch.**

| | *Acres* | *Percent Cover* |
|---|---|---|
| Blue Oak | 14,234 | 6% |
| Valley Oak | 16,886 | 7% |
| Black Oak | 4,910 | 2% |
| Other Land Cover | 204,542 | 85% |
| Tejon Ranch Conservation Area | 240,572 | 100% |

We collected tree, understory, and soil data in 105 20x30 meter plots. Detailed methods and descriptions of these field surveys can be found in Appendix I. The Conservancy plans to use a number of our plots to establish a permanent plot network for long-term monitoring. As a secondary objective we assessed the accuracy of the timber survey map using our field data. Our plot level characterization of primary vegetation agreed with the much larger timber survey polygon 57.7% of the time (Table 1.2). Due to the mismatch in scale between our plot data and the timber survey polygons, it is unclear whether this discrepancy is due to local heterogeneity within timber survey polygons, or inaccuracies of the timber survey. Validation of the timber survey at the polygon scale is necessary to determine this. Our plot level validation informs managers to not expect every point within timber survey polygons to match the timber survey's description.

**Table 1.2 – (Top) Matrix comparing primary tree cover on Tejon Ranch as predicted by the 1980 timber survey map to field data collected in 2010. (Bottom) Number of plots surveyed in 2010 by species. The timber survey map polygons agreed with our plot level characterization of primary vegetation at a rate of 57.7%.**

| *Confusion Matrix* | | | Timber Survey | | |
|---|---|---|---|---|---|
| | | Blue | Valley | Black | **Totals** |
| Data | Blue | 16 | 8 | 0 | ***24*** |
| Data | Valley | 12 | 31 | 8 | ***51*** |
| Data | Black | 0 | 17 | 13 | ***30*** |
| | **Totals** | ***28*** | ***56*** | ***21*** | ***105*** |

| *Total Plots* | *Valley Oak Plots* | *Blue Oak Plots* | *Black Oak Plots* | *Timber Survey Map Agreement With Plot Characterization* |
|---|---|---|---|---|
| 105 | 51 | 24 | 30 | 57.7% |

Note: More detailed methodology for the plot surveys can be found in Appendix I.

## SPECIES ENVIRONMENTAL GRADIENT MODELING

Environmental gradient analysis is a standard ecological method by which the relationships between species' ecological importance and environmental gradients are characterized. We calculated a species' ecological importance in a plot as the sum of relative density and relative basal area of adult trees.

A number of methods have been used to characterize species-environment relationships. We used direct gradient analysis, which models changes in species importance along one or more environmental gradient by fitting a function to sample data where importance and the environmental factor have been observed. Parametric models use a single function such as a linear relationship, a Gaussian relationship, an exponential, or a sigmoidal relationship to describe how species importance varies along an environmental gradient. While these models have the advantage of being relatively easy to construct, they are unrealistic as species' response to environmental gradients are complex and are almost always influenced by multiple factors. We used a non-parametric model that uses a spline function to locally smooth the species response curve. The model also included penalties for over-fitting to ensure parsimonious outputs. Because we expected interaction among environmental gradients we used a general multiplicative model.

A two factor model based upon elevation and solar radiation was used because these two variables accounted for most of the variation in our data and are among the most reliably modeled environmental variables (Figure 1.2).

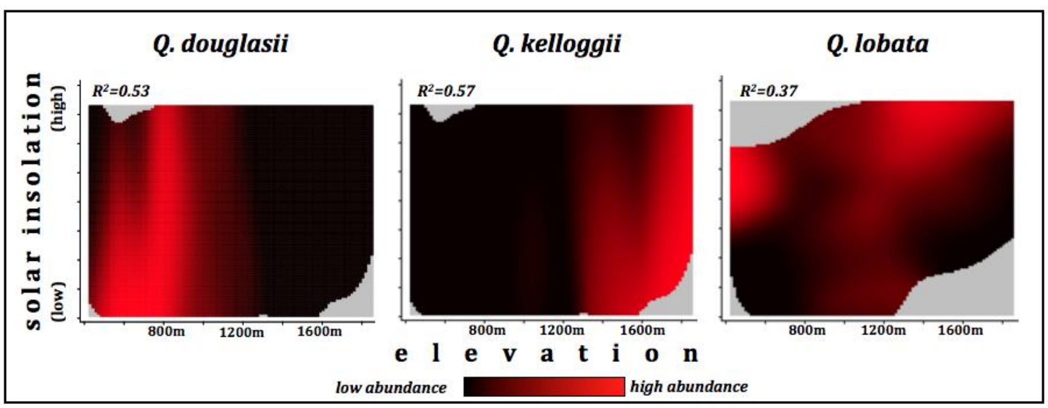


**Figure 1.2 - Graph showing output of two factor model with elevation on the x- axis and insolation on the y- axis. Bright red regions indicate high species importance. The model indicates that blue oaks (left) are more abundant on cooler north-facing slopes at lower, drier elevations, and shift to south-facing slopes at higher, cooler and wetter elevations. Black oaks (center) are found almost exclusively above 1200 meters. Like blue oaks, black oaks are more abundant on north-facing slopes at lower elevations and south-facing slopes at higher elevations. Valley oaks (right) exhibit a bi-modal distribution with high abundance on valley floors, and flat to south-facing ridge tops above about 1200 meters.**

Blue oaks are most abundant between 400m and 1200m of elevation, with abundance dropping off sharply above 1200m. According to Allen-Diaz et al. (2007) blue oaks occur at elevations above 600 meters mostly in the southern part of the blue oak range where the climate is hotter and dryer (Figure 1.3). Tejon Ranch lies at the southern-most extent of the blue oak's range.

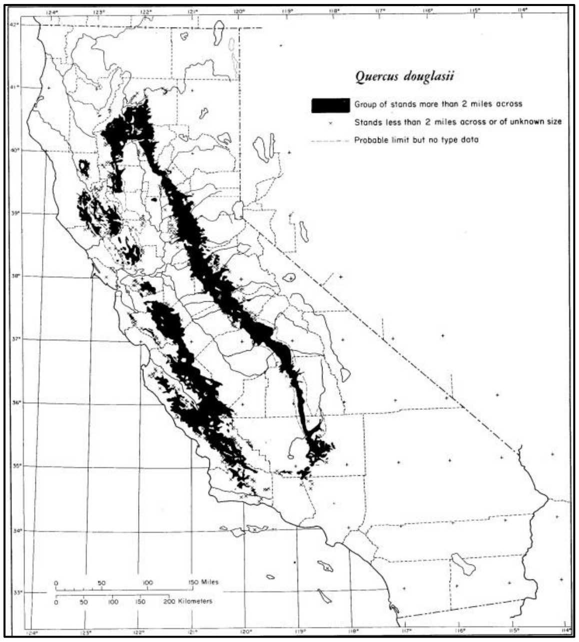


**Figure 1.3 – Distribution of California endemic blue oak.**

| Blue Oak | |
|---|---|
| Statewide Elevation (*Allen-Diaz*) | 150-600m N, up to 1500m S |
| Tejon Elevation | 400-1200m |

Black oaks on Tejon Ranch exist almost exclusively above 1200 meters and are most abundant between 1200 and 1850 meters of elevation. Given that black oaks occur at elevations as low as 60 meters across California, Tejon Ranch's black oak population occupies relatively high elevations. Tejon Ranch lies within the southern portion of the black oak range, however black oak distribution is known to extend significantly further south than Tejon Ranch into Baja California (Figure 1.4).

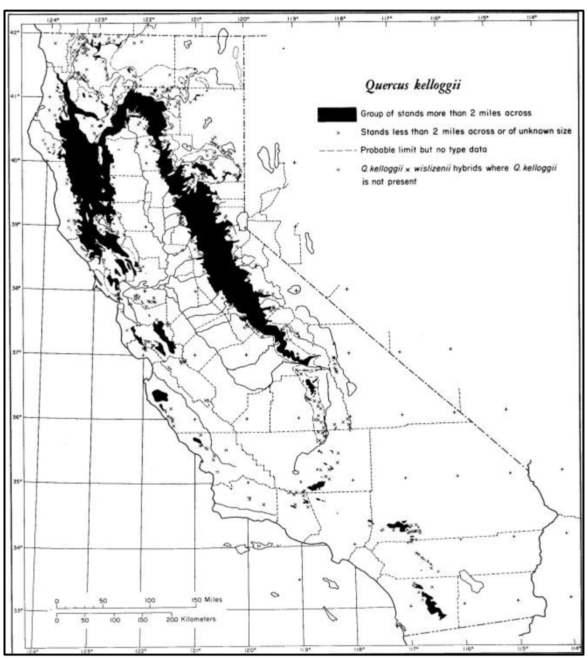


**Figure 1.4 – Distribution of black oak in California.**

| Black Oak | |
|---|---|
| Statewide Elevation (*Allen-Diaz*) | 60-1800m |
| Tejon Elevation | 1300-1750m |

Valley oaks exhibit a bi-modal elevational distribution, with species abundance greatest in valley floors between 400 and 800 meters and on ridge tops between 1200 and 1750 meters (Figure 1.5). An example of a low elevation riparian valley oak stand is located in the Old Headquarters area of the ranch at about 420 meters of elevation. The Old Headquarters stand has an average basal area of 31.6 $m^2$/ha while the remaining valley oak stands on the ranch have an average basal area of 16.8 $m^2$/ha. As with blue and black oaks, valley oaks on the ranch are within the southern-most extent of the specie's distribution where trees occupy relatively high elevations in response to the hotter, dryer climate.

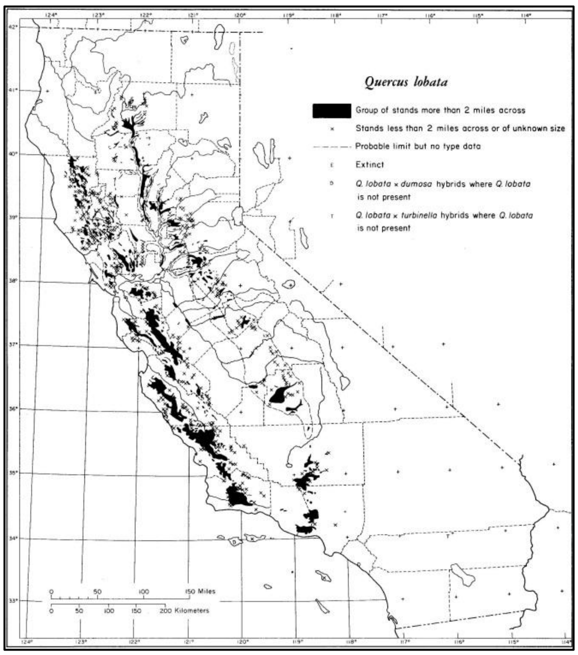

**Figure 1.5 – Distribution of California endemic valley oak.**

| Valley Oak | |
|---|---|
| Statewide Elevation (*Allen-Diaz*) | 150-240m N, up to 1700m S |
| Tejon Elevation | 400-700; 800-1750m |

We ran a two-factor model for blue oak species importance based upon growing degree days and mean annual precipitation (Figure 1.6). The results indicated that blue oaks prefer drier environments. The two factor model for black oak species importance based on aridity and mean annual precipitation indicates that black oaks prefer wetter environments. This is consistent with our finding that black oaks prefer higher elevations. We also ran a two factor model for valley oaks using temperature seasonality and aridity. Like our valley oak model based on elevation and insolation this climate-based model shows a complex, bi-modal distribution.

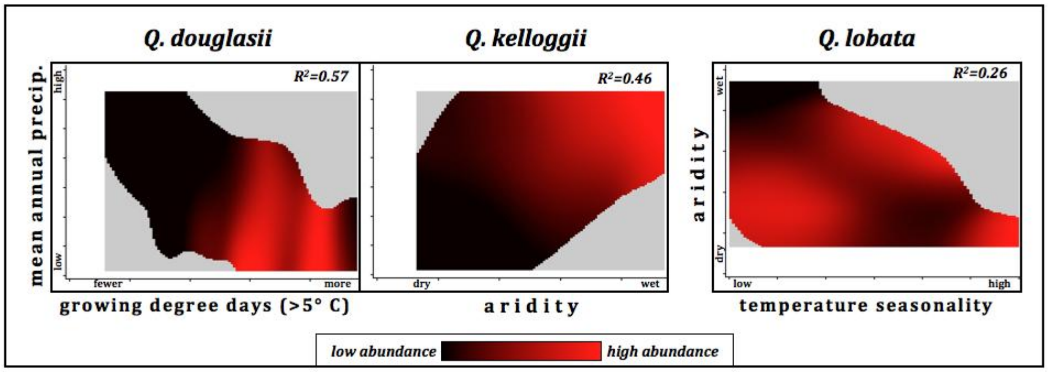


**Figure 1.6 - Two-factor models for blue, black, and valley oaks. Blue oak species importance was modeled against growing degree days and mean annual precipitation (left). Results indicate that blue oaks prefer drier environments. Black oak species importance was modeled against aridity and mean annual precipitation (center). These indicate that black oaks prefer wetter environments, supporting our finding that black oaks prefer higher elevations. Valley oak species importance was modeled against temperature seasonality and aridity (right). Like our valley oak model based on elevation and insolation this climate-based model shows a complex, bi-modal distribution.**

## UNDERSTORY CHARACTERIZATION

We conducted point intercept sampling along understory transects and recorded each plot's understory composition. We characterized understory sample points categorically as tree, shrub, forb, grass, bare ground, leaf litter, woody debris, rock, or cow pie. Figure 1.7 shows the relative contribution of understory categories in all blue oak plots. The blue oak understory is dominated by grass with leaf litter, forb, and bare ground also making small contributions. According to Allen-Diaz et al. (2007), grass dominated blue oak understories are typical across the blue oak range.

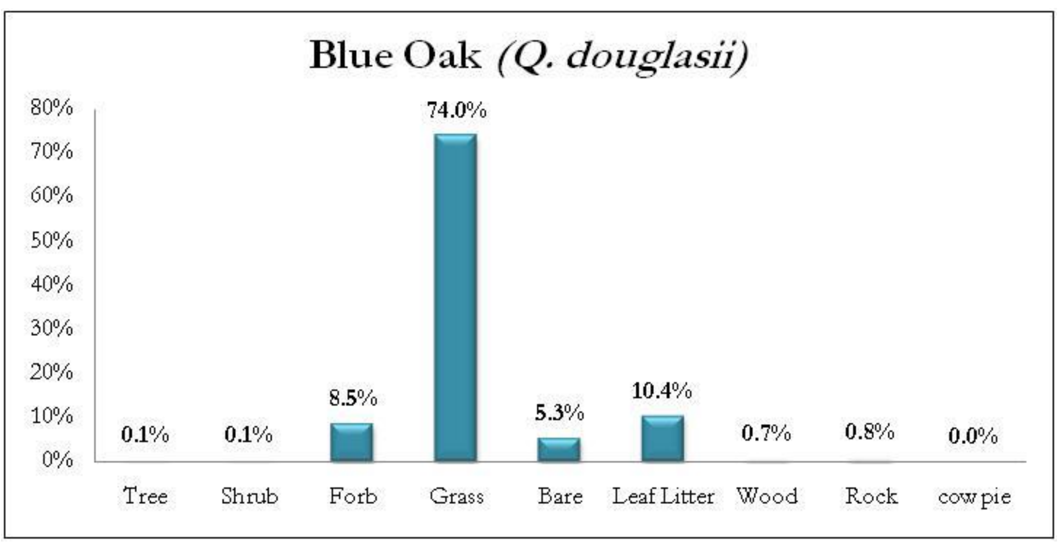


**Figure 1.7 – Blue oak stand understory composition by category.**

The valley oak understory has a composition similar to the blue oak understory and is dominated by grass (Figure 1.8). Allen-Diaz et al. (2007) reported that grass understories are common in valley oak woodlands and that shrub dominated valley oak woodland understories "can be dense along drainages but very sparse in uplands". While shrub cover in valley oak understory was sparse in our original plots, we did survey four additional valley oak woodland plots along the Cottonwood drainage whose understories were shrub dominated.

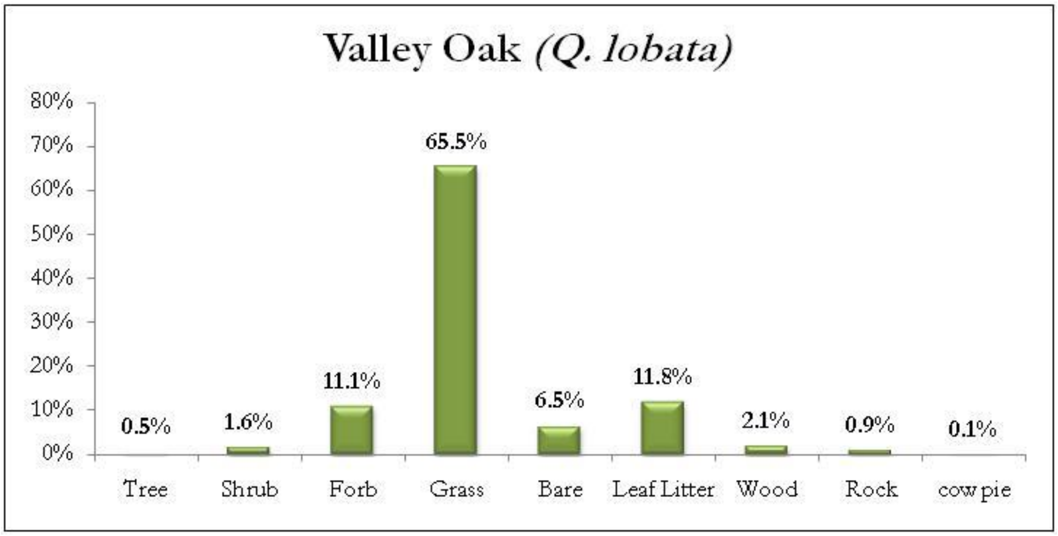


**Figure 1.8 - Valley oak stand understory composition by category.**

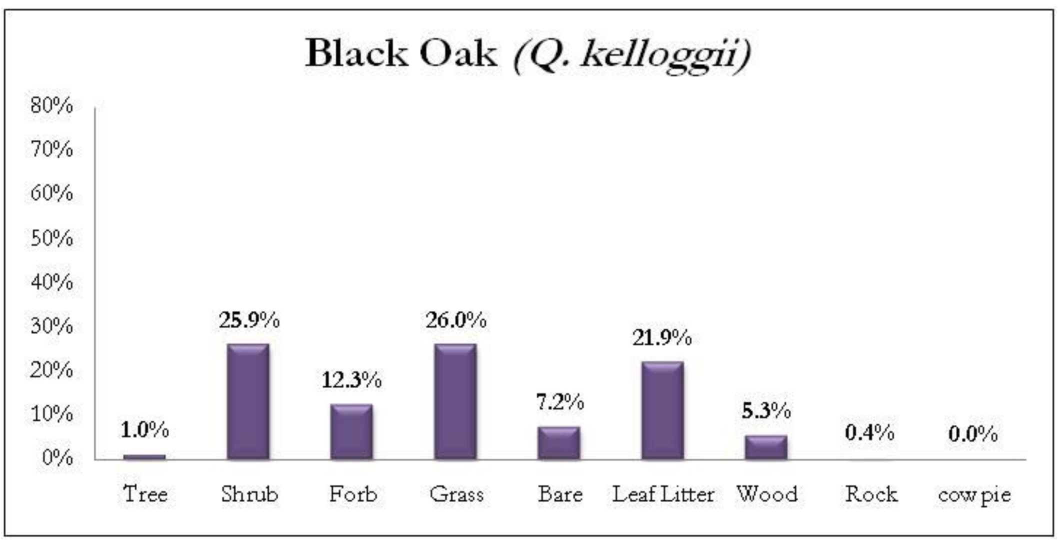


**Figure 1.9 - Black oak stand understory composition by category.**

Black oak woodland understory is dramatically different from valley and blue oak woodland understory. Black oak woodland understory is composed of 25% shrub cover, 26% grass and 22% leaf litter (Figure 1.9). Black oak understory ranged from shrub dominated, to mixed grass and shrub, to grass dominated (Figure 1.10). The dominant understory shrubs are snowberry, *Symphoricarpus mollis,* and gooseberry, *Ribes divaricatum.*

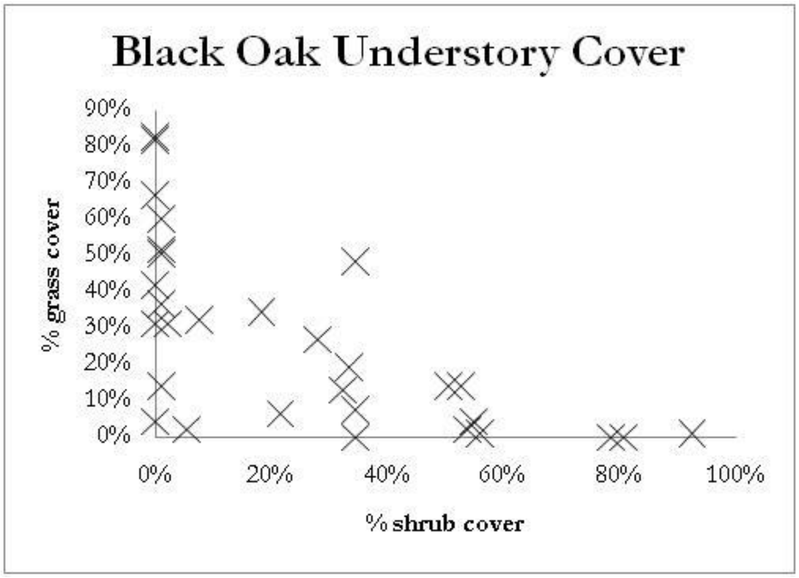


**Figure 1.10 – Chart shows shrub and grass cover of black oak plots. Cover ranges from shrub dominated, to mixed shrub and grass, to grass dominated.**

Further analyses of the ecological condition of Tejon's oak woodlands can be found in Appendix I.

# Q2: How do the oak woodlands on Tejon Ranch compare to those in the rest of California?

We compared stand basal area and tree DBH in our plots to those recorded in a statewide sample of U.S. Forest Service Inventory and Analysis (FIA) plots (Bolsinger 1988) and data reported by Allen-Diaz (2007), in order to contextualize the structure of Tejon Ranch's oak woodlands. Because we did not use the original raw data from the FIA survey, or Allen-Diaz et al., we were not able to obtain relevant statistics such as mean and standard deviation of stocking rates and DBH for the statewide data.

## Comparison of Results: Tejon vs. statewide oak woodlands

### *Valley Oak Woodlands*

Figure 2.1 shows that Tejon's valley oaks stands are better stocked than most in the state. In fact 21% of the ranch's valley oak stands have greater basal area per acre (100 sq. ft./acre) than any stands in the statewide plots. Tejon Ranch also has proportionately more large DBH trees than are present statewide. According to Allen-Diaz (2007) the largest valley oaks in California have DBH of about 2.4 meters (Table 2.1). The largest valley oak we measured on Tejon Ranch was 2.03 meters further suggesting that the ranch's oaks are relatively large, however our 2.03 meter DBH tree was a significant outlier with the second largest valley oak having a DBH of 1.52 meters (Figure 2.2). Unfortunately neither Allen-Diaz nor Bolsinger report the entire distribution of oak DBHs for direct comparison with Tejon's distribution.

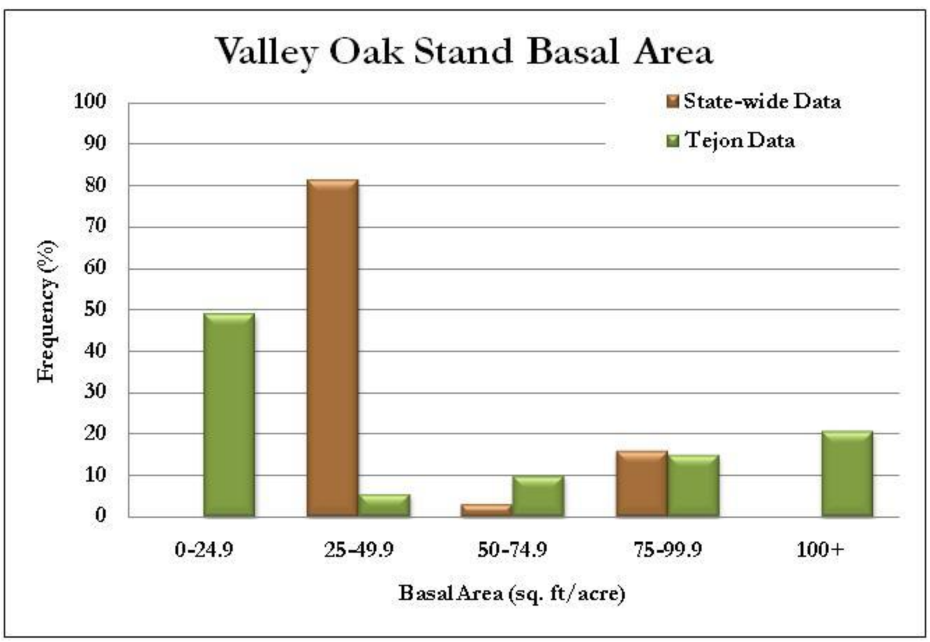


**Figure 2.1 - Comparison of state-wide valley oak stands to stands on Tejon Ranch. Tejon Ranch has greater proportions of plots in both the highest and lowest basal area categories.**

**Table 2.1 - Comparison of Tejon Ranch and statewide valley oak basal area and DBH.**

| valley oak | mean basal area ($m^2$/ha) | DBH |
|---|---|---|
| Statewide (*Allen-Diaz et al.*) | 4-17 | up to 1.2m<br>largest > 2.4m |
| Tejon Ranch | 13.2 (SD=18.3) | up to 2.03m |

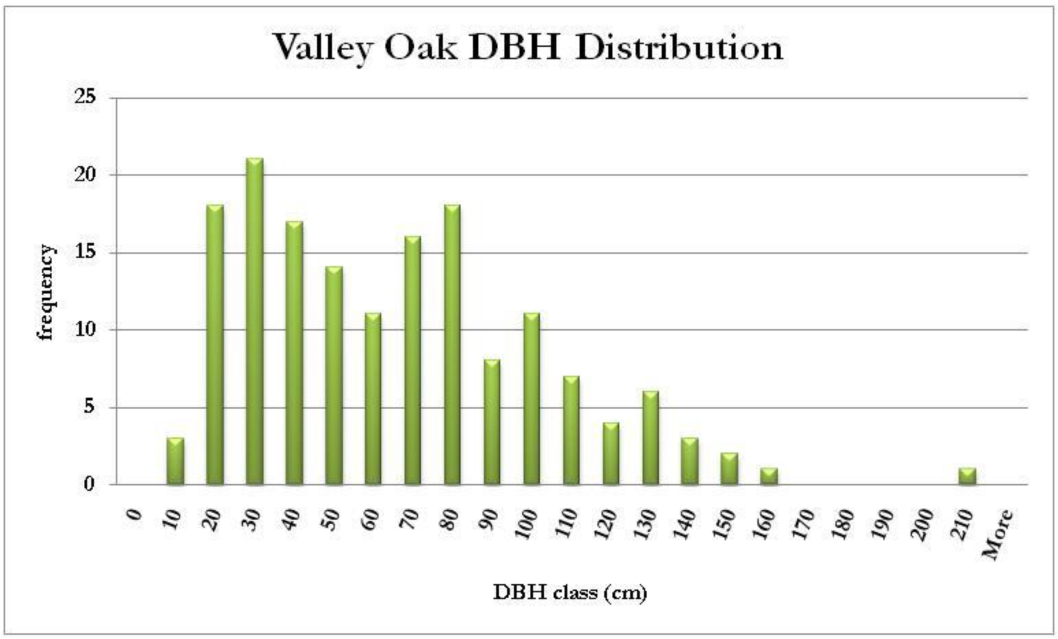


**Figure 2.2 - Histogram showing the distribution of valley oak DBHs on Tejon Ranch. Mean DBH was 60.7 cm with a standard deviation of 36.9 cm.**

### *Black Oak Woodlands*

(Figure 2.3) shows that black oak stands on Tejon Ranch are also relatively well stocked compared to those found in all of California. Fifty-eight percent of the black oak stands at Tejon had basal areas above 100 sq ft/acre whereas only twenty-seven percent of the oaks statewide were in this same category. A significantly larger proportion of black oak trees fall into the largest class of DBH of 29 centimeters or above, suggesting that the ranch's black oaks are relatively large compared to those in all of California. Allen and Diaz report that the largest black oaks in California have DBH of 1.2 meters (Table 2.2), making our largest black oak with a DBH of 1.78 meters unusually large. The three largest black oaks we measured each with DBH above 1.7 meters are outliers, with the smooth distribution ending around 1.2 meters (Figure 2.4). Again only categorical data were available from Allen-Diaz and Bolsinger, making direct comparison of our DBH distribution impossible.

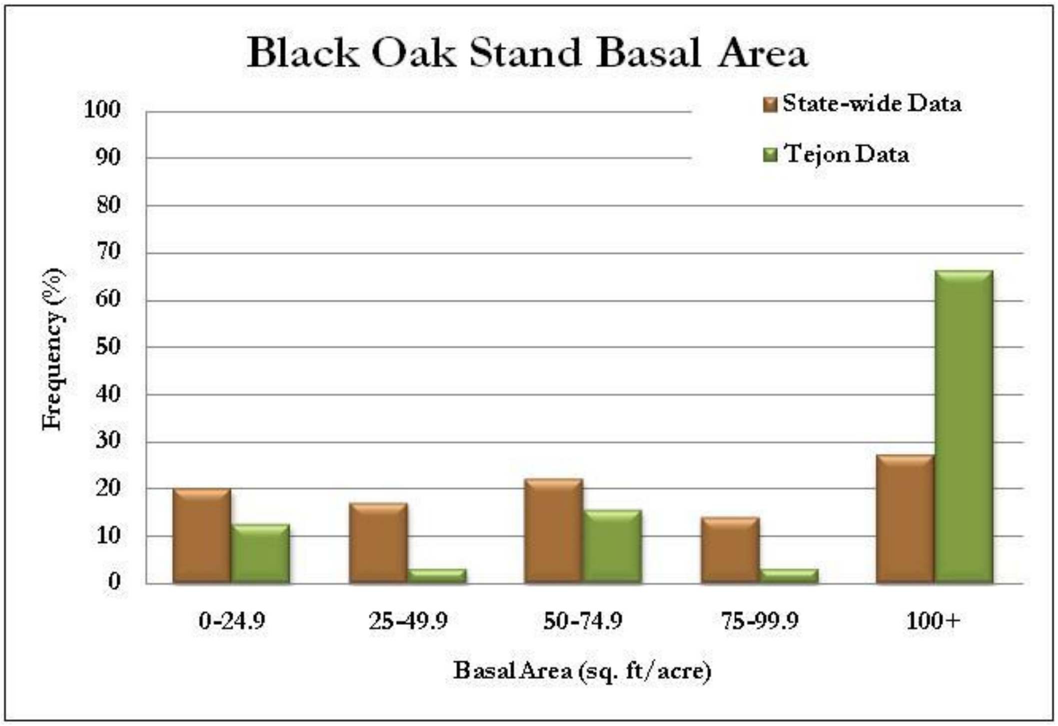


**Figure 2.3 - Comparison of state-wide black oak stands to stands on Tejon Ranch. Black oak stands on Tejon Ranch have higher than average statewide basal area.**

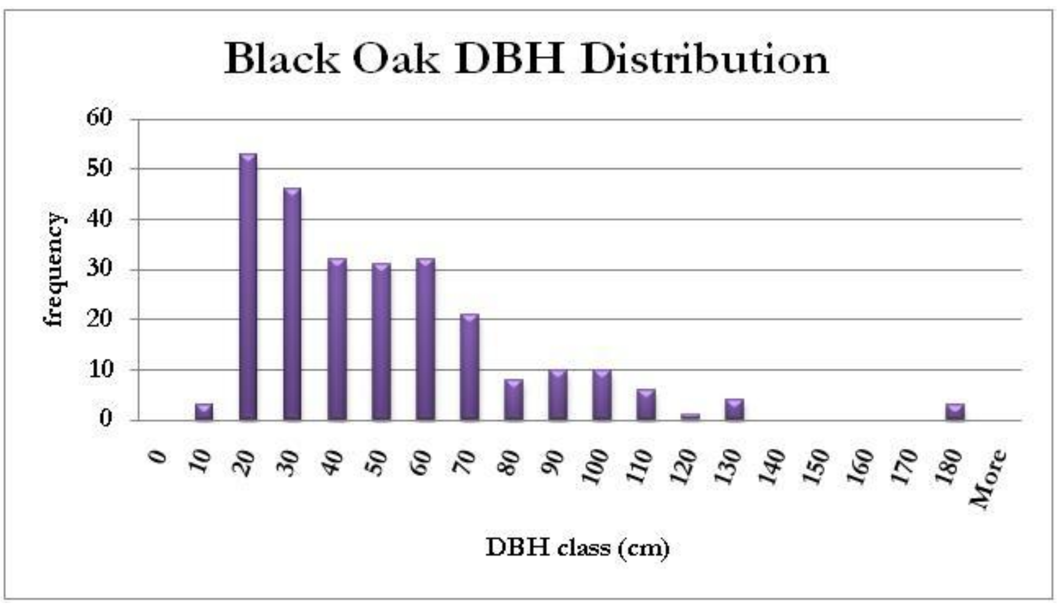


**Figure 2.4 - Histogram showing DBH distribution for black oaks. Mean DBH is 45.7 cm with a standard deviation of 29.9 cm.**

**Table 2.2 - Comparison of Tejon Ranch and statewide black oak basal area and DBH.**

| black oak | mean basal area ($m^2$/ha) | DBH |
|---|---|---|
| Statewide (*Allen-Diaz et al.*) | 11-22 | up to 1.2m |
| Tejon Ranch | 31.6 (SD=19.7) | up to 1.78m |

***Blue Oak Woodlands***

A comparison of blue oak stocking rates on Tejon Ranch and in California also suggests that blue oak on the ranch are slightly better stocked than average across the state (Figure 2.5). Because we did not have access to the original FIA data we could not test the statistical significance of the difference. However a comparison of statewide blue oak DBH with Tejon blue oak DBH strongly suggests that blue oaks on Tejon Ranch are large relative to those in the rest of the state. Allen-Diaz et al. (2007) report that the largest blue oaks in California have DBH of about 1.8 meters while the largest blue oak we measured on the ranch had a DBH of 0.82 meters (Table 2.3). The distribution of blue oak DBH is fairly smooth and the largest blue oak was not a significant outlier (Figure 2.6). Altogether these results suggest that Tejon's blue oaks have roughly average basal area per acre, and are of moderate size compared to blue oaks across California.

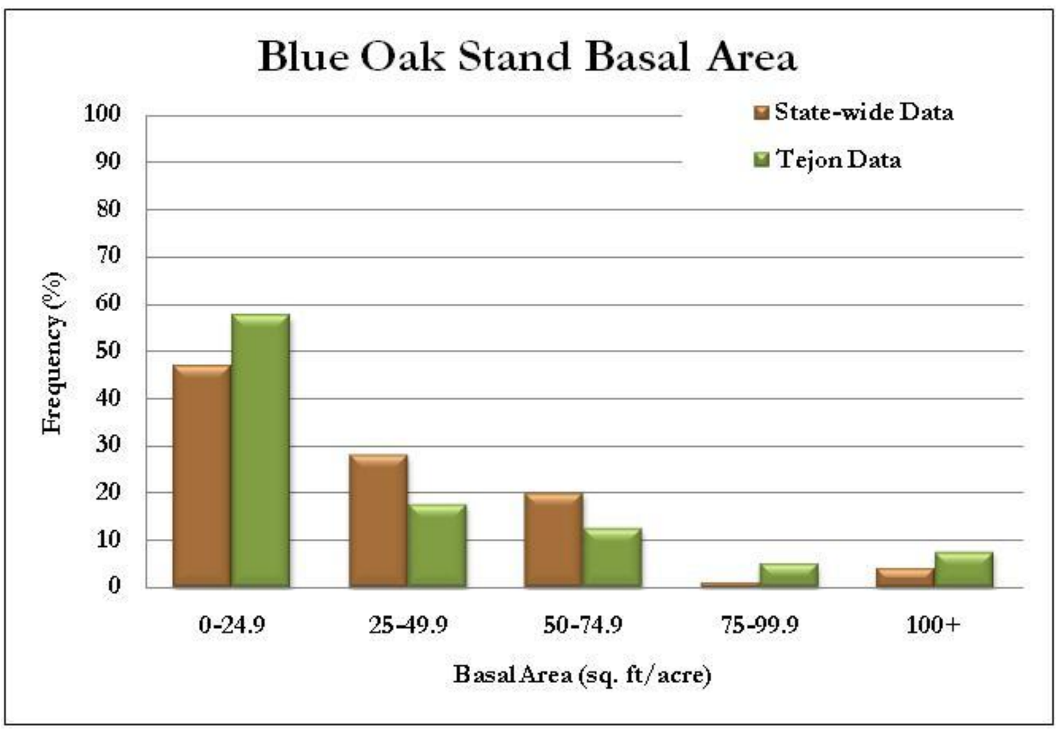


**Figure 2.5 - Comparison of state-wide blue oak stands to stands on Tejon Ranch. Blue oak stands on Tejon Ranch have slightly better than average statewide basal area, however because raw statewide data were not available, we were unable to determine if these differences were statistically significant.**

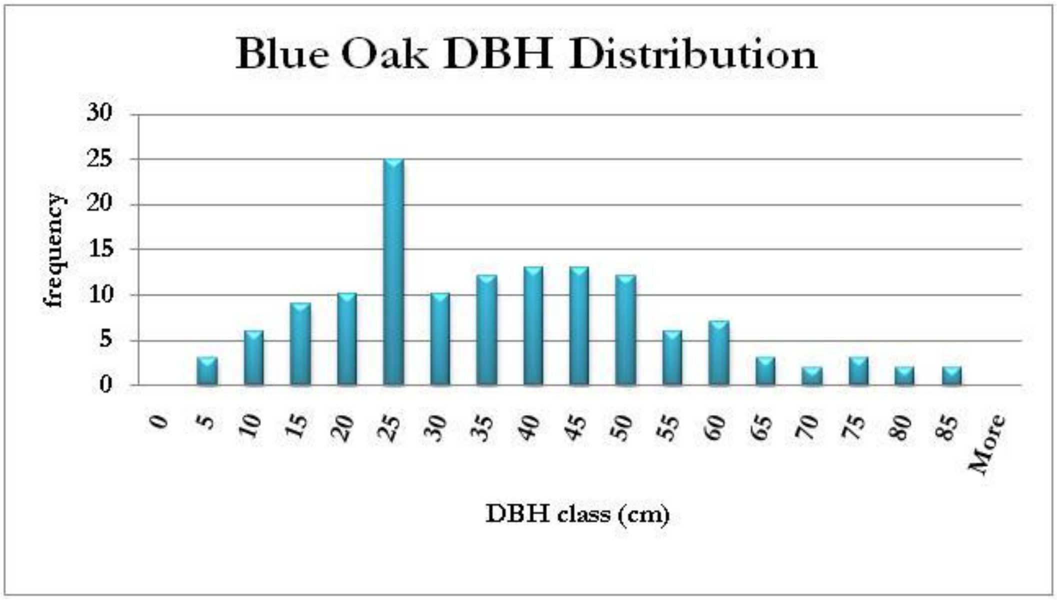


**Figure 2.6 - Histogram showing DBH distribution for blue oaks. Mean DBH is 34.8 cm with a standard deviation of 18.1 cm.**

**Table 2.3 - Comparison of Tejon Ranch and statewide blue oak basal area and DBH.**

| blue oak | mean basal area ($m^2$/ha) | DBH |
|---|---|---|
| Statewide (*Allen-Diaz et al.*) | 6-11 | up to .6m<br>largest > 1.8m |
| Tejon Ranch | 7.2 (SD=9.4) | up to .8m |

In summary Tejon Ranch's blue, valley, and black oak populations are relatively well stocked and relatively large as compared to oaks across the state of California. These trends are especially apparent in the valley and black oak populations. These patterns can likely be explained by the fact that Tejon Ranch has historically been sheltered from the intense development and timber harvest that have reduced oak stocking rates and DBH across the rest of California.

Large oak trees are particularly valuable ecologically as they produce large acorn crops which contribute significantly to oak recruitment and provide a food source for birds, small mammals, and ungulates. Large oaks, especially valley oaks, often have significant standing or fallen dead wood which serves as habitat for cavity nesting birds, reptiles, invertebrates, and small mammals. We recorded DBH for all standing dead snags and found that standing dead wood accounted for 5.8% of all standing wood by volume.

Further comparisons between the oak woodlands of Tejon Ranch and California as a whole can be found in Box 3.1 and Figure III.7.

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## Q3: How are the oak woodlands on Tejon Ranch changing over time, and is there a regeneration problem?

We investigated how Tejon's oak woodlands are changing over time by comparing archived air photos from 1952 with air photos from 2009. We also report data on abundance and location of oak seedlings and saplings across Tejon Ranch.

### Historical Photo Analysis

An historical photo analysis was conducted to quantify the mortality and recruitment of Tejon's oaks from 1952 to 2009. Images from the 1952 aerial flight C-17790 over Kern and Los Angeles counties were obtained from the Map and Imagery Laboratory at the University of California, Santa Barbara. These images are digitally scanned black and white prints whose original scale was 1:31,680. Images from the 2009 USDA National Agriculture Imagery Program (NAIP) were obtained for all of California from a server available through the Environmental Systems Research Institute, Inc. (ESRI) licensed geographic information system (GIS). The 2009 image was an orthro-rectified, digital, color image. Three blue oak, three black oak, and eight valley oak photo stands were surveyed for a total of 14 photo stands. Photo stands were chosen based on a number of factors including how easily individual trees could be distinguished, and how certain we were about which oak species composed stands. Photo stand samples were chosen to be representative of Tejon's oak woodlands as a whole (Figures 3.1 and 3.2).

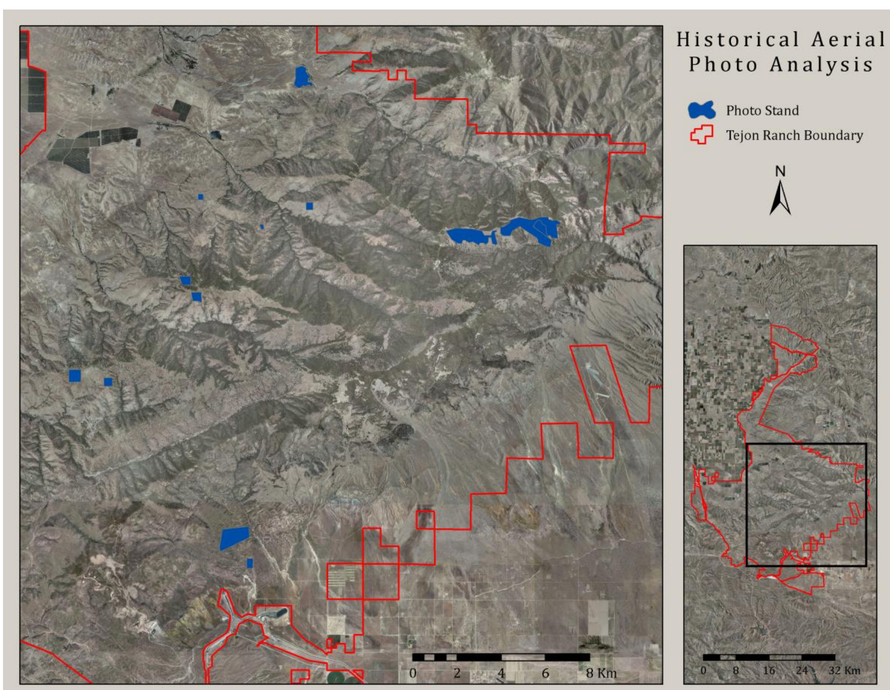



**Figure 3.1 – Overview map of the locations across Tejon Ranch selected for historical photo analyses.**

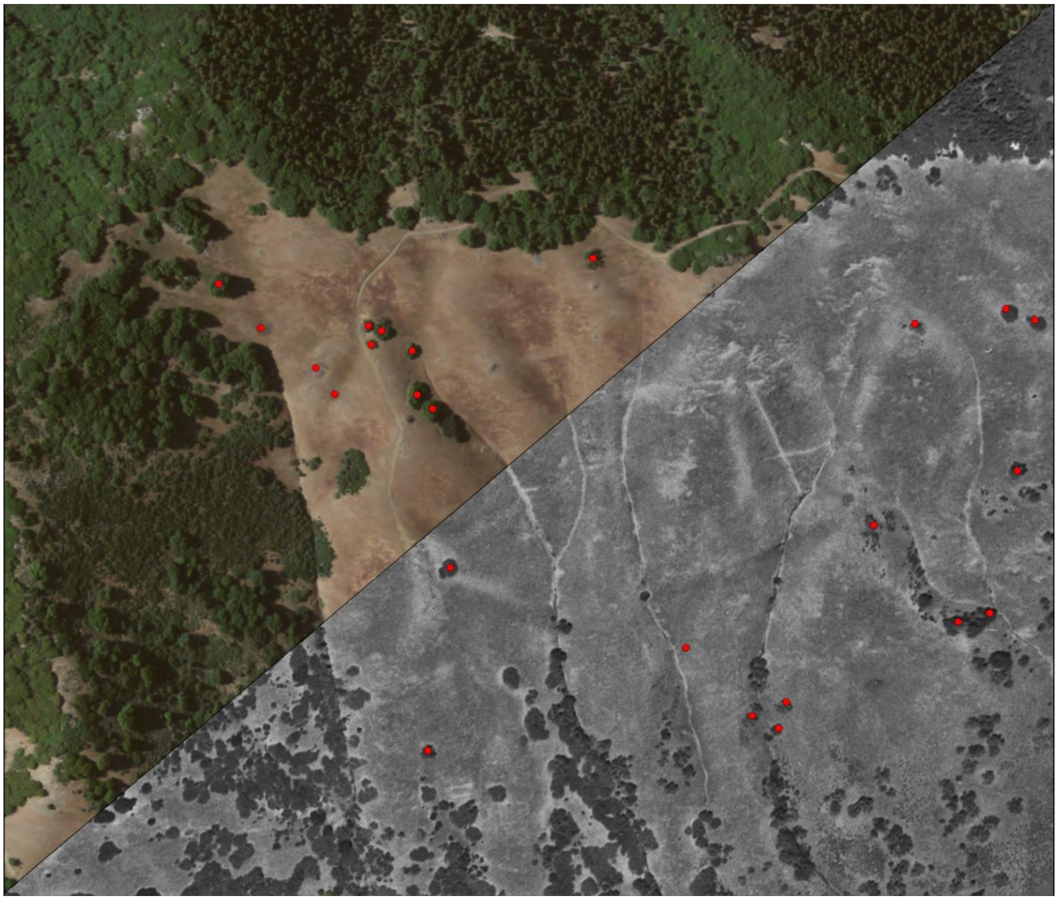


**Figure 3.2 - Close-up image showing an example of the analysis methodology. The upper-left is a current photo, and the lower-right is the historical photo. Red dots indicate trees that were tracked over time.**

### *Methods*

The 1952 and 2009 photos were co registered using the spline and first order polynomial (affine) transformations. To calculate mortality, we marked trees in the 1952 image, then projected those marks over the 2009 image. Marks on the 2009 that did not cover trees were therefore counted as mortality. To calculate recruitment we marked trees in the 2009 image, then projected those marks over the 1952 image. Marks in the 1952 image that did not cover trees were therefore counted as recruitment. With this data we were able to calculate annual recruitment, mortality, and population growth rate. See Appendix II for additional information on how these rates were calculated.

### *Results*

Results from this analysis are summarized in Table 3.1 and Figure 3.3. Mortality rates between 1952 and 2009 were low for Tejon's blue valley and black oaks. Assuming that these oaks have life spans of 200 to 300 years, and that a population has an equal number of individuals in each age class, mortality rates for a stable population should be between 0.5% and 0.3%. The low mortality rates seen in our results may indicate that Tejon's oaks are relatively young; however this appears inconsistent with the fact that oaks on the ranch are relatively large. Recruitment was slightly less than mortality meaning that oak populations on Tejon appear to be in a period of slow decline. Population growth rates even slightly under one can lead to significant population losses over moderate to long time horizons. For example, the blue oak population with a growth rate of 0.998 will suffer a 9.3% loss over 50 years and 18% over 100 years at the current rate. This slow but significant population decline is a serious threat to Tejon Ranch's oak woodlands if current trends continue.

**Table 3.1 - Demographic rates calculated from the historical photo analysis. Population growth rates are slightly less than 1, indicating a very slow population decline for each species. The mortality rates are lower than would be expected given the average lifespan of the species. This could indicate that oak populations on the Ranch are relatively young.**

| ***Species*** | ***N*** | ***Recruitment*** | ***Mortality*** | ***Population Growth Rate*** |
|---|---|---|---|---|
| blue | 366 | 0.023% | 0.197% | 0.998 |
| valley | 1680 | 0.090% | 0.163% | 0.999 |
| black | 634 | 0.063% | 0.162% | 0.999 |
| ***all oaks*** | ***2680*** | ***0.075%*** | ***0.167%*** | ***0.999*** |

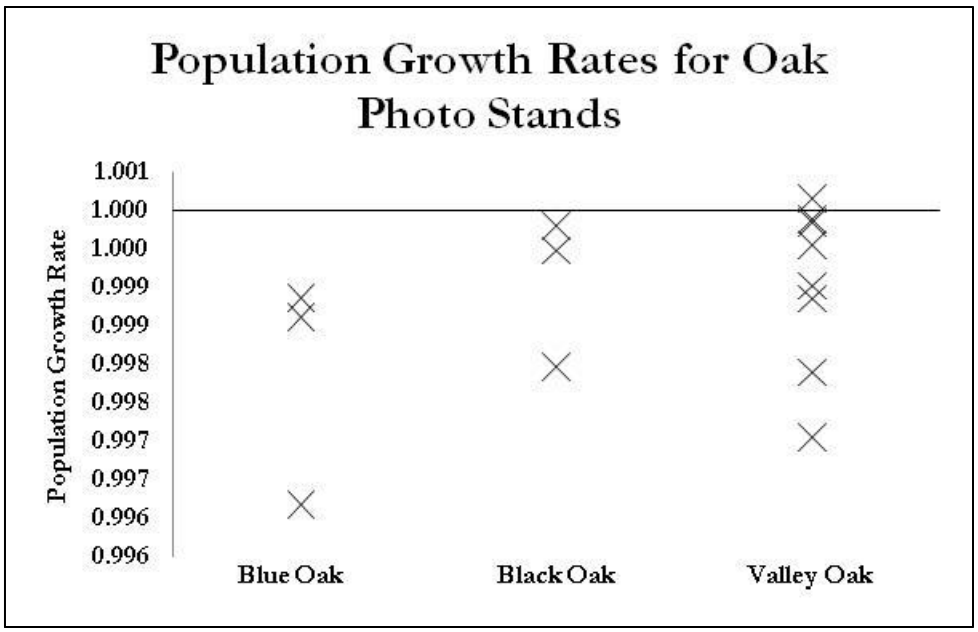



**Figure 3.3 - Scatter plot showing population growth rates for sample photo stands. A solid line is drawn at 1 to highlight which photo stands were found to be increasing in population. While all three species had average population growth rates less than one, only valley oak had any photo stands with population growth rates above one.**

These findings are consistent with those of Applebaum et al. (2010) who found a 1.1% decline in canopy cover in a riparian valley oak stand in the Old Headquarters are of the ranch between 1952 and 2009.

***Sources of Error***

It was only possible to track the history of individual oaks in sparsely distributed stands. In dense stands where canopies overlapped it was not possible to track individual oaks. We found no reason to believe that population growth rates should be different between dense and sparsely distributed oaks, however if oak density does interact with population growth rates, our results are biased and represent only sparsely distributed stands.

It was often not possible to distinguish between blue, valley, and black oaks using only the aerial images. We relied on our plot data and the 1980 timber survey map to identify the oak species present in photo stands. Given that the 1980 timber survey is not 100% accurate, it is likely that not all photo stands were composed entirely of a single species. For example a photo stand identified as containing all blue oaks may have had a few valley oaks or possibly a few non-oak individuals such as buckeye. Given that population growth rates were very similar for all three oak species, we do not believe this was a major source of error.

### NURSE PLANTS PROMOTE VALLEY OAK REGENERATION

During our field survey we observed anecdotal evidence that valley oak regeneration was high in rabbit brush (*Chrysothamnus viscidiflorus*) dominated communities along the Cottonwood drainage. Large numbers of heavily browsed valley oak saplings, around 50 centimeters tall, with multiple relatively thick trunks and branches were visible from access roads. A significant number of small adult trees a few meters in height were also present. We had not observed similar heavily browsed saplings or so many young adult trees anywhere else on Tejon Ranch, and we hypothesized that rabbit brush was serving as a nurse plant for valley oak seedlings, protecting them from browsing, and allowing them to more frequently grow into saplings. It appeared as though sapling shoots that grew beyond the protection of the relatively low rabbit brush were heavily browsed.

Although none of our randomly stratified sampling points fell within this unique rabbit brush-valley oak habitat we randomly chose four plots within this interesting habitat and surveyed them.

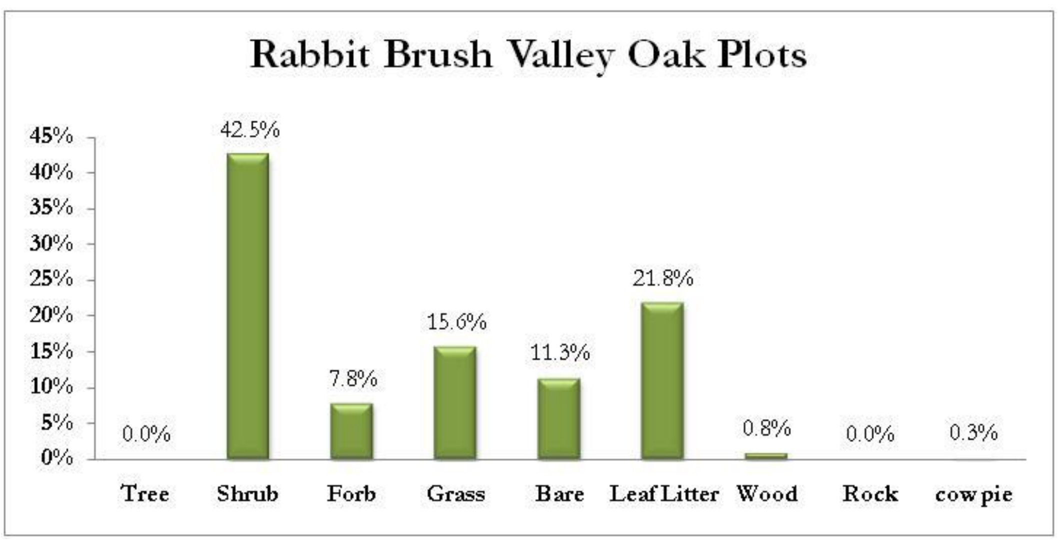



**Figure 3.4- Understory in rabbit brush valley oak plots was dominated by shrub with leaf litter, grass, forb, and bare ground making significant contributions.**

The average shrub cover in the rabbit brush plots was 42.5% (Figure 3.4). The average shrub cover in the original valley oak plots was 9%. A t-test assuming unequal variance found the shrub cover of the rabbit brush plots to be significantly greater than that of the original valley oak plots with a p-value of 0.02.

The rabbit brush plots averaged 3.9 valley oak saplings per plot or 64.6 saplings per hectare, while our other valley oak plots averaged 0.28 saplings per plot or 4.6 saplings per hectare. We surveyed 47 valley oak plots as part of our original sampling scheme, and only four rabbit brush plots. A t-test assuming unequal variance found that the mean sapling density of the rabbit brush plots was indeed greater than that of the original valley oak plots with a p-value of 0.046. This relatively weak statistical evidence is mostly due to the comparatively low sample size of the rabbit brush plots. Based on anecdotal observations of the rabbit brush habitat we believe that it has significantly greater relative sapling density than other valley oak habitat.

We found 3.3 seedlings per valley oak plot in the original plots, while there were 7.8 seedlings per plot in the rabbit brush plots. A t-test assuming unequal variances did not find a significant difference in the mean seedlings per plot between the original valley oak plots and the rabbit brush plots. The p-value of this t-test was 0.44.

Later we identified another area on Tunis Ridge with a rabbit brush dominated understory and similar heavily grazed valley oak saplings along with small adult valley oaks, however there was not time to survey this area.

These nurse plant dominated habitats are important for managers as valley oak recruitment could potentially be boosted significantly in these areas with minimal management effort as the shrub understory has already done the difficult work of transitioning seedlings to saplings. If our hypothesis is correct, simply protecting saplings in these areas for long enough to allow them to exit the browse layer could yield large numbers of new adult valley oaks.

### NUMBERS OF SEEDLINGS AND SAPLINGS

While it is not possible to make conclusions about recruitment rates from seedling and sapling densities alone, we report this data here for future comparisons.

**Table 3.2 - Density of oak seedlings within blue, black, and valley oak woodlands. Blue oak woodlands have only blue oak seedlings, black oak woodlands contain both black and valley oak seedlings, and valley oak woodlands contain both black and valley oak seedlings.**

| | blue oak seedling/ha | black oak seedling/ha | valley oak seedling/ha |
|---|---|---|---|
| blue oak woodlands | 3.5 | 0 | 0 |
| black oak woodlands | 0 | 100.6 | 7.8 |
| valley oak woodlands | 0 | 1.4 | 49.7 |

**Table 3.3 - Density of oak saplings within blue, black, and valley oak woodlands. Blue oak woodlands have only blue oak saplings, black oak woodlands have black and valley oak saplings, valley oak woodlands have only valley oak saplings.**

| | blue oak saplings/ha | black oak saplings/ha | valley oak saplings/ha |
|---|---|---|---|
| blue oak woodlands | 7.6 | 0 | 0 |
| black oak woodlands | 0.06 | 8.9 | 0.6 |
| valley oak woodlands | 0 | 0 | 4.3 |

**Table 3.4 - Density of adult trees in blue valley and blak oak woodlands. Blue oak woodlands had both blue and valley oak, valley oak woodlands had blue, black, and valley oaks, black oak woodlands had both black and valley oaks.**

| | blue oaks/ha | valley oaks/ha | black oaks/ha |
|---|---|---|---|
| blue oak woodlands | 57.1 | 0.83 | 0 |
| valley oak woodlands | 0.25 | 30.57 | 2.7 |
| black oak woodlands | 0 | 2.08 | 129.69 |

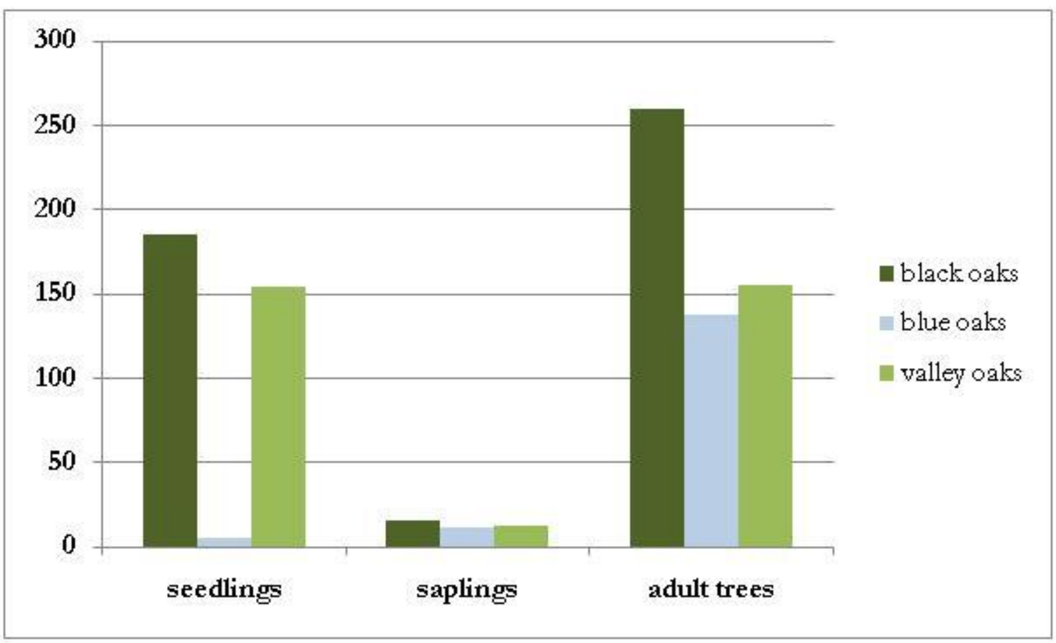
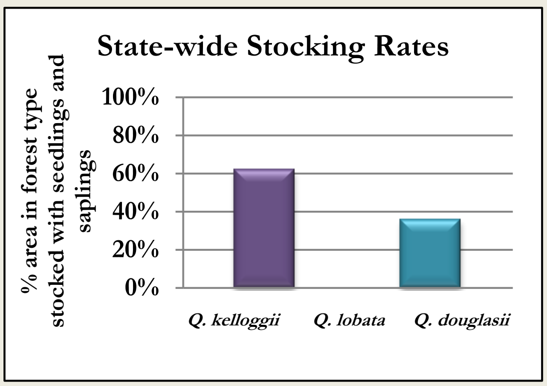



**Figure 3.5 - Number of seedlings, saplings, and adult trees for blue, black, and valley oaks.**

**Box 3.1 - Comparison of stocking rates for oak seedlings and saplings between Tejon Ranch and the rest of California.**

Relative stocking rates for blue, black, and valley oak seedlings and saplings were analyzed for plots on Tejon Ranch and were compared to data from the 1988 Califonia-wide study of hardwood rangelands done by Charles Bolsinger (1988). Relative stocking rates for Tejon Ranch were calculated as mean basal area ($cm^2$/plot) of seedlings and saplings as indicated from the 2010 Group Project field data. The Bolsinger study reported data as a percentage of are in each forest type (blue, black, or valley oaks) stocked with seedlings and saplings. These two data sets are unfortunately not directly comparable due to their differences in data reporting. However, the relative rank of each species compared to the others can be established for each study site. As seen below in Figure 3.6, valley oak seedlings and saplings are significantly more present on Tejon Ranch than they are in the rest of the state. This is likely due to the fact that valley oak are commonly associated with heavily grazed rangelands thus exposing seedlings and saplings to intense browsing pressures from cattle. On Tejon Ranch, there are valley oak populations that are found in areas outside of the traditional heavily grazed lowlands. These regions are still grazed, but the presence of varied topography and a more diverse understory may aid in acorn and seedling establishment and may provide reduced browsing pressures than are typically found in valley oak habitats in the rest of the state.



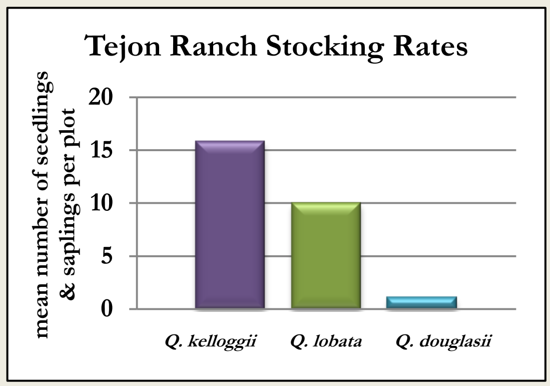




**Figure 3.6 – Relative stocking rates for seedlings and saplings state-wide and on Tejon Ranch.**

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# Q4: How do we expect the oak woodlands of Tejon Ranch to be impacted by climate change?

### Significance of climate change for oak species

Climate change is a prominent issue in today's discussions of conservation biology and environmental management, and the Tejon Ranch Conservancy is particularly interested in how climate change might affect hardwood rangelands on the Ranch. Species range shifts due to climate change are commonly attributed to temperature warming, and resulting uphill shifts in distribution have been well documented (Moritz et al. 2008, Walther et al. 2002). However, Crimmins et al. (2011) showed an overall downhill trend in oak species range shifts in California over the past 80 years. Recent climate change in California has led to both warmer and wetter conditions, and it appears that changes in climatic water balance may be more important to most oak species than changes in temperature. This study by Crimmins et al. also demonstrates the ability of oaks to track climate change on relatively short time frames (<50 years). Temperatures in California are expected to continue to increase over the next century, although models differ in their predictions for trends in climatic water balance (Cayan et al. 2008). Previous modeling studies have shown that statewide, climate related habitat loss could to be as high as 59% for blue oaks and 54% for valley oaks (Kueppers et al. 2005). Given these state-wide predictions for climate related habitat loss, as well as the demonstrated ability of oak species to track these relatively rapid changes, we wanted to model the potential shifts in climatically suitable habitat for blue, black, and valley oaks on Tejon Ranch over the next 50 and 100 years.

### Species-climate Forecasting

To address the issue of climate change and how it relates to the oak resources on the Ranch, we employed Maximum Entropy (MaxEnt) models to analyze our field data and generate maps showing current and future climatic suitability for blue, black, and valley oaks. MaxEnt (Phillips et al. 2006) is a climate suitability model that is commonly used to map and predict potential distribution of species over space and time. It is a well established method and has been extensively used in many aspects of conservation science (Elith et al. 2006). Generally speaking, MaxEnt uses species observations and current spatial climate data to tease out the relationships between species presence and environmental predictors. MaxEnt can then apply the species' climate space to downscaled maps of modeled future climate to yield an output of predicted future climatic suitability. These predicted species distributions however are solely based on climate space; they do not account for species dispersal, inter-specific competition, changes in community assemblages, niche elasticity, or evolution. (For more on MaxEnt, species distribution models, and detailed methods, see Appendix III).

MaxEnt was used to make future climatic suitability predictions based on a moderate-high (A2) carbon emission scenario and two general circulation models (GCMs): the NCAR Parallel Climate Model (PCM), and the NOAA Geophysical Fluid Dynamics Laboratory CM2.1 Model (GFDL). The A2 emissions scenario, developed by the Intergovernmental Panel on Climate Change, assumes a continued increase in $CO_2$ emissions from current levels (390 ppm) to 3x pre-industrial levels (840 ppm) by the end of the 21st century (Flint & Flint 2010, Nakic'enovic et al. 2000). Of the GCMs, PCM predicts a warmer wetter climate (2.5° C increase in mean annual temperature, +8% change in annual precipitation), and GFDL predicts a warmer drier climate (4.4° C increase in mean annual temperature, -26% change in annual precipitation) for California by the end of the century (Cayan et al. 2008). These two climate models were used for the California State Climate Assessment and they do well at bounding the potential climatic changes the region is likely to experience over the next century.

Many tree species in California have wide ranges and high genetic diversity (Buck et al. 1970). Studies on the genetic associations of oaks with regional climate gradients have shown that responses to climate change can vary greatly across the species' range (Sork et al. 2010). Because of this population scale individualistic response to climate change, we based our models only on oak occurrence data from the Tehachapi Mountains, and not from the entire range of the species. (More information on the differences between local and regional species distribution modeling can be found in Appendix III).

For this analysis, data points from our field study were augmented by oak occurrences from other data sets to yield 51 blue oak, 32 black oak, and 90 valley oak unique occurrences across and around Tejon Ranch. Environmental data downscaled to a grid cell size of 90m (see Box 4.1 on data resolution) were derived from North American climate data sets for current, mid-century (30 year average centered on 2055), and end of century (30 year average centered on 2085) (Flint & Flint 2010). Eleven environmental predictors thought to be important to the distribution of oaks on Tejon Ranch were initially selected to model species distributions, although after preliminary model test runs and analysis of correlation matrices these were reduced to the 4 most influential variables (Table 4.1). These environmental predictors were paired with the oak occurrence data to generate climate space outputs for blue, black, and valley oaks.

**Table 4.1 - Selection of environmental predictors. Results from the initial runs of MaxEnt showed all four soil variables to contribute <1% to the model. Also, the correlation matrix showed maxtemp, tseas, mtdq, and gdd5 to be highly correlated. We eliminated unnecessary variables and performed the final analyses with the final set of environmental predictors.**

| ***Original Set of Environmental Predictors*** | | ***Final Set of Environmental Predictors*** | |
|---|---|---|---|
| Minimum temperature | (mintemp) | Minimum temperature | (mintemp) |
| Maximum temperature | (maxtemp) | — | — |
| Temperature seasonality | (tseas) | — | — |
| Aridity index | (arid) | Aridity index | (arid) |
| Maximum temp. of driest quarter | (mtdq) | — | — |
| Mean annual precipitation | (mppt) | Mean annual precipitation | (mppt) |
| Growing degree days > 5° C | (gdd5) | Growing degre days > 5° C | (gdd5) |
| Available soil water holding capacity | (awc) | — | — |
| Soil pH | (ph) | — | — |
| Soil particle size < 40mm | (seive40) | — | — |
| Soil particle size < 4mm | (seive4) | — | — |

Summary statistics (cross-validated AUC scores) indicate that MaxEnt accurately modeled the local relationships between species occurrence and climate gradients for all three oak species. The model for black oak was the strongest (AUC = 0.96), followed by valley oak (AUC = 0.87), and then blue oak (AUC = 0.83). Cross-validated AUC scores greater than 0.8 generally indicate an acceptable model. (More information on AUC scores can be found in Appendix III).

**Box 4.1 - Effects of data resolution on predictive modeling of species distribution for oaks on Tejon Ranch.**

Spatial congruence (Dice-Sorensen) = ________

| | | Finer Resolution + | Finer Resolution - |
|---|---|---|---|
| **Coarser Resolution** | + | a | b |
| | - | c | d |

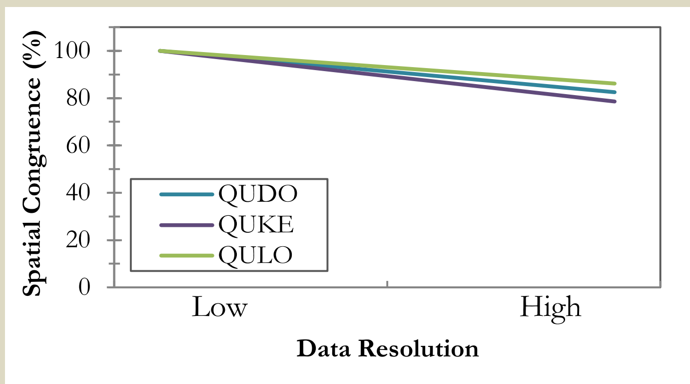


**Figure 4.1 - Spatial congruence of MaxEnt climatic suitability models between two input data spatial resolutions. (Left = 90m, Right = 270m)**

A comparative analysis of climatic suitability modeling using climate data resolved at two different levels showed an overall difference in spatial congruence of less than 20% (Figure 4.1). QUKE demonstrated the largest difference in spatial congruence between the 90m climate data models and the 270m climate data models (QULO = 78.60), and QULO demonstrated the narrowest divergence (QULO = 86.22). This analysis doesn't indicate that there is enough of a change in spatial distribution between the two data resolutions to warrant further modeling and sensitivity analyses. We therefore chose to use the highest-resolved data (90m) for all of our analyses, as this data is most likely to capture the environmental and climatic elements that are most significant predictors of biological habitat suitability.

The results from this analysis show a general decline in climatic suitability for oaks on Tejon Ranch between now and mid-century, and further reductions by the end of the century (Table 4.2). The overall trend is movement upslope and toward north-facing aspects. These results hold true with both GCMs and for all species. Of the three species modeled, blue oaks showed the most significant loss of climatically suitable habitat (Figure 4.2). By mid-century, blue oaks are predicted to lose between 70-80% of their range on the Ranch. The percentage of stable range for the species is predicted to be between 10-16%. By the end of the century, this figure may decrease to less than 2%. These results are more dramatic than those found by (Kueppers et al.

2005), and may warrant a heightened awareness from land managers as to the year to year and long-term viability and persistence of blue oak populations on the Ranch.

**Table 4.2 - Blue, black, and valley oak responses to climate change.**

| | **blue oak** | | | |
|---|---|---|---|---|
| | *suitable acres* | *% of ranch* | *% net change* | *% stable range* |
| current | 154,811 | 57% | — | — |
| GFDL mid-century | 31,120 | 11% | -80% | 10% |
| PCM mid-century | 44,300 | 16% | -71% | 16% |
| GFDL end of century | 12,646 | 5% | -92% | 0.6% |
| PCM end of century | 10,923 | 4% | -93% | 1.4% |
| | **black oak** | | | |
| | *suitable acres* | *% of ranch* | *% net change* | *% stable range* |
| current | 54,359 | 20% | — | — |
| GFDL mid-century | 11,733 | 4% | -78% | 22% |
| PCM mid-century | 20,948 | 8% | -61% | 38% |
| GFDL end of century | 134 | 0% | -100% | 0.2% |
| PCM end of century | 5,572 | 2% | -90% | 10.2% |
| | **valley oak** | | | |
| | *suitable acres* | *% of ranch* | *% net change* | *% stable range* |
| current | 106,449 | 39% | — | — |
| GFDL mid-century | 47,126 | 17% | -56% | 38% |
| PCM mid-century | 85,853 | 31% | -19% | 74% |
| GFDL end of century | 6,207 | 2.3% | -94% | 3.1% |
| PCM end of century | 23,255 | 8.5% | -78% | 18% |

Similar results were found for black and valley oak (Figures 4.3 and 4.4), but nothing as dramatic as the blue oak statistics. Stable range by mid-century is predicted to be between 22-38% for black oaks, and between 38-74% for valley oaks. Contrary to the (Kueppers et al. 2005) study, climatic suitability, and thus predicted distribution, is expected to remain relatively stable for valley oaks on Tejon Ranch.

Due to the inherent uncertainties in the GCMs and the downscaled climate data, there is significant uncertainty in our model outputs as to where and at what magnitude these range shifts

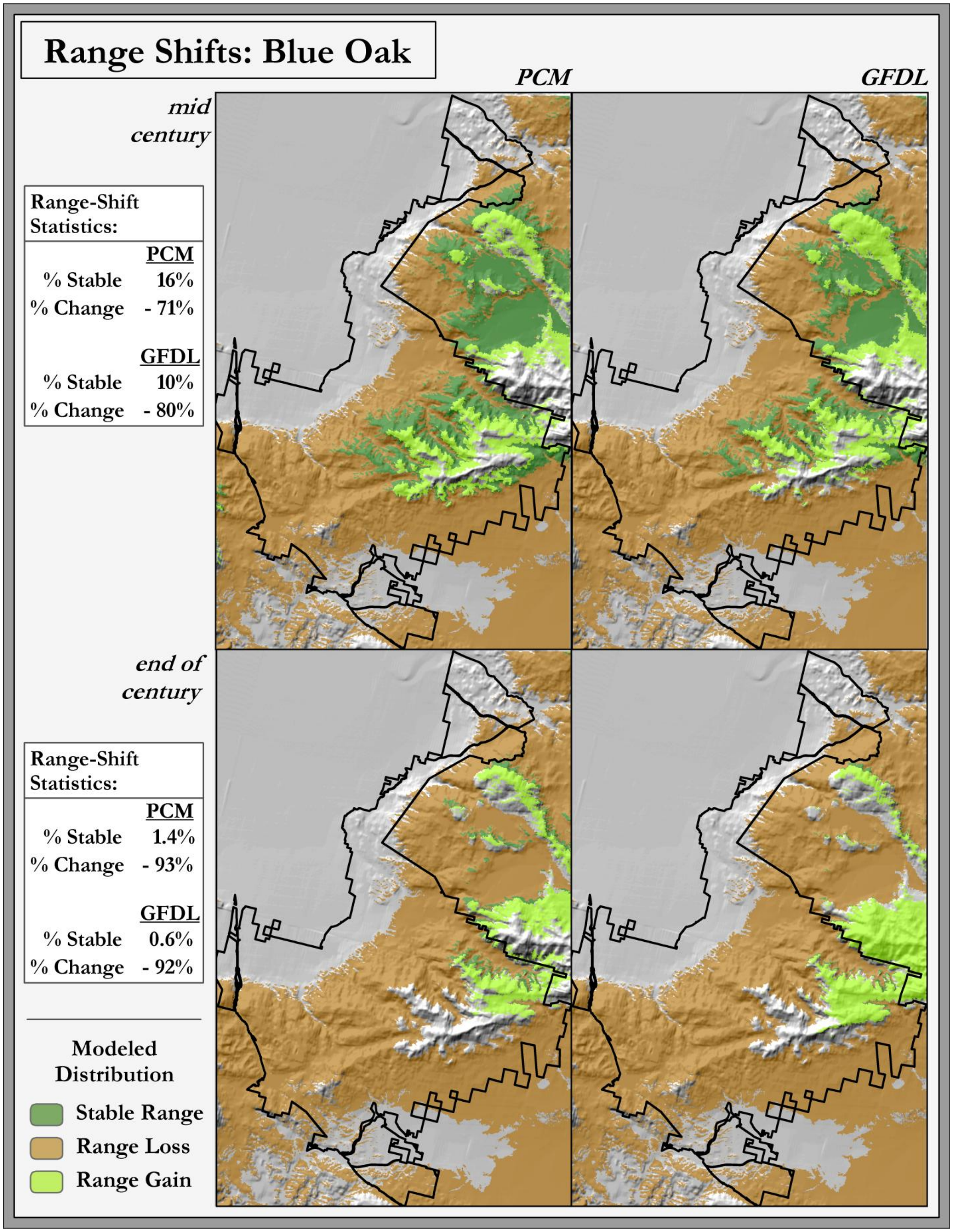


**Figure 4.2 - Predicted range shifts for blue oak due to future climate change. This figure shows four climate suitability modeling results (MaxEnt): mid-century and end of century, for both PCM and GFDL general circulation models. Maps depict current distribution of climatic suitability, future distribution of climatic suitability, and distribution overlap. Also depicted are calculated statistics for range shifts (% stable range and % change in range).**

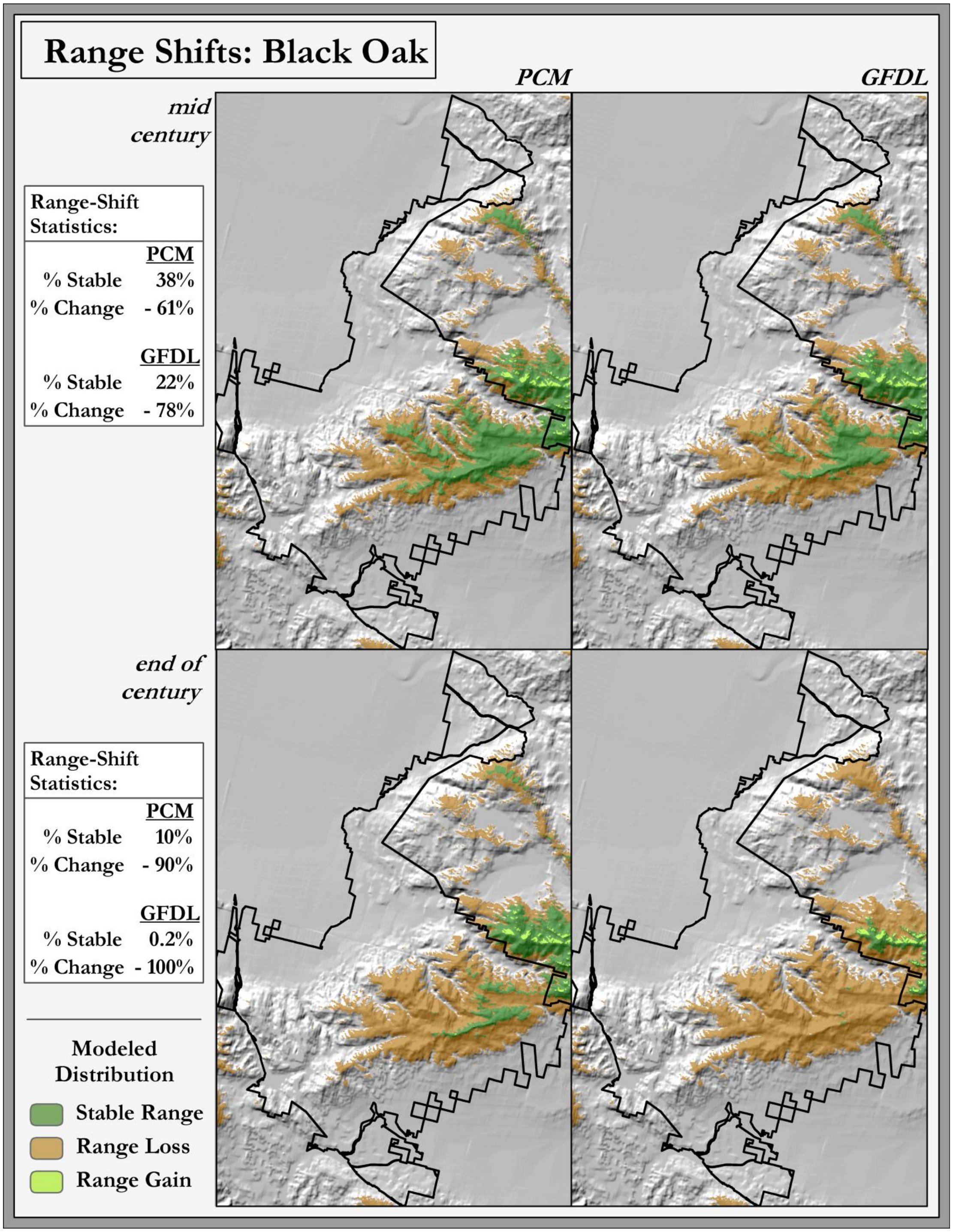


**Figure 4.3 - Predicted range shifts for black oak due to future climate change. This figure shows four climate suitability modeling results (MaxEnt): mid-century and end of century, for both PCM and GFDL general circulation models. Maps depict current distribution of climatic suitability, future distribution of climatic suitability, and distribution overlap. Also depicted are calculated statistics for range shifts (% stable range and % change in range).**

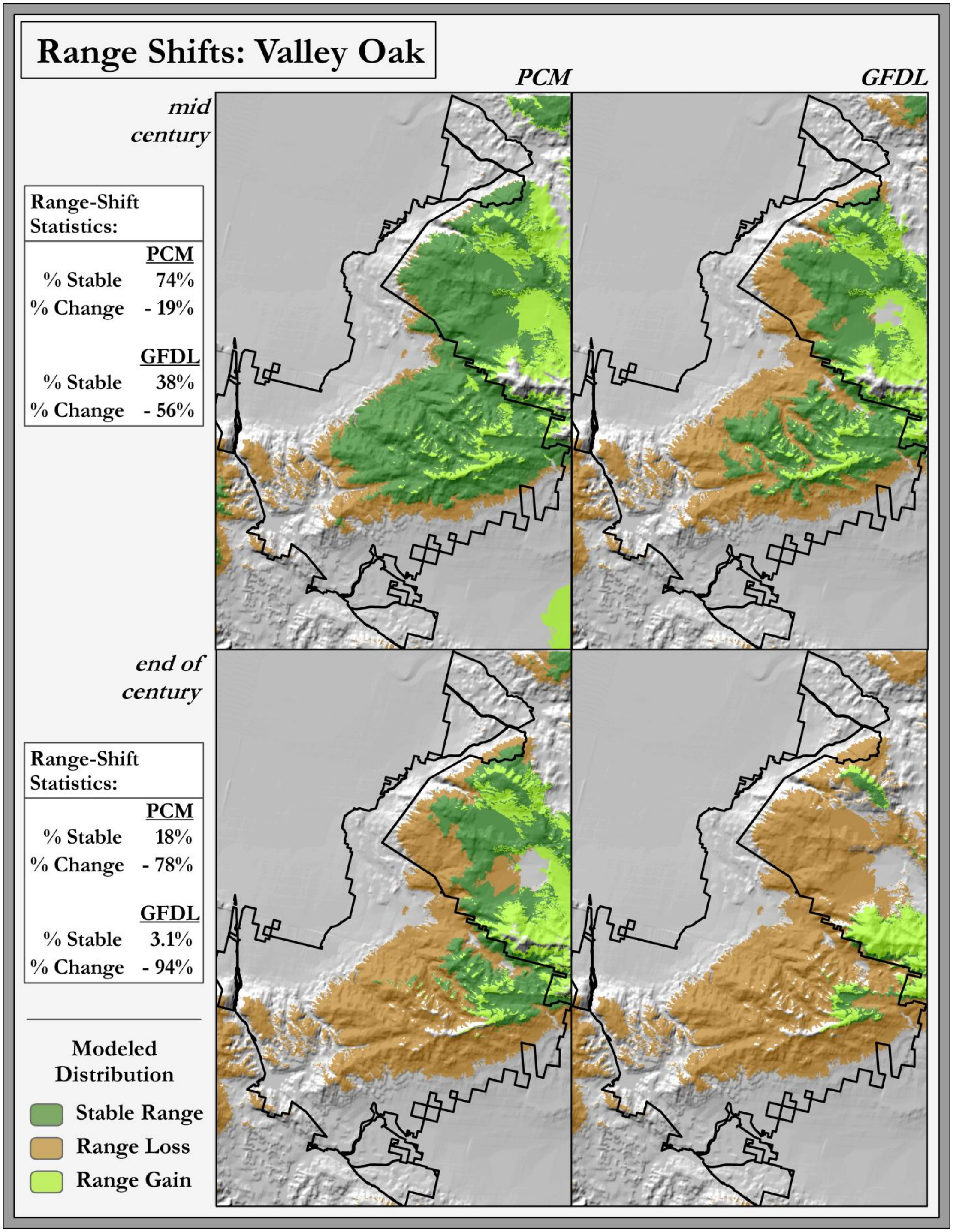


**Figure 4.4 - Predicted range shifts for valley oak due to future climate change. This figure shows four climate suitability modeling results (MaxEnt): mid-century and end of century, for both PCM and GFDL general circulation models. Maps depict current distribution of climatic suitability, future distribution of climatic suitability, and distribution overlap. Also depicted are calculated statistics for range shifts (% stable range and % change in range).**

will occur. The general trend remains though, showing a decline in climatic suitability over the next century for oaks on Tejon Ranch. Fortunately, the presence of varied topography on Tejon may provide refugia for species undergoing shifting climatic suitability. This topography – e.g. deep canyons and broad ranges of elevations and aspects – may help buffer oak species on the Ranch from severe habitat loss due to climate change. Such refugia effects can be seen in Figures 4.2 - 4.4, as well as Figures III.2 - III.4 in Appendix III, where areas of suitable climate are reduced to localized pockets of microclimates and micro-topography.

These models imply replacement of one oak dominant on the Ranch by others. This is particularly true for black oak - by mid-century most of the current climatically suitable habitat for black oak will become habitat predicted to be climatically suitable for both valley and blue oaks. Table 4.3 summarizes these replacement statistics. By the end of the century, much of the current climatically suitable oak habitat becomes unsuitable for any of the three oak species assessed in this analysis. Other modeling studies suggest that grassland communities are likely to replace oak woodlands as they become displaced by climate change (Lenihan et al. 2007, Hayhoe et al. 2004). Using the same GCMs and emissions scenarios as this study, Lenihan et al. (2007) report an average loss of woodlands of 29% across the state by the end of the 21st century, and an average gain in grasslands of 68%. This replacement of woodlands by grasslands is accentuated by climate change related alterations in fire regimes are taken into account.

**Table 4.3 - Predicted replacement of current oak dominants by future oak dominants. Calculations are for climatic suitability modeled for each species over two time frames and two GCMs. (Oak species in the columns are predicted to replace those in the rows).**

| | | dominant oak replacement: mid-century | | | dominant oak replacement: end of century | | |
|---|---|---|---|---|---|---|---|
| | | blue oak | black oak | valley oak | blue oak | black oak | valley oak |
| blue oak | *GFDL* | — | — | 4.8% | — | — | — |
| | *PCM* | — | — | 24.5% | — | — | 4.1% |
| black oak | *GFDL* | 48.9% | — | 66.3% | 22.7% | — | 11.1% |
| | *PCM* | 70.0% | — | 94.7% | 15.0% | — | 29.2% |
| valley oak | *GFDL* | 3.0% | — | — | 5.4% | — | — |
| | *PCM* | — | — | — | 0.1% | 0.1% | — |

Again, our analysis shows that there may be significant range-shifts for oak species on Tejon Ranch by mid-century. Climate change is predicted to be a driving force in the future distribution of oak resources across the Ranch. However, Tejon's land managers can use these results to identify species and landscapes that are in critical need of attention and future management. These results can help the Conservancy prioritize their management actions to those relevant for the future. Additionally, this analysis helps to inform Tejon's land managers on what to expect and what to prepare for within a reasonable planning horizon.

# Q5: How are current land management practices affecting Tejon's oak woodlands?

Our research identified population decline and climate change as serious threats facing blue, valley, and black oak woodlands on Tejon Ranch. For the Conservancy to sustainably manage these oak woodlands, staff must understand what options are available to influence oak woodland structure and function, and what ecological outcomes might result from different management.

Characterizing the relationships between specific management regimes and oak woodland structure and function was beyond the scope of this project, and would ideally be accomplished through adaptive management trials on Tejon Ranch. However, current scientific knowledge about the ecology of oak woodlands provides a fair amount of guidance regarding management of hunting, grazing, fire, and active oak restoration.

## Hunting

Deer, elk, feral pigs, bear, bobcat, pronghorn, turkey, ground squirrels and upland game birds such as quail are all hunted on the ranch. Deer and elk are known to browse oak seedlings and saplings, as well as eat acorns. Pigs, ground squirrels, and game foul are known to eat acorns, and pigs can severely damage oak woodland understories by overturning the soil with their tusks usually in search of acorns. (Appelbaum et al. 2010). Managers can influence the interactions between game species and oak woodlands by influencing the population sizes of hunted species.

## Grazing

Cattle grazing is practiced on 90% of the ranch and influences oak woodlands in two ways: 1) direct browsing of oak seedlings, saplings and trees and 2) browsing of oak understory grasses, forbs and shrubs (Tejon Ranch Company & Tejon Ranch Conservancy 2009). Both of these impact oak woodland condition, demography, composition and structure. Grazing can negatively and positively influence oak woodlands and the degree of impact depends on the grazing seasonality, duration, and stocking density as well as the forage productivity.

Grazing negatively impacts oak regeneration through acorn consumption and can impede oak recruitment through soil compaction (Swiecki & Bernhardt 1998, Barbour et al. 2007, Trimble & Mendel 1995). Reduced sapling recruitment can be attributed to intense browsing (Swiecki et al. 1993). Research by Hall et al. (Hall et al. 1992) showed that blue oak seedlings had the lowest survivorship when heavy grazing occurred during the spring and summer seasons.

Grazing can positively impact oak regeneration by controlling annual grasses and other herbaceous plants (Hall et al. 1992, Tyler et al. 2008) that compete with seedlings for soil moisture. Barbour et al. (Barbour et al. 2007) observed that the mortality of valley oak saplings appears to be related to the competition from annual grasses. Tyler et al. (Tyler et al. 2008) concluded that low to moderate grazing had little to no effect on oak regeneration and that grazing had a slight positive effect on seedling survival in grazed pastures when seedlings were protected.

Grazing can have a number of effects on oak woodland soils but the most common are soil compaction and reduced infiltration. Soil compaction reduces infiltration (Ferrero 1991), making it more difficult for seedlings to establish and roots to access water (Trimble & Mendel 1995); (Clary & Kinney 2002). Dahlgren et al. (1997) conclude that it can take decades for the soil bulk density to return to normal after being heavily grazed.

In the absence of cattle, cover and biomass of annual grasses increases dramatically (F. Davis personal communication) and the removal of cattle in many cases has not improved oak recruitment (Callaway 1992b, White 1966).

Although the difference was not significant, a study by Purcell & Verner (2000) found more nesting birds in non-grazed plots than in grazed plots. However, it was noted that the biggest difference between the grazed and non-grazed plots was the proportion of shrub cover, which is important habitat for many bird species. In regards to invasive bird species, there were more starlings in the grazed sites and the authors noted the importance and lack of data on the cowbird species in oak woodland communities (Purcell & Verner 2000). Also, fewer insect families have been found in moderately grazed sites than in low to non-grazed plots (Allen-Diaz 2000). Since grazing reduces understory cover, grazing can indirectly reduce seedling herbivory from small mammals that prefer high herbaceous cover.

In blue oak woodlands grazing is thought to increase the presence of exotic understory plants but also increase understory species richness (Keeley 2002). Further, Keeley et al. (2003) suggest that removing grazing will not reduce exotic understory species.

Most of the literature agrees that intense grazing can severely impede oak regeneration and recruitment while low to moderate grazing may be beneficial. However, many grazed landscapes are above their cattle carrying capacity (McDougald et al. 2000) and therefore precaution should be taken when managing grazing on oak woodlands. Although the literature is generally in agreement, the interaction between grazing and its impact on oaks is highly dependent upon the type of oak community, and the season, duration, intensity and rotational pattern of livestock grazing.

## FIRE

Fire has historically been a large regulating force on the environment of Southern California (Stephens et al. 2007). Ignitions from lightning strikes as well as from Native American landscape management have dominated the landscape and played a large role in shaping the environment that is currently present (Stephens et al. 2007). The effects of fire on oak communities is still a topic of much debate with some research finding a large effect on mortality, growth and recruitment while other findings show the contrary. The effect of fire on oaks is dependent on the type of oak. Below are descriptions of how blue, valley, and black oaks respond to fire.

Blue oak seedlings that survive the initial stress of the fire are negatively affected due to retarded growth (Swiecki & Bernhardt 2002). Fire does not generate re-growth or stimulate sprouting in these oaks (Swiecki & Bernhardt 2002), and the impact of fire on seedling recruitment and regeneration is largely uncertain. While young trees can stump-sprout readily after fire, older trees are unable to re-sprout, making young stands more likely to re-sprout after fire. (Allen-Diaz & Bartolome 1992, Gervais 2006).

Mature valley oaks have thick bark which protects the inner sensitive portions of their trunk (Pavlik 1991). They are relatively fire tolerant and the survival of this inner tissue is what determines the valley oaks' ability to re-sprout and rebuild its canopy (Pavlik 1991).

Mature black oaks are fire intolerant (Kobziar et al. 2006) likely due to their relatively thin bark (Stephens & Finney 2002). Re-sprouting has been observed in trees that survived the initial fire stress (Stephens & Finney 2002), but fire does not appear to increase seedling sprouting (Collins et al. 2007).

## RESTORATION

Active oak restoration is also an option for the Conservancy. Restoration projects are typically initiated either to mitigate oak loss due to development or to promote oak regeneration. In areas of existing oak woodlands protection of seedlings and saplings using small individual cages is an effective way to recruit oak out of the browse layer. Once protected trees exit the browse layer cages can be removed. This method has the advantage of avoiding the costly and time-consuming task of planting acorns, protecting them from small mammals and ungulates, and possibly irrigating them. Planting acorns or transplanting seedlings and saplings becomes necessary if managers wish to locate restoration in areas lacking existing seedlings and saplings.

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# MANAGEMENT RECOMMENDATIONS

The Conservancy is faced with the challenge of managing declining blue, valley, and black oak populations whose ranges are predicted to shift with climate change. Given the uncertainty of future climate predictions we recommend that Conservancy staff and managers plan for a variety of climate change scenarios and employ flexible strategies that can be quickly adjusted as new information becomes available.

There is a general consensus among oak researchers and managers that increasing recruitment is the most effective way to increase oak population growth. There is widespread evidence that ungulate grazing and browsing in oak understories suppresses oak recruitment, and if this can be reversed, oak population growth rates will increase. Planting acorns is a costly method of increasing recruitment as many hundreds of acorns may need to be planted in order to yield a single sapling. Managers can increase the likelihood that a single acorn will produce a sapling, but this method involves protecting acorns, seedlings, and saplings from ungulates and small mammals over a long period and may require irrigation. Planting acorns is necessary for oak restoration in areas lacking existing seedlings and saplings. Protecting existing large seedlings and saplings is a far more cost effective strategy to increase oak recruitment because protection from small mammals and irrigation are not necessary, established seedlings and saplings have relatively low mortality rates, and protected seedlings and saplings can exit the browse layer within a few years.

Our observation that seedlings and saplings on the ranch are heavily browsed supports the idea that protection from ungulate browsing will effectively allow them to grow out of the browse layer. The most cost-effective way to protect saplings and large seedlings from ungulate browsing is with small individual exclosures called vaca cages. Large exclosures can also be effective but are significantly more expensive.

There is less uncertainty about the direction and magnitude of future changes in temperature than future changes in local precipitation. For this reason we modeled future distribution under a warmer wetter scenario and a warmer dryer scenario. By focusing management efforts in areas of stable range that are common to both of these scenarios (Figures 6.1 - 6.3), managers increase the likelihood that restoration efforts will be in areas of climatically suitable habitat whether the future is wetter or dryer.

We recommend that oak restoration efforts be focused in areas of consensus stable range where oaks are already present. We recommend focusing on areas of stable range because they are climatically suitable today, and are expected to remain stable for the next 50 years. We do not suggest targeting areas of 100 year stable range as the different climate models diverge significantly by the end of the century.

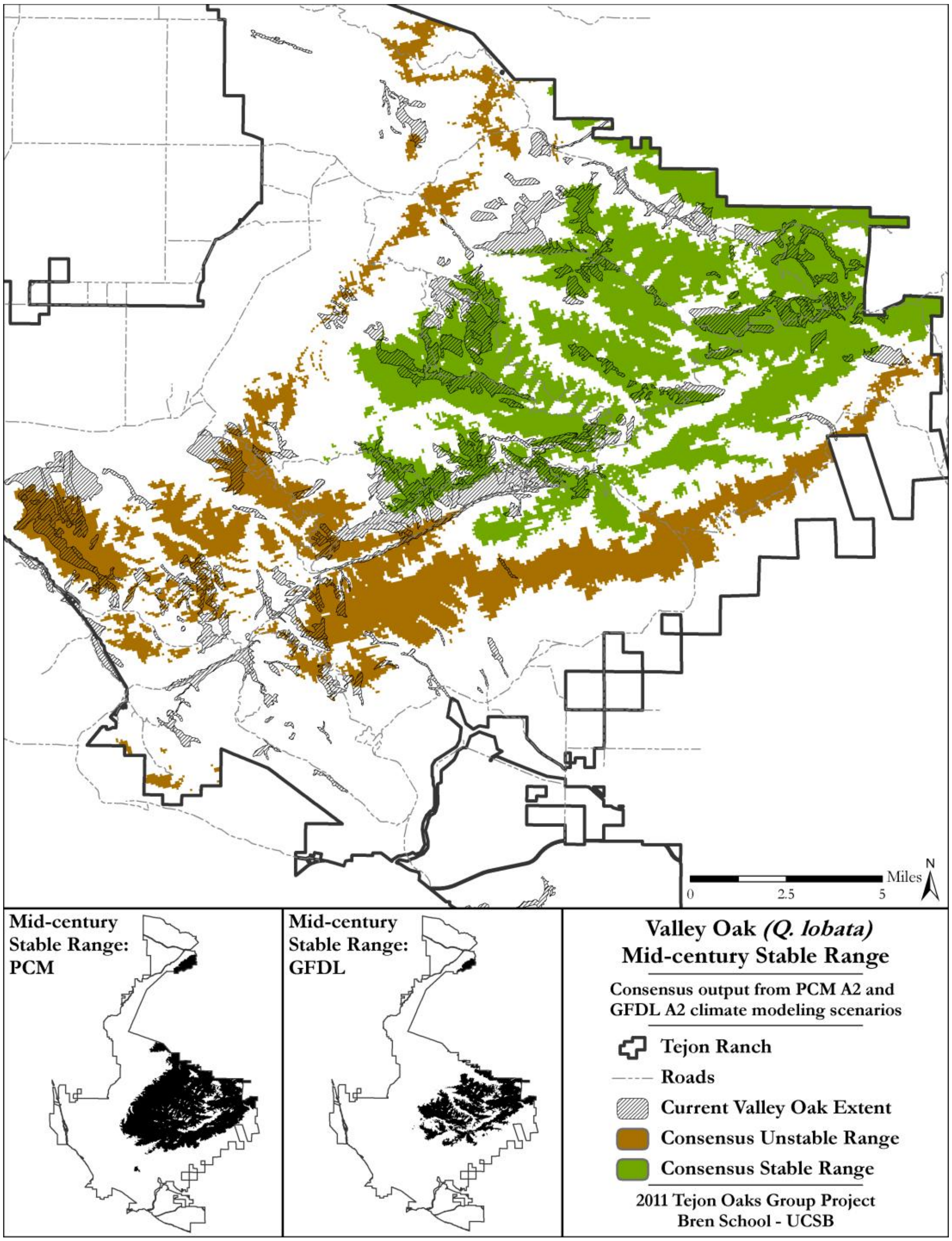


**Figure 6.1 – Map showing mid-century stable and unstable ranges for valley oak on Tejon Ranch. Consensus output is of climatic suitability as predicted by the PCM A2 and GFDL A2 climate modeling scenarios.**

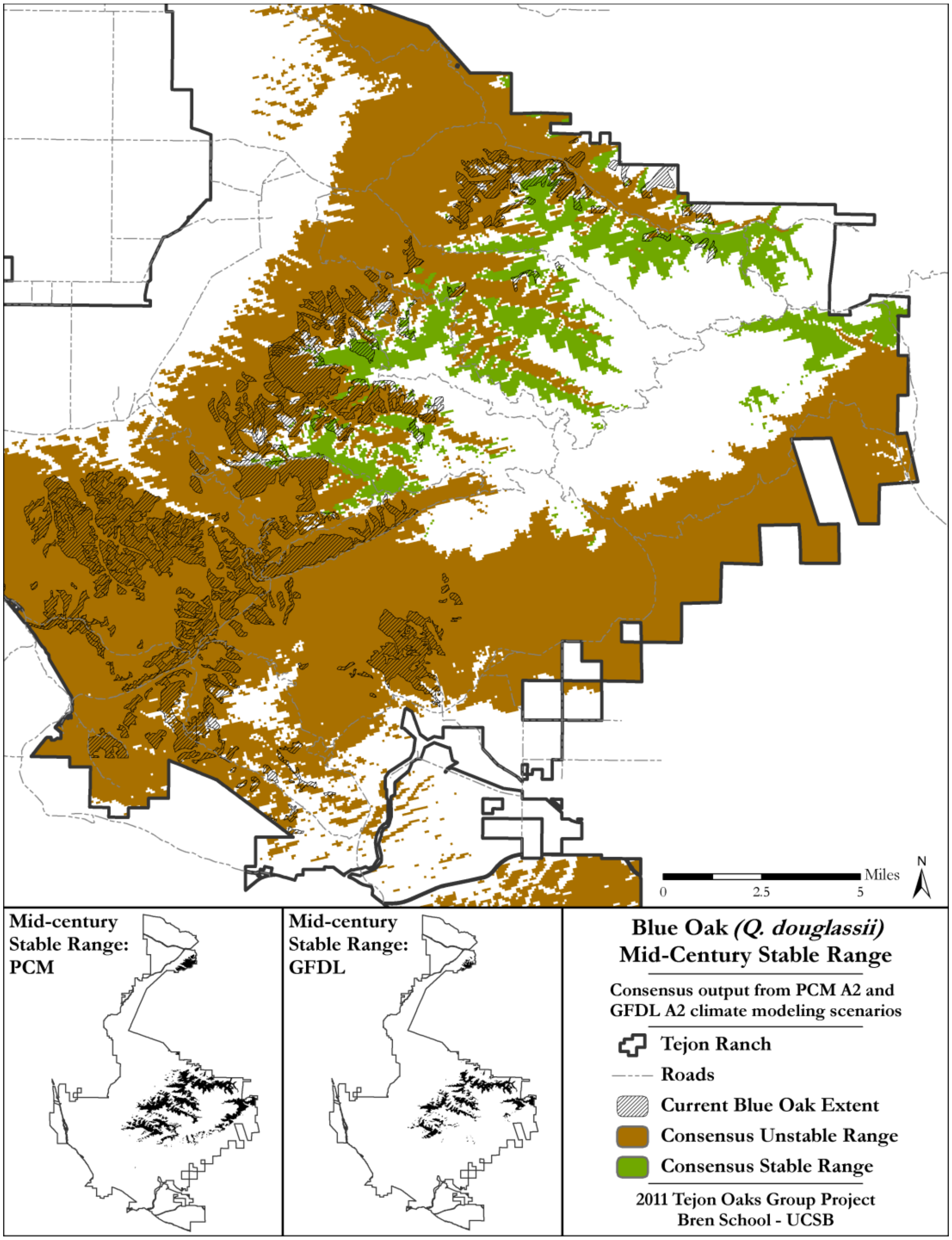


**Figure 6.2 - Map showing mid-century stable and unstable ranges for blue oak on Tejon Ranch. Consensus output is of climatic suitability as predicted by the PCM A2 and GFDL A2 climate modeling scenarios.**

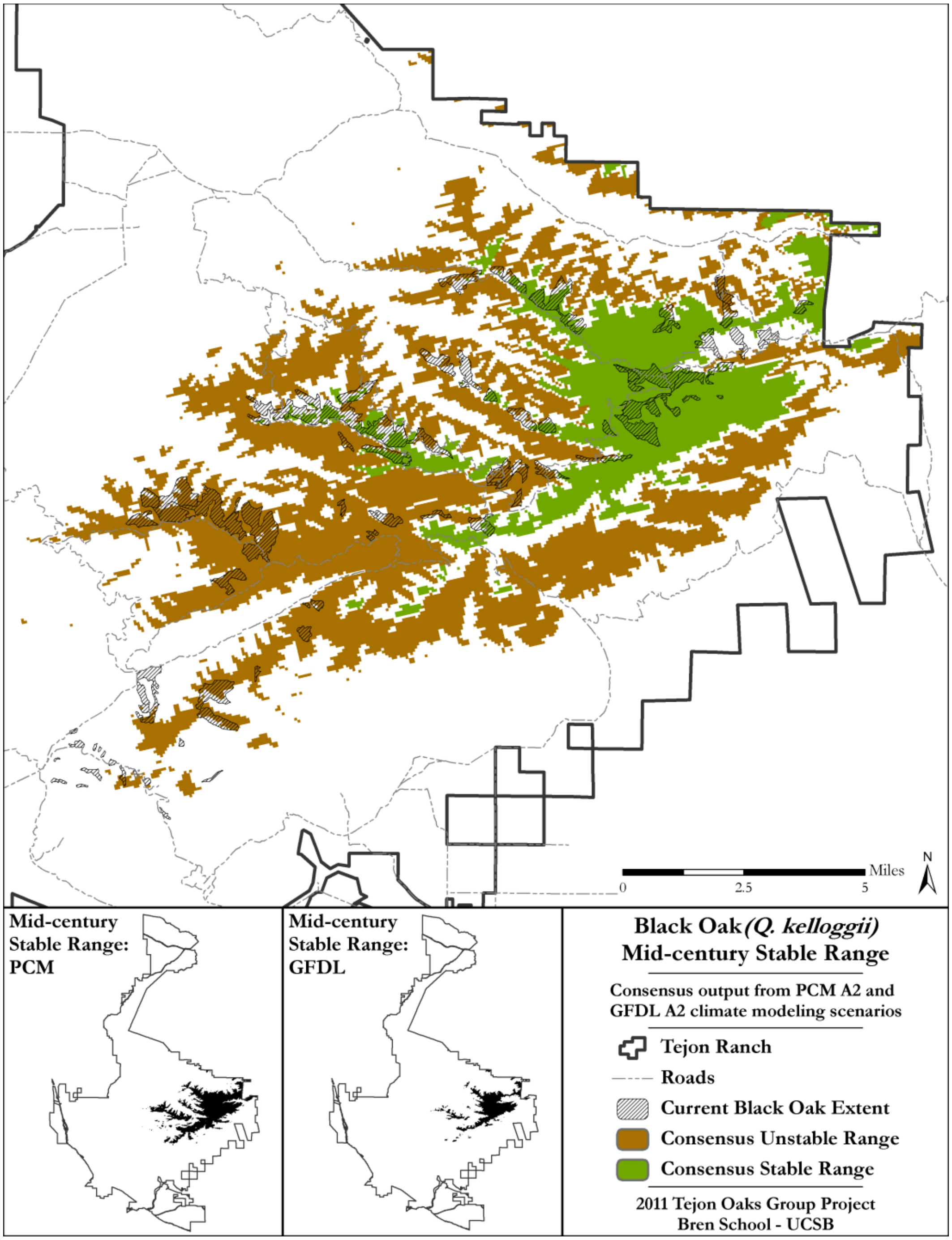


**Figure 6.3 - Map showing mid-century stable and unstable ranges for black oak on Tejon Ranch. Consensus output is of climatic suitability as predicted by the PCM A2 and GFDL A2 climate modeling scenarios.**

Once protected with vaca cages, we estimate most multi-year seedlings and saplings will escape the browse layer within about five years. Five years is a coarse and conservative estimate of how many vaca cages need to be deployed. Once out of the browse layer protective vaca cages can be removed and transferred to other seedlings and saplings. In order to bring oak population growth rates up and stabilize oak population numbers, enough seedlings and saplings must be protected to off-set adult mortality. Assuming that these management actions take place within area of overlap between predicted stable range and current distribution for all three target species, and that 5 years of protection is needed for each sapling, we can estimate the number of protected saplings needed to at least balance adult mortality. The Conservancy can monitor outcomes to refine our preliminary estimates listed in Table 6.1.

**Table 6.1 - Size of target restoration areas, current estimated population sizes, and recommended vaca cage densities for blue, valley, and black oak. We estimate that protecting large seedlings and saplings at these densities will halt the decline of Tejon Ranch's oak populations.**

| | target area (ha) | current population size | 5-year population decline | vaca cages/ha |
|---|---|---|---|---|
| **blue oak** | 369.62 | 330,492 | 3,292 | 8.49 |
| **valley oak** | 3299.14 | 217,857 | 1,087 | 0.21 |
| **black oak** | 630.38 | 276,114 | 1,378 | 1.62 |

As climate changes, oak species ranges are predicted to shift, creating leading edges of distributions where ranges are expanding. Because protection of existing seedlings and saplings must occur within current species distributions, this method cannot facilitate expansion of leading edges. To anticipate leading edges, managers will need to employ the costly method of planting and protecting acorns in areas of predicted range gain. Because areas of predicted range gain overlap with existing communities, managers will need to consider where oak planting will be most successful. For example planting and protecting valley oak acorns under a dense oak canopy will likely be unsuccessful regardless of whether it is within predicted valley oak range gain because valley oak seedlings are shade intolerant. Conservancy staff will likely need to identify where grasslands and open savannahs overlap with areas of predicted range gain and conduct planting experiments in these area in order to test model predictions of range gain.

## FUTURE RESEARCH

While the relationships between grazing, pig damage, and oak regeneration are generally well understood, Conservancy staff need to learn more about how impacts of grazing and pig damage vary across different oak species and different environmental factors such as soil type using carefully designed exclosure experiments. Grazing duration and timing may also play important roles in the health of oak woodlands, and rotational grazing trials may be effective in testing these relationships.

Staff should also seek to understand specifically what impacts pigs have on oak woodland health, how widespread these impacts are, and where they occur. Time to recovery from pig damage is also important to understand as anecdotal evidence suggests recovery may take years.

Because significant new development is possible on Tejon Ranch in the near future, it is important for the Conservancy to investigate how these developments will impact oak woodlands. Impacts from development will likely be greatest in directly adjacent oak woodlands and may include disease, light pollution, noise pollution, increased introduction of invasive species, and domestic dogs and cats.

The environmental gradient models we constructed for valley oaks highlighted an interesting observation made by other ecologists: valley oaks are most abundant on either ridge tops or valley floors. The fact that these two physical environments are so different suggests that there may be significant genetic differences between populations of valley oaks on ridge tops and in valley floors. Planting valley oak acorns from valley stands on ridge tops, and planting acorns from ridge top stands in valley floor stands should yield evidence regarding the genetic differences of these two populations.


## APPENDIX I – FIELD METHODS AND ADDITIONAL ANALYSES

### *Site Selection and Field Methods*

Site selection for vegetation plots was performed using a random and stratified technique. Mutual information (MI) analysis is a method for grouping samples based on their associations with categorical predictor variables (Davis & Dozier 1990). For this study, an MI analysis was performed using 3000 randomly selected blue, black and valley oak woodland points (as identified by the Ranch-wide timber survey maps), and eight environmental parameters: elevation, growing degree days greater than 5° C, maximum temperature, minimum temperature, mean annual precipitation, insolation, soils, and geology (Flint & Flint 2010). Results from this analysis and from a classification tree indicate that elevation and geology are the two most significant environmental parameters in determining where blue, black, and valley oaks grow on the Ranch. The mutual information score for "elevation" was 341, and the score for "geology" was 254. "Soils" had the next highest score with 117. These scores are relatively low, (high MI scores are typically > 1000), but elevation and geology were nonetheless used to stratify our study site selection. The initial 3000 random points were narrowed to those within 500 meters of access roads, and those with close proximity to existing survey points already established on the Ranch. These restrictions resulted in 254 points.

Based on the distribution of oak woodlands across the ranch, we identified the following nine site classifications:

- alluvium/low elevation
- alluvium/mid elevation
- alluvium/high elevation
- granodiorite/low elevation
- granodiorite/mid elevation
- granodiorite/high elevation
- schist/mid elevation
- schist/high elevation
- mica-schist/high elevation.

Points were randomly selected from each of these strata until between-strata representation was relatively equal, and the ratio of blue vs. black vs. valley oak points was representative of the overall ranch-wide composition (40%/14%/47%). This list of 200 potential sites was used over the duration of the field data collection period in order to guide site selection.

Inaccessibility, road intersections, lack of focal oak species or time constraints resulted in only 105 of the 200 selected sites actually being surveyed (Figure 1.1). Of these, 24 sites were dominated by blue oak (23%), 30 sites were dominated by black oak (29%), and 51 sites were dominated by valley oak (48%) (Table 1.2).

***Vegetation Plot Methodology***

**Point-intercept understory vegetation sampling**

- A series of three numbers from the set of 1, 2, 3 was randomly chosen using a random number chart. These three numbers determined the location of three perpendicular transects on the western 20m boarder of the plot. Using the three randomly selected numbers one transect was located on meter 17, 18, or 19 along the 20m binding plot edge, one transect was located on meter 9, 10, or 11 on the and a final transect was located on meter 1, 2 or 3.
- Each transect located at these three locations was 30m long. A point-intercept sample was taken at each meter mark for the full 30m
- The sample was obtained by using a 55cm long pointing rod which was touched vertically to the ground at each meter mark. The type of vegetation/ground covering that touched the rod at the highest point, or closest to the samplers hand, was recorded as the vegetation at that point.
- Categories of vegetation available to be recorded were: tree (T), bare ground (B), forb (F), grass (G), rock (R), leaf litter (L), wood (W), and shrub(S). If the point fell on a cow pie, this was recorded by writing "cow pie" in on the record sheet (Figure I.1).

**General Characteristics**

- A plot narrative qualitatively describing the site was recorded along with a plot sketch capturing major site characteristics and to a lesser extent tree distribution within the plot.
- The slope and aspect of the plot were recorded using a clinometer and compass, respectively. The dominate slope of the plot was measured by having one sampler stand at the highest point within the plot and a second sampler stand at the lowest point within the plot. The measurement was made consistently by the taller sampler lining up the clinometers measurement at the point that was at their eye level on the shorter sampler. For example the top of the shorter samplers head was exactly at eye level to the taller sampler so the measurement was made from viewing the clinometer from the taller person's eye to the top of the shorter samplers head. This insured that the slope taken was consistently that of the ground and not influenced by arbitrary head tilting. The aspect was taken using a compass based on the direction of the dominant slope of the plot. Directions were based off of magnetic north as opposed to true north.
- A plot photo was taken from the plot origin aimed in a northeastern direction.

**Soil Sampling**

- Three soil samples were taken. The first sample was taken 5 paces northeast of the origin, the second taken 5 paces northeast from the first sample, and the third was taken 5 paces northeast from the second sample.

**Tree Data Collection (**Figure I.2)

- Diameter at breast height (DBH)
- Seedling counts
- Sapling counts/measurements
- Aluminum tags were nailed to at least one focal oak tree in the plot. Most plots have all the focal oak trees tagged, however, if there was a shortage of time, tags or nails, not all the trees in the plot received a tag.

| | Transect 1 | | | | | | | | Transect 2 | | | | | | | | Transect 3 | | | | | | | |
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| **T** | | | | | | | | | | | | | | | | | | | | | | | | |

| **Shrub/Tree spp.** | **count** | **Shrub/Tree spp.** | **count** | **Shrub/Tree spp.** | **count** |
|---|---|---|---|---|---|
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**Figure I.1 - Understory transect data sheet.**

| Seedlings (< 1 cm): | | | | | Tallest Tree: | |
|---|---|---|---|---|---|---|
| Saplings (> 1 cm) | | | | Trees | | |
| Spp. | basal area | height | browse | Spp. | DBH | Snag |
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**Figure I.2 - Tree survey data sheet.**

***Soil Compaction***
A penetrometer was used to attempt to characterize soil compaction. A penetrometer is a device that measures the force required to drive a metal probe into surface soil. Soil compaction is relevant to infiltration and runoff of precipitation and is often linked to cattle grazing intensity. Calculating soil compaction involves time consuming soil collection so we hoped that our penetrometer measurements could be used as proxies for soil compaction.

Sheri Spiegal of the Bartolome Range Ecology Lab at UC Berkeley provided us with soil bulk density data from a number of plots on the Central Valley portion of Tejon Ranch. We took penetrometer measurements at the same grassland plots hoping that a calibration curve could be developed relating the penetrometer measurements to bulk density (Figure I.3).

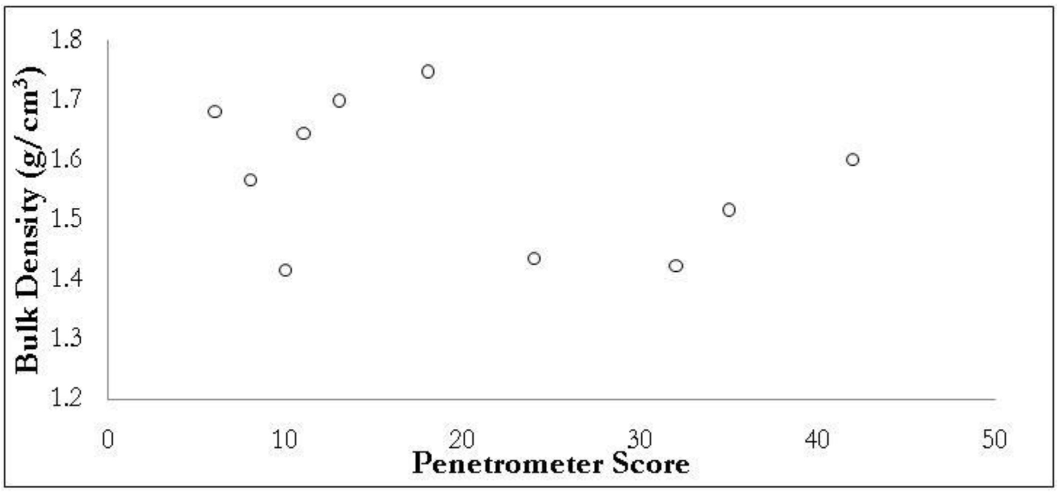


**Figure I.3- Calibration of penetrometer and bulk density measurements. We hoped that a calibration curve could be created whereby our penetrometer measurement could be used as a proxy for soil bulk density. No calibration curve was present.**

Our results show that no strong relationship between soil bulk density and penetrometer measurements was found. This is likely because penetrometer measurements were taken only once at a single location within plots and bulk density was taken as an average across entire plots. This may indicate that the penetrometer is not an appropriate tool for assessing soil conditions. Multiple penetrometer readings will need to be taken in a single plot to determine if the penetrometer can bear useful data.

We examined the relationship between percent bare ground in our plots and our penetrometer measurements to determine if there is a clear trend. Figure I.4 fails to show a strong relationship between percent bare ground and penetrometer measurements. Again this likely reflects the fact that penetrometer measurements are taken only in one place while understory data represents an entire plot.

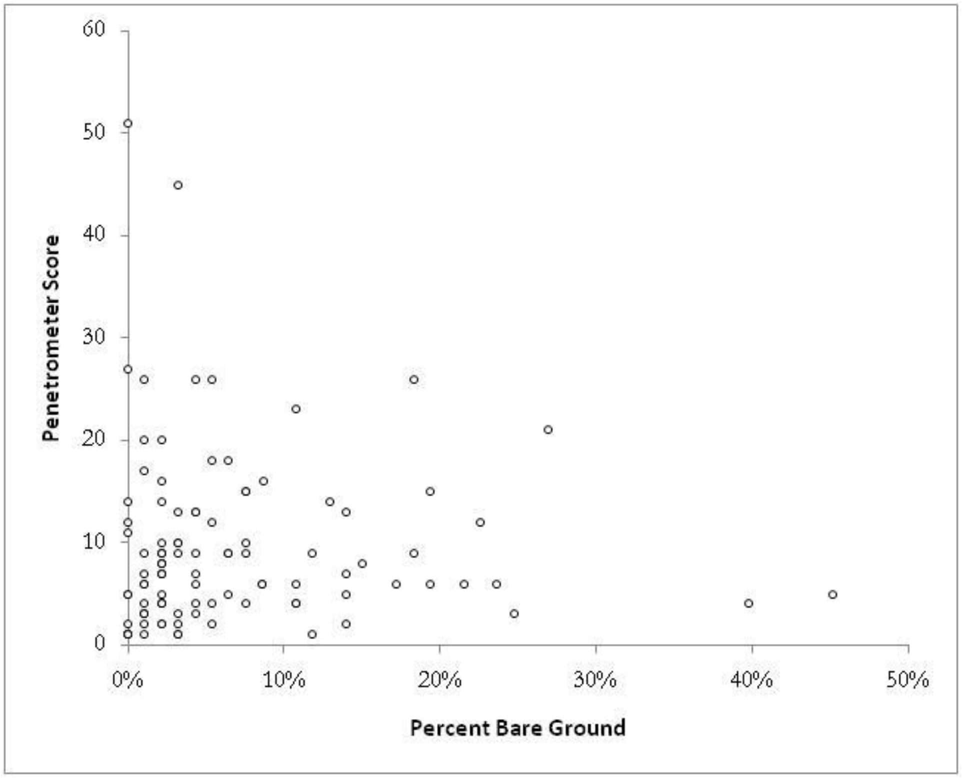


**Figure I.4 - Relationship between percent bare ground and penetrometer readings. We hypothesized that there should be a positive correlation between percent bare ground and penetrometer readings. The data do not support our hypothesis.**

### *Understory, Seedlings, and Saplings*

We also investigated the relationship between understory characteristics and the presence of oak seedlings and saplings. We expected to find bare ground – associated with disturbance and grazing – to be negatively associated with seedlings and saplings, and shrubs – possibly serving as shelters from grazing – to be positively associated with seedlings and saplings. Our results were analyzed to determine if the mean understory conditions were statistically different between plots with seedlings and saplings, and those without seedlings and saplings (Table I.1).

**Table I.1 - T-test table. We conducted a number of t-tests comparing plots with and without seedlings, and plots with and without saplings to determine if there were significant differences in mean shrub cover and bare ground. No t-tests supported our hypothesis that seedling and sapling density should be positively correlated with shrub cover and negatively correlated with bare ground.**

| *Species* | *T-test* | *P- Value* |
|---|---|---|
| valley oak | seedling presence/absence and % bare ground | 0.315 |
| valley oak | seedling presence/absence and % shrub cover | 0.306 |
| black oak | seedling presence/absence and % bare ground | 0.043* |
| black oak | seedling presence/absence and % shrub cover | 0.463 |
| black oak | sapling presence/absence and % shrub cover | 0.383 |
| blue oak | seedling presence/absence and % shrub cover | 0.057 |
| blue oak | seedling presence/absence and % bare ground | 0.401 |

T-tests were conducted to determine if the plots with seedlings had a significantly different mean percent bare ground contribution than plots without seedlings. Individual tests were conducted for each oak species. Only in black oaks was a significant difference found. This significant difference was that bare ground was greater in plots with seedlings. In blue and valley oaks no significant difference was found between plots with and without seedlings.

It was found that across all species, plots with and without saplings did not have significantly different percent bare ground contributions.

We also examined the relationship between percent shrub cover and number of seedlings for the three focal species (Figure I.5). We hypothesized that shrub cover would provide grazing refugia allowing seedlings to develop more easily. For blue oaks, plots with saplings had a marginally significantly more shrub cover than plots without saplings. No significant difference was found for valley or black oaks. Black oaks showed a weak positive correlation between percent shrub cover and number of seedlings, while blue and valley oaks showed no significant relationship.

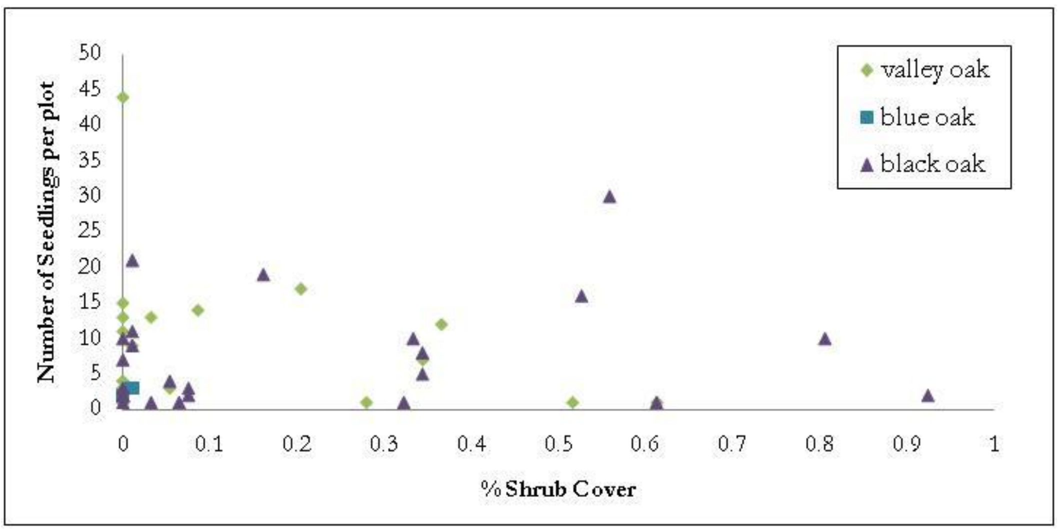


**Figure I.5 - Density of seedlings for blue, valley, and black oak as a function of shrub cover. We hypothesized that shrub cover and seedling density would be positively correlated because shrubs should provide a refuge from grazing. No clear relationship was present however.**

We hypothesized that increased shrub cover might also aid in the development of saplings (Figure I.6).

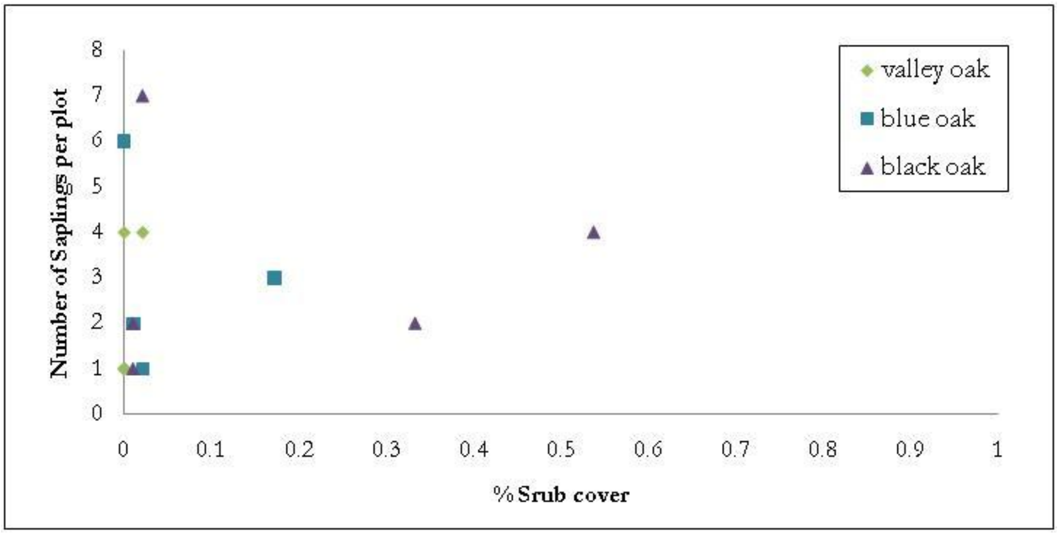

**Figure I.6 - Sapling density as a function of shrub cover. We hypothesized that sapling density and shrub cover would be positively correlated as shrubs should provide a refuge from grazing and allow seedling to develop into saplings. No clear relationship was present however.**

Again no strong relationships can be seen between sapling density and shrub cover for the three focal species.

### *Bolsinger methods*

Oak woodland statistics on lands other than National Forests were collected from the Forest Inventory Analysis (FIA) Research Work Unit at the Pacific Northwest Research Station. Information on the oak woodlands on National Forest lands was provided by personnel from each forest. Each National Forest inventory involved an aerial photo analysis and ground sampling. Ground sampling included five points, where two chains (132ft in length) were laid in an L-shape. "At each of the five points, tree attributes were collected on a variable-radius plot, and a seedling count was made on a fixed-radius plot." Information collected at each plot was used to determine per-acre tree volume and these values were averaged for each type (species and size class).

Before doing any comparisons between the two data sets, we converted the stand density (cross sectional area, CSA) values from Tejon Ranch into the units that Bolsinger reported. We had CSA values in $cm^2$ and converted these values into $ft^2$/acre.

## Appendix II: Historical Photo Analysis

### *Population Growth Rate Calculations*

By counting trees that died over the 57-year period we obtained a 57-year mortality rate. We subtracted the 57-year mortality rate from 1 to get the 57-year survivorship. The 57-year survivorship could then be annualized by calculating the 57$^{th}$ root (*equation 1*). Annual recruitment is then calculated by subtracting annual survivorship from 1 (*equation 2*)

By counting the trees that recruited over the 57 year period we obtained a 57-year recruitment rate. This also needed to be annualized. To do this we first calculated a population growth rate taking into account only recruitment, not mortality. This rate could be annualized by calculating the 57$^{th}$ root. We then subtracted one to obtain an annual recruitment rate (*equation3*).

Annual population growth rate is calculated by subtracting annual mortality from annual recruitment and adding one (e*quation 4*).

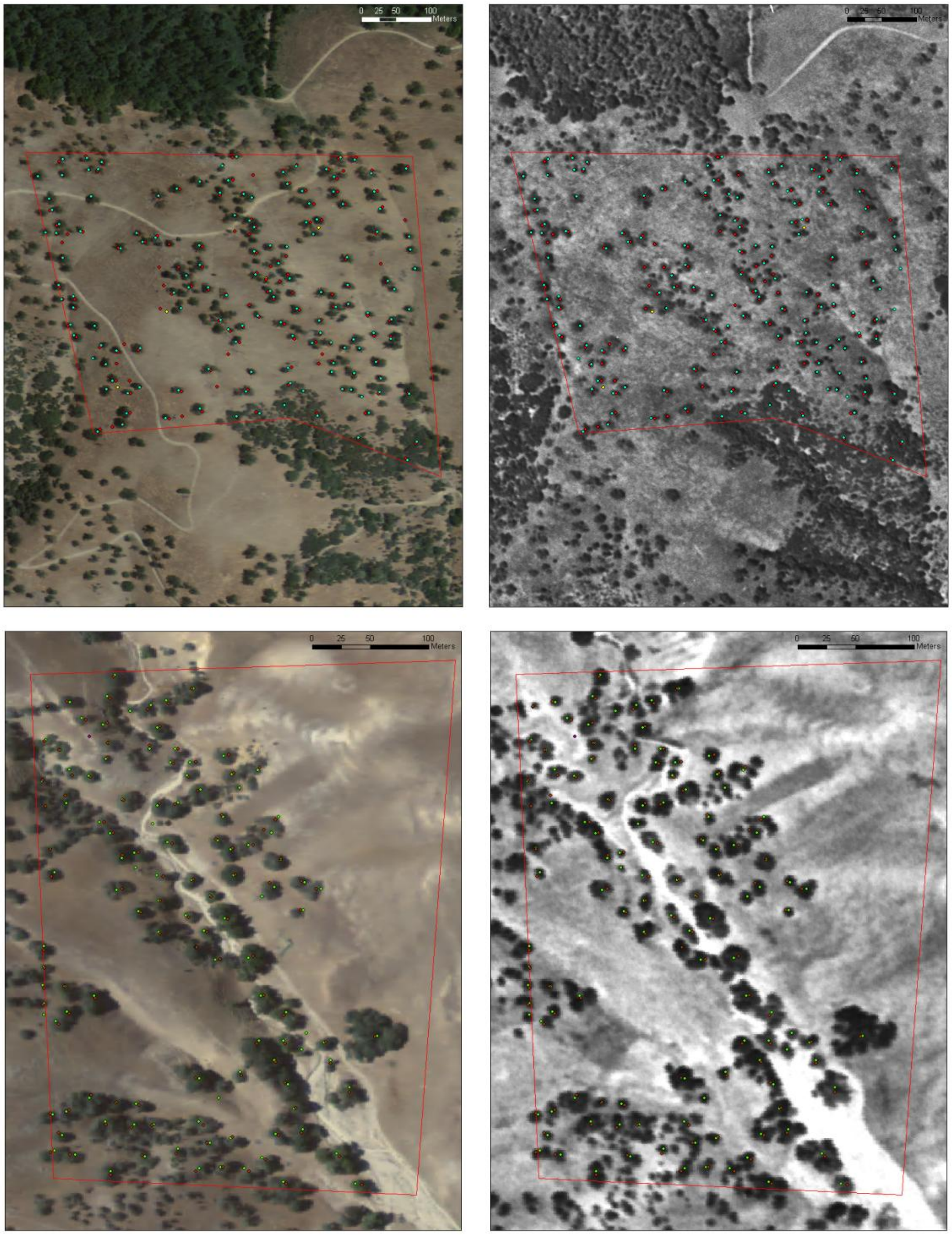


**Figure II.1 - Additional examples of historical photo analysis sample plots.**

## APPENDIX III: SPECIES DISTRIBUTION MODELS

### *Overview*

Species distribution models, (SDMs), are probabilistic models which statistically relate species occurrence data to the underlying environmental and/or spatial characteristics of those occurrence locations (Elith & Leathwick 2009, Elith et al. 2011, Guisan 2000). Also known as bioclimatic models, climate envelopes, ecological niche models, and habitat models, SDMs have their roots in ecology and natural history, as well as in modern statistics and information technology (Elith & Leathwick 2009). The reliability of these models has increased significantly over the past two decades with the rise of new and powerful statistical techniques and GIS tools, and the individual uses and methods are quite varied (Elith et al. 2011, Guisan 2000). In conservation science they are used to predict distributions of species and communities across both space and time, to gain insight into ecological and evolutionary processes, and to predict potential effects of climate change (Elith & Leathwick 2009, Pearson 2007).

In correlative SDMs, there are some underlying critical assumptions. First, it is assumed that observed occurrence records accurately reflect the true environmental space occupied by the species (Pearson 2007). Secondly, species are assumed to be at equilibrium with the current environmental conditions (Elith & Leathwick 2009, Pearson 2007). This assumption can easily be violated when making predictions for climate change, as current species occurrence records are not necessarily representative of the novel conditions and community assemblages possible with climate change. Similarly, biotic interactions may change in a new climatic context, as might genetic variability, phenotypic plasticity, and dispersal pathways (Elith & Leathwick 2009). Model robustness and viability depends on consideration of scale, degree of model complexity (more is not necessarily better), and most importantly, the quality and selection of input data.

Another potentially confounding factor to species distribution modeling is the presence/absence confusion matrix (Pearson 2007). In most occasions, systematic presence/absence biological survey data for the species or community in question has not been collected, and thus only presence data is available. Knowing where a species is present does not necessarily mean that one knows where it is absent, and when modeling this can lead to false negatives.

Maximum entropy (MaxEnt) is a method that makes it possible to model species distributions from presence-only species records (Phillips et al. 2006). This method seeks the probability distribution of maximum entropy, (or more simply, the most spread-out distribution), which still is subject to the constraints inputted by known species occurrences and environmental factors (Pearson 2007). To put it another way, MaxEnt minimizes entropy between two probability densities: one from the species presence data and one from the environmental parameters of the landscape; MaxEnt minimizes entropy in covariate space and maximizes entropy in geographic space (Elith et al. 2011). An important element to the MaxEnt of which it is important to be aware is that it runs on an exponential model that can lead to predictions of high suitability for areas with environmental conditions that are beyond the range of the data used to calibrate the model (Pearson 2007). This extrapolation can lead to false positives when predicting future scenarios and distributions. Nonetheless, since its creation in 2004, MaxEnt has been among the top performing SDMs available, and has been extensively utilized throughout the conservation world and beyond (Elith et al. 2006). While it is a powerful model which corrects for many of the shortfalls of its predecessors, MaxEnt is still only as good as its data and its users.

Another type of correlative SDM is HyperNiche (McCune 2006). This model was described earlier, and works similarly to MaxEnt. However, instead of using simple species presence data, it takes into account the relative importance values of each species at each occurrence location. This yields a distribution output of not only location but expected abundance as well.

### *Methods*

For this analysis, data points from our field study were augmented by oak occurrences from other data sets to yield 51 blue oak, 32 black oak, and 90 valley oak locations across and around Tejon Ranch. Environmental data downscaled to a grid cell size of 90m was derived from North American climate data sets for current, mid-century (30 year average centered on 2055), and end of century (30 year average centered on 2085) (Flint & Flint 2010). Models were run using outputs from the A2 emissions scenario for two general circulation models (GCMs): the Parallel Climate Model (PCM) and the NOAA Geophysical Fluid Dynamics Laboratory (GFDL). These two models were used for the California Climate Assessment (citation) and are widely accepted as accurate models for the region. They each predict was a warmer climate in the future, but PCM results ina wetter climate, whereas GFDL results in a drier climate (Cayan et al. 2008). In the A2 scenario, CO2 emissions continue to increase from current levels and reach 3x pre-industrial level by the end of the 21st century (Flint & Flint 2010). The following eleven environmental variables were analyzed in a correlation matrix (Table III.1) and in preliminary runs of MaxEnt to determine which should be used in the final analysis:

- minimum temperature (mintemp),
- maximum temperature (maxtemp),
- temperature seasonality (tseas),
- maximum temperature of the driest quarter (mtdq),
- mean annual precipitation (mppt),
- aridity index (arid),
- growing degree days > 5° C (gdd5),
- available soil water holding capacity (awc),
- soil pH (ph),
- soil particle size < 40mm (seive40), and
- soil particle size < 4mm (seive4).

Results from the initial runs of MaxEnt showed all four soil variables to contribute <1% to the model. Also, the correlation matrix showed maxtemp and tseas, and mtdq and gdd5 to be highly correlated. We eliminated these unnecessary variables and performed the final analyses with the following environmental predictors:

- minimum temperature (mintemp),
- mean annual precipitation (mppt),
- aridity index (arid),
- growing degree days > 5° C (gdd5).

Correlation matrices were generated for future climate scenarios as well. Correlation in all variables decreased with time, but not by a significant amount.

**Table III.1 - Environmental predictor correlation matrices. Two correlation matrices are shown above: one for 10 environmental predictors, and the other for 6. These matrices, along with others, were used to identify which environmental predictors showed the highest correlation, and therefore could be eliminated from the models. See Table 4.1 for the final set of predictors used in the models.**

**Environmental Parameter Correlation Matrices**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **precip** | 1.00 | | | | | | | | | |
| **aridity** | 0.88 | 1.00 | | | | | | | | |
| **gdd5** | -0.94 | -0.85 | 1.00 | | | | | | | |
| **tesas** | -0.90 | -0.83 | 0.97 | 1.00 | | | | | | |
| **maxt** | -0.94 | -0.83 | 0.99 | 0.93 | 1.00 | | | | | |
| **mint** | -0.75 | -0.74 | 0.84 | 0.87 | 0.75 | 1.00 | | | | |
| **seive40** | -0.21 | -0.16 | 0.21 | 0.26 | 0.20 | 0.16 | 1.00 | | | |
| **seive4** | -0.11 | -0.09 | 0.12 | 0.18 | 0.10 | 0.11 | 0.95 | 1.00 | | |
| **ph** | -0.12 | -0.10 | 0.14 | 0.19 | 0.12 | 0.12 | 0.90 | 0.93 | 1.00 | |
| **awc** | -0.16 | -0.13 | 0.17 | 0.22 | 0.15 | 0.14 | 0.93 | 0.87 | 0.85 | 1.00 |
| | **precip** | **aridity** | **gdd5** | **tesas** | **maxt** | **mint** | **seive40** | **seive4** | **ph** | **awc** |

| | | | | | | |
|---|---|---|---|---|---|---|
| **gdd5** | 1.00 | | | | | |
| **mppt** | -0.94 | 1.00 | | | | |
| **arid** | -0.85 | 0.88 | 1.00 | | | |
| **mtdq** | 1.00 | -0.94 | -0.85 | 1.00 | | |
| **mint** | 0.84 | -0.75 | -0.74 | 0.86 | 1.00 | |
| **tesas** | 0.97 | -0.90 | -0.83 | 0.98 | 0.87 | 1.00 |
| | **gdd5** | **mppt** | **arid** | **mtdq** | **mint** | **tesas** |

MaxEnt model parameterization included the use of 10,000 background points, 10% of sample points reserved for random seed model validation, and each model ran through 5 replicates to produce the final output. "Maximum sensitivity plus specificity" threshold was used for determination of Presence/Absence. AUC was used as a measure of goodness of fit (Table III.2). Figure III.1 shows the response curves to and percent contributions from each environmental predictor for one of our MaxEnt model runs.

**Table III.2 - Cross-validated AUC results for MaxEnt model runs. Cross-validated AUC is a measure of model's ability to minimize false positives and false negatives. AUC values greater than 0.8 are generally accepted as an indicator of a good model.**

| ***species*** | ***model AUC*** |
|---|---|
| blue oak | 0.83 |
| black oak | 0.96 |
| valley oak | 0.87 |

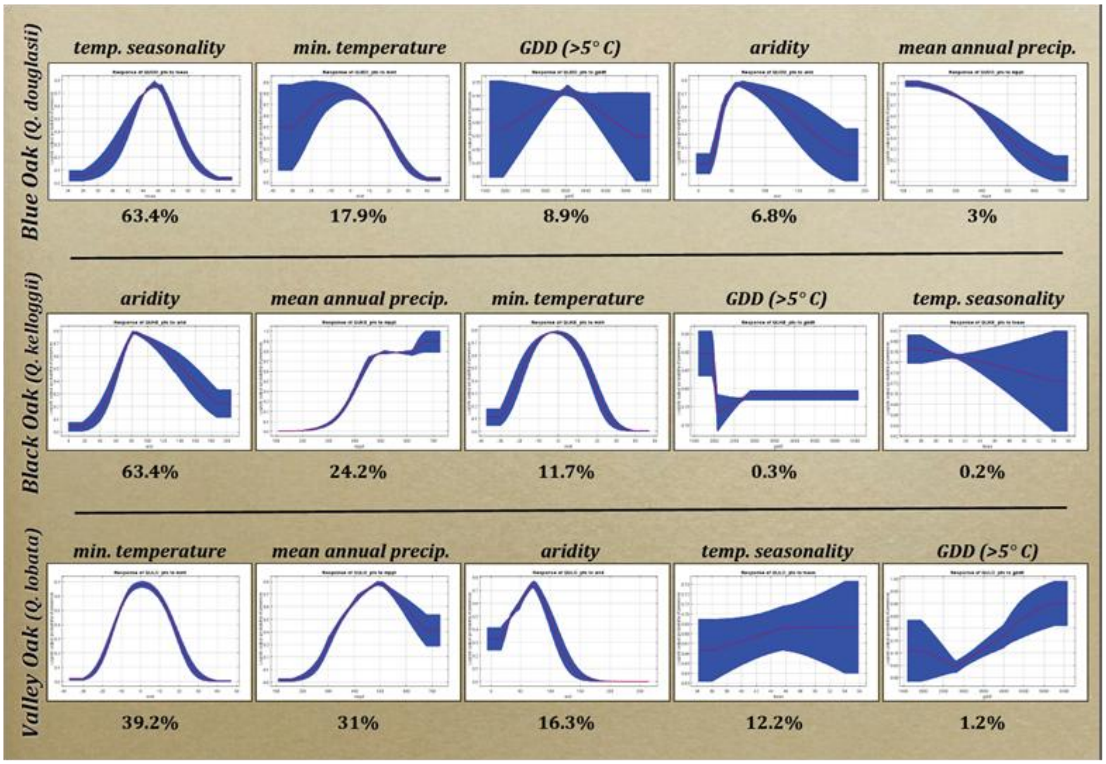


**Figure III.1 - Environmental predictor response curves and the associated percent contribution from each to the MaxEnt climatic suitability model for each species of oak. Environmental predictor importance varied greatly by species.**

Figures III.2 – III.4 show the current and mid-century results from this analysis for each of the three oak species that were modeled.

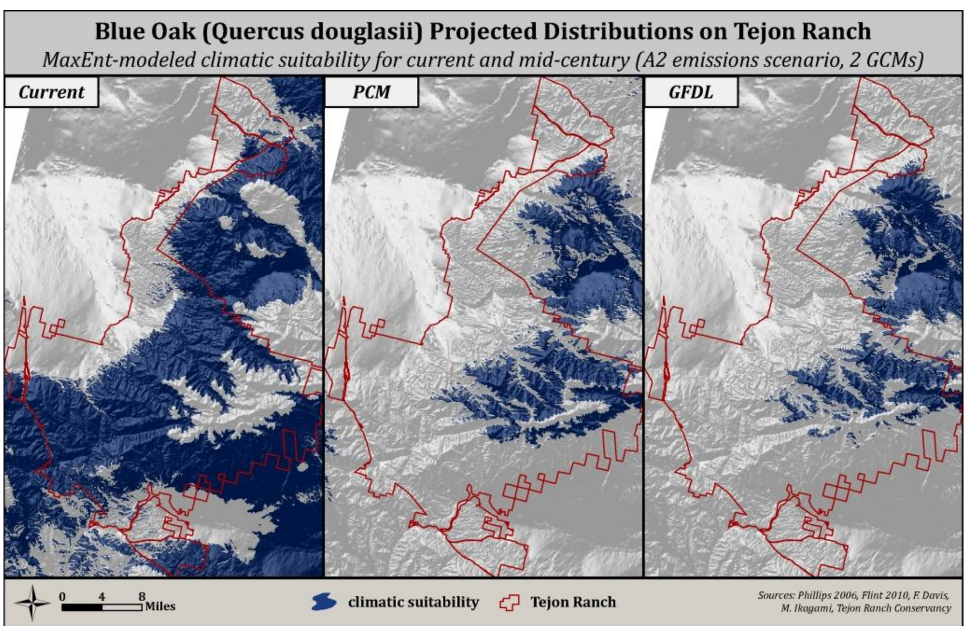


**Figure III.2 - MaxEnt-modeled climatic suitability for blue oak for current (left), mid-century PCM A2 climate model (center), and mid-century GFDL A2 climate model (right).**

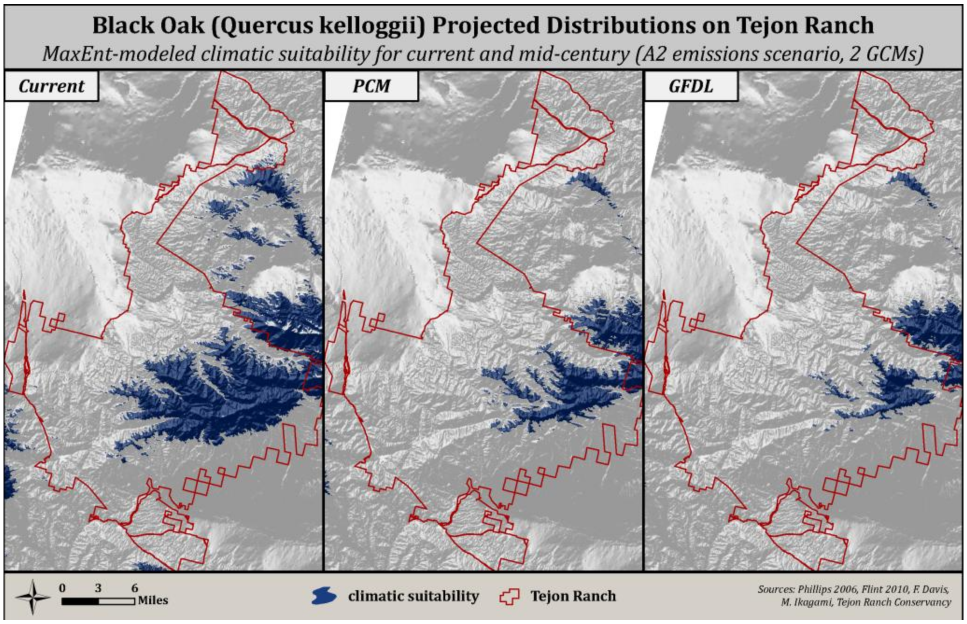


**Figure III.3 - MaxEnt-modeled climatic suitability for black oak for current (left), mid-century PCM A2 climate model (center), and mid-century GFDL A2 climate model (right).**

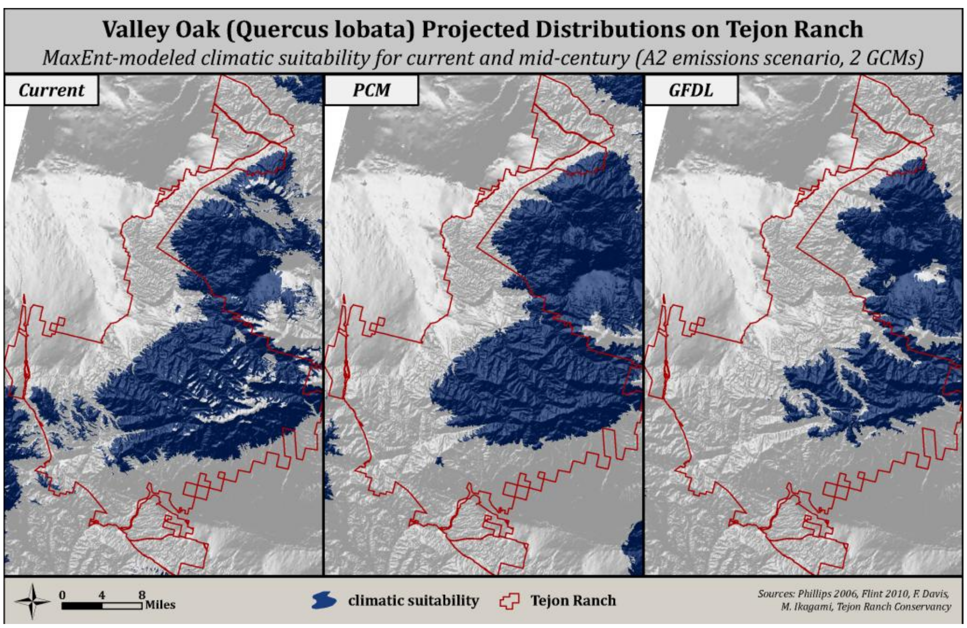


**Figure III.4 - MaxEnt-modeled climatic suitability for valley oak for current (left), mid-century PCM A2 climate model (center), and mid-century GFDL A2 climate model (right).**

The same environmental predictors were input into HyperNiche (Figures III.5 – III.6) along with the oak occurrence data and species importance values (sum of density and relative basal area of adult trees) as calculated from our field data. Models are based on the A2 emissions scenario, and the *PCM* general circulation model.

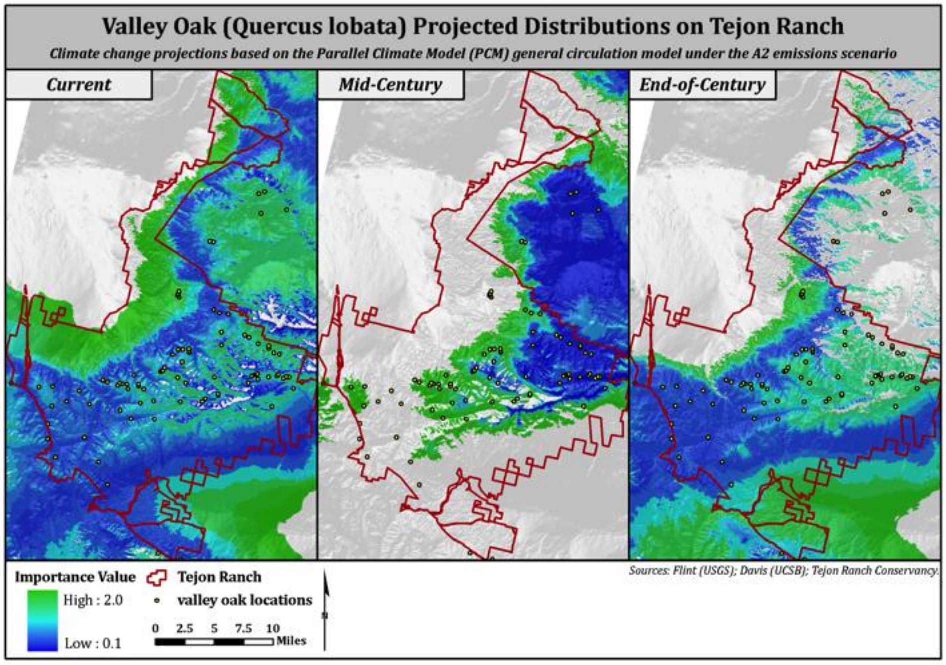


**Figure III.5 - Projected distributions of valley oak on Tejon Ranch in current (left), mid-century (center), and end of century (right). Areas with higher predicted importance values signify areas with greater probability of higher density presence of the species.**

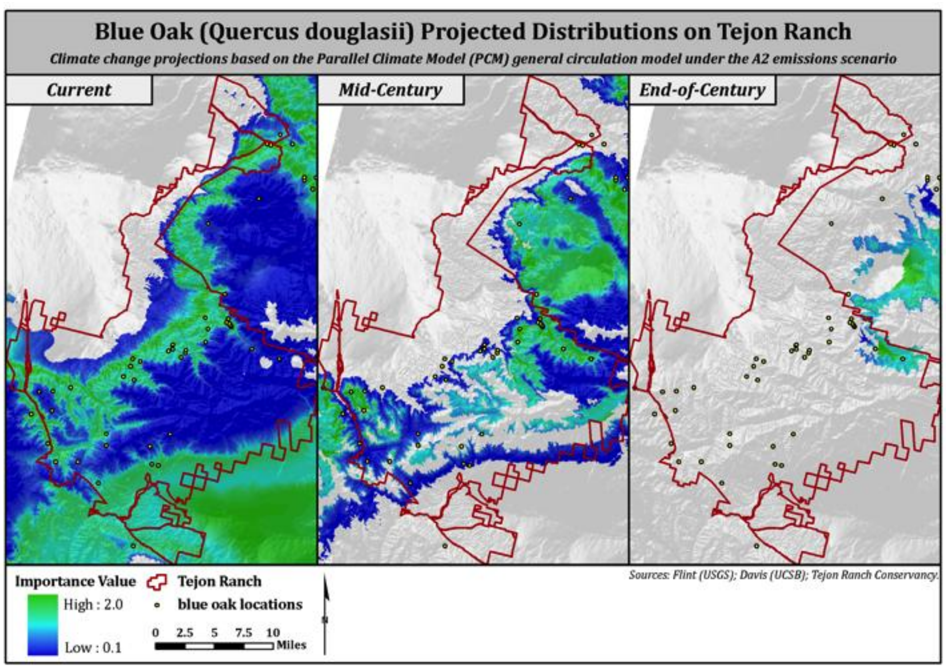


**Figure III.6 - Projected distributions of blue oak on Tejon Ranch in current (left), mid-century (center), and end of century (right). Areas with higher predicted importance values signify areas with greater probability of higher density presence of the species.**

***State-wide training data comparison:***

An analysis of current MaxEnt-modeled valley oak distributions was performed comparing outputs from a model trained on Tejon Ranch specific occurrence data, to a model trained on occurrence data that is California-wide (Figure III.7). The results show the distribution to be much narrower for the Tejon-specific model than for the CA-wide model. The analyses were run on corollary, although not identical sets of environmental parameters. These results suggest one of two possible things. It could be that oaks on Tejon Ranch are indeed unique, and occupying a more narrow environmental niche there than in the rest of California. On the other hand, this test could be further verification of the degree to which training data can affect model outputs, thereby reinforcing the single most important assumption to species distribution modeling: the need for high quality, unbiased sample points. Whatever the case may be, we feel that the Tejon-specific model is a more accurate tool to use when dealing with the oak resources for this region. Local models will likely catch more of the subtle variations within species such as seed zones, and phenotypic and genetic variability.

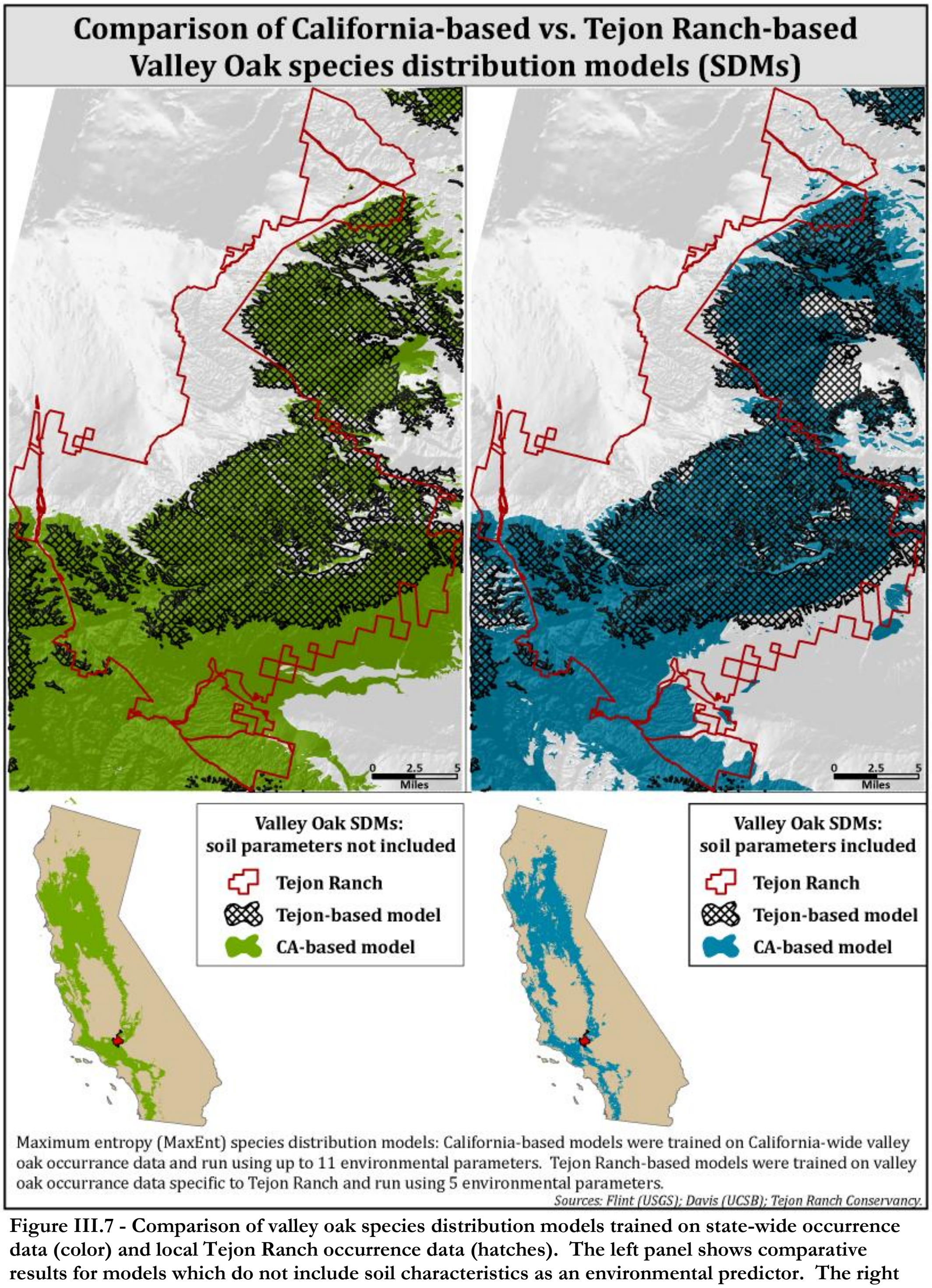


**Figure III.7 - Comparison of valley oak species distribution models trained on state-wide occurrence data (color) and local Tejon Ranch occurrence data (hatches). The left panel shows comparative results for models which do not include soil characteristics as an environmental predictor. The right panel shows comparative results for models which do include soil characteristics as an environmental predictor. These comparisons highlight the distinctions in environmental conditions determining suitable habitat for regionally different populations of valley oak in California.**

## APPENDIX IV: COMPARATIVE MANAGEMENT ANALYSIS

We compared Tejon Ranch's management practices to those of other organizations throughout the state whose primary mission is oak conservation. Because oak conservation involves a great deal of learning by doing, it is important for the Conservancy to stay abreast of what management practices other conservation organizations are employing, which practices are succeeding or failing, and why. Conservation management trials are time consuming and costly, making it crucial for conservation organizations to learn from each other's successes and failures.

We focused on groups whose primary goal was oak woodland conservation because these groups would provide specific information that pertained to the Tejon Ranch Conservancy's mission. We initially sent out emails to land managers, conservation directors, and others who would 1) be interested in our project, and 2) be willing to share information about their oak woodland management plan. Some participants responded only via e-mail. We spoke over the phone and briefly in person with others.

Below (Table IV.1) is a summary of results from the conversations we had with individuals from: County of Santa Barbara, Chimineas Ranch, and Wind Wolves Preserve.

**Table IV.1 - Current oak woodland specific management practices employed on four different large-scale managed landscapes in south-central California.**

| ***Area*** | ***Oak Woodland Management Scheme*** | ***Manager*** |
|---|---|---|
| Wind Wolves Preserve | *Active restoration; periodic grazing; no hunting; no timber harvesting.* | The Wildlands Conservancy |
| Chimineas Ranch | *In the process of creating an oak woodland management plan; currently have rotational grazing.* | Chimineas Ranch Foundation, CA Dept. of Fish & Game |
| Santa Barbara County | *Control oak removal; complaint-driven enforcement.* | Santa Barbara County Agriculture Commissioner |
| Tejon Ranch | *Rotational grazing; major hunting; no timber harvesting; fire suppression.* | Tejon Ranch Company, Tejon Ranch Conservancy |

### *General Notes:*

Comments from Santa Barbara County (Plant Pathologist)

They are most worried about controlling the removal of oaks, and preventing Sudden Oak Death from entering the county through nurseries.

Comments from Chimineas Biologist (CA Dept Fish and Game)

The Chimineas Ranch is located in southern San Luis Obispo County, east of Santa Maria and is about 30,000 acres in size and contains about 4,000 acres of oak woodlands. The Chimineas Ranch is dry and only receives about 10-15 inches of rain annually. The Chimineas Ranch primarily has blue and tucker oak savannas. They have a few small stands of coast live oak and valley oak but these are pretty rare. The Chimineas Ranch is currently in the process of creating their land management plan which will include a section on oak woodland management.

We asked the Chimineas Biologist questions concerning their future management plan and the dialogue is below:

*How does your organization want to manage the oak woodlands at Chimineas?*
Oak woodland management is just one part of their land management plan. Their mission is to maintain and enhance oak woodlands. The Chimineas Biologist reported that they have seen decent blue oak recruitment, especially on slopes. The flatter areas on the Ranch are impacted by grazing and do not have the same levels of recruitment. Livestock currently graze on the Ranch and have been for last 100 years. Unlike the Tejon Ranch Conservancy, the Chimineas Ranch Foundation has the power to remove cattle. However, they did an initial analysis of the impacts of grazing on oak woodlands and their results weren't very clear.

*Do you have a particular policy on grazing, fire management, downed wood management, hunting, timber harvesting, etc. that may impact the oak woodlands on your ranch?*
There are about 400 cattle that graze the land and they use rotational grazing. These cattle rotate through National Forest (10,000-15,000 acres) that is adjacent to their land. Usually forest lands are grazed in spring and the cattle are moved to the Chimineas Ranch later in the year. Fall and winter seasons are when the cattle are on the Chimineas Ranch, however this may change. Historically this is how it has happened for at least the past 70-80 years. They are considering comparing the National Forest grazing sites to their land to see if they can find any significant impacts. They have conducted riparian exclusion projects in the past that included some oak woodlands. These results can be used to compare among treatments. As for fire management, they support prescribed burns, but in reality, admit that this is very difficult and costly to perform. They would prefer to do burns in the fall and hope to work with the Forest Service to burn patches of chamise, which has not burned for decades, and the oak understory to ensure that a catastrophic fire will not occur in the future. They have also surveyed for masting events. Some years they do not observe masting and other years they did. They mainly observed production on slopes, not on valley floors. Downed wood is left unless it is on a fence or in a road. They do not harvest any timber. They do allow hunting but it is on a very small scale, something like 5 people per season.

*Is there anything that concerns you about oak woodland management at your ranch?*
The vegetation matrix is very complex at Chimineas. Dense chamise stands weave through their oak woodlands and they are very concerned about a fire coming through, which could devastate their oak woodlands. They hope to manage fire through prescribed burns. In reality this may be very difficult. With prescribed burns they hope to burn some of the chamise so that an accidental burn would not be catastrophic.

They believed that oaks seem to be reproducing on the ranch. As you move east of the ranch there is a creek and everything east of that creek has been tilled and farmed in the past. They don't know if there used to be oaks there originally and if they should restore them. In the past they did not have a lot of success during plantings projects. In mid-90s, the California Water Authority planted oaks as mitigation for a water pipeline project but 95% of plantings failed. The successful plantings were on north facing slopes. They are still unsure why there was such a low success rate. He said they planted thousands of oaks for that mitigation project. Lastly, there are some feral pigs on the Chimineas Ranch. They are unsure about whether or not it is a competition for the seeds or if the real problem is the rooting.

Comments from Wind Wolves Preserve Resource Ecologist (The Wildlands Conservancy)
Wind Wolves Preserve (WWP) is located west of Tejon Ranch and is approximately 95,000 acres. It is the largest non-profit owned land in the state and is managed by The Wildlands Conservancy (TWC) whose mission is "to preserve the beauty and biodiversity of the earth and to provide programs so that children may know the wonder and joy of nature."

Comments:
We allow periodic grazing to reduce fire fuel loads of annual grass to minimize oak mortality resulting from inevitable wildfires. We have an on-going restoration program for oaks. Acorns are gathered on the Preserve, propagated in a greenhouse on-site, then planted, protected with treeshelters and weed mats, and irrigated until their crown is above the deer browse line. No hunting is allowed, except that we actively eradicate any feral pigs that immigrate onto the Preserve from neighboring properties. At this time, we are pig-free.

The Wildlands Conservancy does not allow timber cutting of any kind on Wind Wolves Preserve. Only dead and down wood that blocks roads is cut and removed. Otherwise, dead wood is allowed to remain where it fell, as this decaying wood provides an important habitat niche for rodents, amphibians and invertebrates. On rare occasions, large deadfall has been dragged from underneath the canopy of heritage trees, so it would not become ladder fuel that would kill the tree during a fire.

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