Status and Trends of Black Oak (*Quercus kelloggii*) Populations and Recruitment in Yosemite Valley (a.k.a. Preserving Yosemite's Oaks)

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Introduction

California black oak (*Quercus kelloggii*) represents an integral component of the vegetation of Yosemite National Park. It is found throughout the western side of the park between elevations of approximately 2000 and 7000 feet. California black oak is one of nine arborescent oak species within the Beech family (Fagaceae) found in California. There are seven oak species within Yosemite, four of them attaining canopy height. Although black oak is also abundant throughout the state (Bolsinger, 1988), it rarely occurs as monospecific stands; it is usually found as a component of other hardwood woodlands and mixed forests. In Yosemite, this species if found as a component of woodlands and forests on approximately 37,300 acres. The extent of areas where it is the dominant species is approximately 5,300 acres; the extent of areas where it is a subdominant species of a mixed forest dominated by conifers is approximately 32,000 acres.

Oak woodlands and savannas cover much of the state of California (approximately 11%) (Davis et al., 1998) and contain more than 1400 species of flowering plants, and provide habitat to over 300 vertebrates and thousands of invertebrate species, making them the most diverse natural communities in the state. It is also well documented that oaks and their acorns have been and continue to be a valuable resource to both wildlife and humans. Acorns have provided sustenance for indigenous Americans for centuries and acorns and oaks have been used for medicine, dyes, timber for shipbuilding and furniture, housing, and for fuel (Keator, 1998; Johnson et al., 2002; Anderson, 2005). An abundance of wildlife species depend upon oaks for both habitat and sustenance, relying on acorns or oak leaves as a primary food source (McShea and Healy, 2002).

Since the early 1900s, scientists in California have recorded an apparent lack of 'regeneration' within oak woodlands and savannas (Sudworth, 1908; Jepson, 1910). The

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lack of recruitment of new individuals into populations has left many oak populations skewed in their demographics, with many adult oaks and few to no seedlings and saplings. More recently, this phenomenon has been recorded throughout North America in California (Holzman, 1993; Swiecki et al., 1993), Texas (Russell & Fowler, 1999), and Tennessee (Loftis & McGee, 1992), and in other parts of the world including Britain (Watt, 1919; Shaw, 1968) and Asia (Saxena & Singh, 1984; Singh et al., 1997; Abrams et al., 1999).

A recent review of demographic and recruitment research of oaks in California has found conflicting and incomplete evidence of the apparent regeneration problem of oaks (Tyler et al, 2006). Only three of California's oaks have been studied well enough to draw conclusions on their trends in the state: blue oak (*Q. douglasii*), coast live oak (*Q. agrifolia*), and valley oak (*Q. lobata*). But at least for some of California's oaks, evidence would suggest that populations are not recruiting enough new individuals to sustain densities at current levels.

Many factors have been promulgated to explain the apparent lack of recruitment in most oak species in California and elsewhere. These include: 1) acorn diseases; 2) acorn predation; 3) herbivory of established seedlings and saplings; 4) competition between oak seedlings and non-native annual grasses for water; 5) soil compaction by cattle; 6) lack of fire; 7) low rainfall in some years; and, 8) low adult densities.

The common perception by researchers, resource managers, and Native Americans of black oak populations in Yosemite Valley is that these populations have undergone a dramatic transformation over the last 150 years. When the first Euro Americans arrived in Yosemite Valley, they encountered an environment strikingly different to that found today. The Valley was a patchwork of meadows and open woodlands/savannas dominated by oaks and shrubs (Anderson, 2005; Colby, 1953; Ernst, 1961). After the arrival of Euro Americans and the subsequent decline in the influence of the Miwok and their traditional practices, the Valley had become progressively more and more filled in with conifers and shrubs (Ernst, 1949). Even 40 years later, Galen Clark (1894) remarked how differently the Valley looked since he first visited in 1855, with conifers more abundant at the time of his second visit. The Miwok tribe of the Western Sierra occupied Yosemite Valley periodically prior to the arrival of Euro Americans. The personal Miwok stories of the black oaks in Yosemite Valley describe a significant reduction in tree numbers in the last 150 years (Anderson, 1993).

Today there is a common perception that black oaks have been declining and continue to decline in Yosemite Valley and elsewhere in the park. It appears that black oaks are also suffering from the same apparent lack of recruitment that has been found in oaks throughout the world. It would be beneficial to document whether a reduction or lack of recruitment in black oaks in Yosemite is occurring and to direct research toward the goal of determining the proximate and ultimate factors responsible for any documented declines.

Here, we address what, if any, changes have occurred in black oak population demographics over time and examine the role of some of the potential drivers of change. Specifically, we addressed five research questions during the course of this study: 1) What is the status of black oak populations or stands throughout Yosemite Valley?; 2) Do the demographic structures of the stands indicate anything about population dynamics?; 3) What physical and ecological factors may explain any location differences in stand

demographics?; 4) Is there a road effect on stand demographic structure that may explain differences observed?; and, 5) which, if any, biological or physical factors may be causing a lack of oak recruitment if indeed one if found? Additionally, we have reviewed and compiled past research and management actions to understand and maintain black oaks in Yosemite Valley.

Considering the long history of human occupation and manipulation of Yosemite Valley (whether aboriginal or modern), the ecological components and system of the Valley today may be out of natural balance. However the degree to which the natural system of the Valley may be operating dysfunctionally and what effect, if any, this may be having on the distribution and abundance of black oaks, is unknown. The research contained in this report is presented in the hopes of clarifying the current situation and offering suggested management actions to address any conclusions that the ecological system may be in a disturbed state.

Drivers of Change in Black Oak Populations

If we find that black oaks within Yosemite Valley are indeed declining, we would hope to identify potential proximate or ultimate factors that are responsible. These factors may operate at the individual or population level and may be static or dynamic in nature. In this section we explore some potential drivers that may be causing a perceived or real decline of black oaks in Yosemite Valley.

In response to the drivers discussed below, we posit that there are two processes at work that have created the real or perceived decline of California black oaks in Yosemite Valley. The first is the infilling of once pure black oak woodlands and savannas with conifers (primarily Ponderosa pine, incense cedar, and white fir) that have invaded these stands. As conifers infill, it is believed that they shade out the smaller oaks. It is believed by many that oaks are much more shade intolerant than conifers and that they do not survive well in the understory below a closed canopy and some research suggests this may be true (McDonald, 1969). The other process at work is the apparent lack of oak recruitment into the existing black oak stands. Here we are defining recruitment as the introduction of new individuals into the population. The first process leads to a decline in the relative dominance of black oaks, but not necessarily a real change in actual numbers or density and will depend on whether recruitment is sufficient to offset adult mortality. The second process will lead to a decline in the density of oaks as extant adults die off. These two processes operate independently, but may produce the same perceived result – population decline.

As the pure black oak stands in Yosemite Valley were identified as a sensitive resource requiring restoration and protection (USDI, 1985), both of the processes described above may need to be addressed in order to accomplish a goal of preserving these black oak stands. The current research addresses the second phenomenon – the apparent lack of recruitment and the potential causes and consequences. It is hoped that this research will lead to a more informed management of black oaks in Yosemite Valley.

Black oaks and fire

During Native American occupation of the Valley, they actively burned the forest floor, usually annually (Wickstrom, 1987). It has been well documented through early settler observations and first hand accounts from Native American tribe members that

they heavily manipulated their natural environment across the state. The Native American burning was used to maintain or even expand the dominance of black oaks in the Valley (Heady & Zinke, 1978; Gibbens & Heady, 1964). Today much of the Valley is a dense forest dominated by conifers, mostly Ponderosa pine, incense cedar, and white fir, though black oak and canyon live oak are still abundant. The result has been that their relative abundance or dominance has apparently declined substantially.

Anderson and Carpenter (1991) examined pollen and charcoal within sediment cores from Woski Pond (in Yosemite Valley) and determined that the Miwok's last lengthy occupation of the Valley occurred during the period from 650 years ago until approximately 150 years ago when American settlers first arrived. Significant evidence documents that during this period of occupation, the Miwok and other tribes used fire frequently as a management tool in the Sierra Nevada and across the state (Anderson, 2005). According to first hand accounts and translations (Anderson, 2005; Colby, 1953; Gibbens and Heady, 1964; Heady and Zinke, 1978; Reynolds, 1959), the Miwok burned the Valley every fall, resulting in several advantages: 1) an open environment with few trees kept the area free of hiding locations for potential enemy invaders; 2) the fires killed the new conifer seedlings, preventing them from growing up to outcompete the oaks; 3) the open system made it easier for oak acorn collection; 4) the fires suppressed acorn diseases and pests; and 5) frequent burning decreased the likelihood of intense fires that would burn down the adult oaks.

Perhaps the primary reason the Miwok and other tribes frequently burned was to maintain an environment that favored oaks (Anderson, 1993). Acorns were one of the, if not the most important part of the Miwok diet, for at least a significant portion of the year (Anderson, 1993). Acorns were second only to salt as the most traded resource amongst tribes in California (Anderson, 2005). The central and southern Sierra Nevada tribes, including the Miwok, preferred black oak acorns over those from other oak species (Barrett & Gifford, 1933; Latta, 1977). For this reason, it is highly likely that the Miwok actively managed the forests and woodlands in order to maximize the amount of black oak acorns harvested. There are stories of the Miwok actively burning or pulling up seedlings of other tree species while black oaks were protected and favored (Anderson, 2005). This management may then have created a landscape that was artificially high in the relative and absolute abundance of black oaks. The weight of evidence suggests that this was the case.

Prior to the arrival of Euro Americans, the Miwok tribe of the Western Sierra occupied Yosemite Valley periodically. It has been estimated from archeological history that the Miwok occupied the Central Sierra Nevada starting about 3,000 years ago and that they exploited acorns from certain species of oaks in the Sierra beginning about 2,000 years ago (Anderson, 1993). Acorn use then increased with the advent of the mortar and pestle technology used to pound acorns into mush; this technology first emerged somewhere during the period between 1300 and 650 years ago (Moratto, 1984). Intense use of acorns (and thus management of oaks) likely occurred from this time up until the arrival of Euro Americans in about 1850. Thus there was a period of between 1,850 and 1,150 years during the most recent past when the Miwok actively managed oaks and oaks woodlands for acorn exploitation.

Historically there were likely relatively infrequent natural fires in Yosemite Valley as evidenced by the lack of lightning strikes in the Valley itself in contemporary

times (van Wagtendonk, pers. comm.). However, some fires that made it to the Valley rim may have spread down into the Valley. It may be that there were infrequent catastrophic fires that consumed much or most of the Valley forests in pre-human times. The Native Americans changed the fire regime substantially, instituting a regime of frequent fires. So, rather than a suppression of relatively infrequent natural fires, the current conditions seen in the Valley are the result of a step change in the fire regime that the forests and woodlands experienced (from annual to very infrequent). Since the 1970s however, prescription burning has been instituted to attempt to recreate the managed landscape as found by the first Euro American settlers in the mid 1800s. It is not yet clear if this management action has led to a relative increase in the densities of black oaks over conifers in those areas burned.

Oaks and Browsing

There is a broad literature base that has documented the negative effects of deer browsing on the growth and survival of seedlings and saplings and on the decline of certain browse plant species (e.g. Abrams, 2003; Alverson et al., 1988; Gill & Beardall, 2001; Rooney, 2001; Waller & Alverson, 1997). These and many other studies have found that certain forest tree species throughout North America and Europe, especially species of oak, are very susceptible to the effects of deer browsing (Bratton, 1979; Bratton & Kramer, 1990; Cooke & Farrell, 2001; Fuller & Gill, 2001; Hough, 1965; Russell, et al., 2001; Strole & Anderson, 1992; Stromayer & Warren, 1997; Trumbull et al., 1989). Where deer densities are greater than the historical average (which is the case in most locations), deer overbrowse the seedlings and saplings of certain species, leading to low near-term survival rates and a long-term significant reduction of those species within the forest. In some cases, oaks and other species have become almost completely absent from the forest understory and even the overstory composition is changing, with those species preferred by deer declining significantly (Hough, 1965; Bratton, 1979, Frelich & Lorimer, 1985; Healy & Lyons, 1987; Healy, 1997; Stromayer & Warren, 1997). The decline of these tree species has been directly linked to overbrowsing by a local high density deer population. Deer overabundance and excessive browse pressure has been cited as the reason for regeneration failure in oaks in some eastern U.S. parks (Storm et al., 1989; Healy, 1997).

To further complicate the story, there have been numerous reports that many oak species are experiencing little or no recruitment (regeneration). These scientific observations and many others have documented an apparent lack of regeneration in many oak woodlands and forests throughout the world. This apparent lack of recruitment of oaks in California has been debated for decades (e.g. Sudworth, 1908; Jepson, 1910; Muick & Bartolome, 1987; Swiecki et al., 1993). The apparent lack of recruitment in oaks has largely been inferred from observations of skewed population demographics, where populations are composed of mature adults with few if any saplings and young trees. However, a thorough examination of the literature on oak demography and recruitment in California found that while some of the species are experiencing a relative lack of recruitment, the situation may not be as urgent as believed (Tyler et al., 2006). This is at least partly due to the fact that while recruitment is low, so is adult mortality and adult oaks can live for hundreds of years.

Deer and Trophic Dynamics

The Miwok hunted mule deer (*Odocoileus hemionus hemionus*), likely keeping the density of the resident Valley population relatively low. There was and is likely infrequent immigration of new individuals into the Valley due to its insular nature. We can argue that today there exists an environment in the Valley that is favorable to mule deer. We can think of the Valley as containing a simple three level trophic system – a top carnivore, an herbivore, and a plant. The trophic system is a food web where each trophic level is comprised of species within the same functional group (such as herbivores). The carnivore in this case is either mountain lions or humans, the herbivore is the mule deer, and the plant is the black oak. Although this is much simplified, we can use it as a general model of how the system is functioning. In the system of Yosemite Valley, we may have effectively removed the two top carnivores: mountain lions and humans. In doing this we may have altered the trophic system, leading to what is called a trophic cascade of effects as the effect of removing a top carnivore cascade down to and through the lower trophic levels. The removal of a top carnivore will have the effect of increasing the densities of their prey base (the mule deer), which would in turn results in a decrease in the health, density, or abundance of their food source -- oaks. Unfortunately, Yosemite does not have long-term data on the densities of mule deer either in the Valley or the entire park.

The trophic cascade theory has been supported by research that examined the fate of the growth and survival of certain plant species both in the presence and absence of a top predator. McLaren and Peterson (1994) studied the interactions of wolf and moose populations and the effects on balsam fir growth. On Isle Royale in Canada where wolf are absent, they studied the response of balsam fir to the introduction of moose. Since moose introduction, the overstory cover of this species declined from 46 percent to five percent over a period of 150 years. Terborgh et al., 2001 examined islands within a newly created reservoir in Venezuela and found that on those islands where there were no mammalian predators, the densities of herbivores (monkeys and iguanas) increased dramatically, which had a negative effect on the densities of many tree saplings and seedlings. The same was not found on the nearby mainland where the predators were present. Schmitz et al. (2000) reviewed 60 studies that each examined a case of a potential trophic cascade. They found that in 45 of them where a top carnivore was removed from the system, there was a significant negative impact on the growth and/or survival of plants studied.

Ripple and Beschta (2006) have linked the decline of cougar abundance in Zion National Park to the presence of visitors. They hypothesize that this decline has led to an overabundance of their prey, mule deer, which in turn have overbrowsed their preferred plant, the riparian cottonwood, leading to its decline. The authors have also attempted to link black oak decline in Yosemite Valley to an overabundant deer population that was created through a hypothesized effective removal of the top predator, the mountain lion (Ripple and Beschta, 2008). In both these cases, the area examined was not truly insular in nature where the predator was demonstrably absent, but instead only functionally insular if predator avoidance of humans is occurring. The authors presented a case that this avoidance was indeed occurring in Yosemite and Zion. Other research has found high ungulate (e.g. deer) densities and/or high browsing pressure near areas of human development in national parks, including Banff in Canada (Hebblewhite et al., 2005) and Denali in Alaska (Wolf & Cowling, 1981).

Mountain lions may be effectively removed from Yosemite Valley through their avoidance of humans. Although there are few studies that have documented that mountain lions actively avoid humans and areas of human habitation and disturbance (Van Dyke et al., 1986), it is generally thought amongst cougar specialists that this is the case. However, there are cases where lions have become habituated to humans (Cougar Management Working Group, 2005). Yosemite does not have data on the frequency of mountain lion activity in the Valley. There have been visitor sightings of mountain lions in the Valley, though no hard data has documented the numbers and frequency of those occurrences. The other predator – human – is removed from the system since hunting is not allowed within the park. Hunting was initially banned in Yosemite sometime in the period 1889 to 1890 (Johnston, 1995), but the policy may not have actually been implemented until several years later. There is a reference to Colonel S.B.M. Young refusing to issue new firearm permits in 1896, and warning that he will confiscate any guns found (Greene, 1987).

The herbivores in this trophic system -- mule deer -- appear to be abundant throughout the park and in the Valley. The Valley is unique in that it contains a resident population of mule deer that do not migrate with the seasons, as the others do outside the Valley. As the Valley has only one outlet down the gorge to the west that is itself a difficult passageway, it is believed that the deer in the Valley remain there year round (S Thompson, pers. comm.). Staff wildlife biologist Steve Thompson knows of several sightings of mountain lion in the Valley in the last twenty years and he believes that those instances were when either a mother was attempting to teach a cub to hunt, or several juveniles were forced into the Valley by an unusually high lion population in the Sierra Nevada. Given the information known about mountain lion behavior, it is certainly possible that mountain lions avoid Yosemite Valley due to its high abundance of humans and human noises. Furthermore, on one recent occasion when lions were observed in consistently close proximity to humans the Valley, they were killed to avoid any potential harm to staff and visitors.

It is very difficult to monitor the populations and movements of mountain lions due to their nocturnal and generally secretive movements. Few estimates of population densities have been made, but one in California and one in Texas found that their densities range between 0.21 and 3.6 per 100 km^2 (Cougar Management Working Group, 2005). Yosemite is approximately 3000 km^2. Using the range of densities found elsewhere, the population of cougars within the park would be in the range of six to 108 animals.

If we assume, based on limited evidence, that mountain lions are either absent or infrequent visitors to the Valley, then the three tiered trophic system of Yosemite Valley is thus thrown out of balance, with an abnormally high density of mule deer which then exert an abnormal pressure on the plants that they feed upon. An absence of oak tree seedlings, and especially saplings, and an aging adult population would certainly suggest the disrupted trophic system as one potential cause, though it would not prove this hypothesis. Only extensive field research and rigorous analysis of data would lend credence to the trophic cascade theory. The trophic imbalance situation is mentioned by Cahalane (1941) in his discussion of wildlife overabundance in parks. The author examines the problem of overabundance of deer and other ungulates in national parks. In Yosemite, he posits that while deer are habituated to human presence, mountain lions are

not, resulting in an increase in the deer herd in Yosemite Valley which has in turn caused heavy destruction of browse plants. Deer and other ungulates have in fact been found in higher densities within national parks and other protected areas than in surrounding public and private lands (Wright et al., 1933; Underwood & Porter, 1997; Porter & Underwood, 1999).

Mule deer are primarily browsers, feeding on the leaves and stems of shrubs and seedlings, as well as oak acorns and other seeds or fruit. There are several species of broadleaf oaks in the Valley which are a food source for deer: black oak, canyon live oak, and huckleberry oak. Only canyon live oak and black oak are found on the Valley floor. The leaf structure of the black oak and canyon live oak are different in that the leaves of the live oak are evergreen and are thicker (contain more cellulose), while those of black oak are winter deciduous and are much thinner (containing less structural cellulose). This likely makes the black oak leaf more palatable than the live oak leaf to any leaf browsers.

Oaks and Roads

Throughout much of the distribution of the arboescent oak species in California, recruitment of new trees appears to occur preferentially along roadsides. Roadsides are the strips of land immediately adjacent to the road that are usually separated from the surrounding lands by a fence of some type. Research has suggested that the roadsides act as refugia for oak recruitment where they are able to recruit in the absence of browsing. Deer and other ungulates, the primary browser of oaks, avoid road corridors (Carbaugh et al., 1975; Singer, 1975; Rost & Bailey, 1979; Forman & Alexander, 1998), while cattle and other browsing mammals are kept out of the roadside by the fence. The noise and presence of moving traffic along roads may also act as a deterrent to deer activity. The effects of roads on animals and their behavior have been well documented (Forman et al., 2003). In Yosemite Valley, the authors have observed areas along roads where black oak recruitment is high. Theoretically, these areas are acting as a refuge from deer and other mammal browsing.

Management Efforts by the National Park Service

An attempt was made in the 1930s (likely between 1932 and 1934) by the Yosemite Field School to create deer exclusion areas within the Valley to see what effect this would have on plants (Allen et al., 1970). This effort was made in response to a perceived overabundance of mule deer and the negative effect they were having on certain plant species in the Valley. Three plots of about 50 square feet were surrounded with eight foot fencing, located in Bridalveil meadow, El Capitan meadow, and near the "Indian caves." These plots were revisited in 1959 and observations made of vegetation types and health both inside and outside the plots. In general, vegetation was somewhat to much thicker and taller within the exclosures. Shrubs like *Ceanothus integerrimus*, *Ribes nevadensis*, and *Rubus parviflorus* were present and healthy inside the exclosures but either entirely absent or heavily browsed and stunted outside. It was noted at the El Capitan plot that while there were abundant black oak seedlings inside the plot, there were none in the vicinity outside the plot. There was no mention of any oak saplings either inside or out of the El Capitan plot. There was also no mention of oak seedlings or saplings either inside or outside the other two plots.

An effort was begun in 1990 to address this perceived (whether real or not) decline of black oaks in the Valley and in response to the designation of the black oak stands as a sensitive resource. This restoration effort included planting 500 black oak seedlings within a pure stand of black oaks just south of the Valley schoolyard (Fritzke, 1997). At the time, the perceived decline in black oaks was attributed to the suppression of frequent fires that then allowed invasion of the stands by conifers. This implies that there used to be frequent natural fires that were then suppressed when Yosemite became settled by Euro-Americans. A more accurate statement would be that the infilling of black oak dominated stands by conifers could be the result of a return to pre-Native American managed landscapes where black oaks were a component of the mixed forest, rather than it's dominant or only species. The restoration project was and is apparently attempting to restore the landscape (at least partially) to its state as encountered by the first Euro-American settlers in approximately 1850; this state was one of intense management by the Native Americans inhabiting the Valley (Reynolds, 1959; Angress, 1985; Wickstrom, 1987).

Following the initial restoration effort in the early 1990s at least another 150 black oak seedlings were planted near or within the same schoolyard stand and within the newly renovated mall south of the Visitor Center. The progress of all planted seedlings was monitored closely for the next two years, then periodically after that.

Methods

Study Site

The research study area included the floor of Yosemite Valley from the eastern end including Mirror Lake and Happy Isles to the Pohono bridge on the western side (Figure 1). This area encompasses approximately 1,342 hectares. Within that general study area, we selected vegetation polygons from the 1997 vegetation map (Aerial Information Systems, 1997) where black oaks were either the dominant species (California Black Oak Forest Alliance; California Black Oak-Incense Cedar Forest Association; California Black Oak/Bracken Fern Forest) or named as a significant subdominant species (Ponderosa Pine-Incense cedar/Black Oak-Canyon Live Oak Forest). The spatial extents that each type covered are listed in Table 1. Black oaks were present in most areas in the Valley. The Valley floor is dominated by Ponderosa Pine-Incense Cedar/Black Oak-Canyon Live Oak Forest, though there are significant areas of meadows, Douglas Fir-Incense Cedar Forest, Ponderosa Pine-Incense Cedar Forest, and Canyon Live Oak-Ponderosa Pine Forest, and some developed areas.

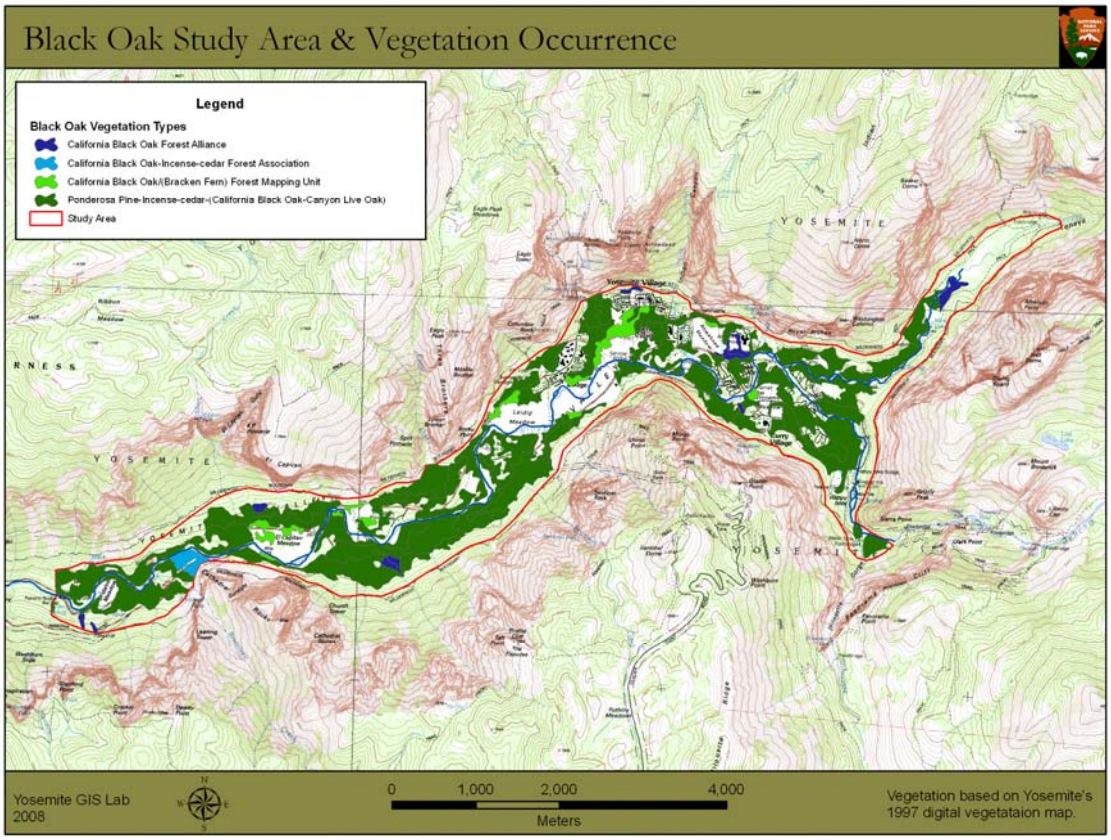

Figure 1: The study area and extent of black oak occurrence. Includes all occurrences of black oak as mapped and classified using 1997 aerial photography (Aerial Information Systems, 2007)

Table 1: Spatial extent of forest and woodlands with black oak as a component within the study area.

Vegetation Type	**Black Oak Status**	**Area (ha)**	**% Total**
California Black Oak Forest Alliance	Dominant	18.7	2.9
California Black Oak-Incense Cedar Forest Association	Dominant	8.2	1.3
California Black Oak/Bracken Fern Forest	Dominant	30.2	4.7
Ponderosa Pine-Incense Cedar/Black Oak-Canyon Live Oak Forest	Subdominant	582.4	91.1
Total		639.4	100

There were two components to the description and analysis of black oak distribution and abundance in the Valley. The first was the examination of the current demographic structure of black oak populations Valley wide, both independent of roads, and next to roads. The purpose of the demographic analysis was to document the current

state of black oak population structure and then to relate possible differences across its distribution within the study area to various ecological and physical factors that may explain those differences. The second component was a historical analysis of the temporal change in black oak distribution, mortality, and recruitment. This component sought to establish any trends in the distribution of black oaks in the Valley and to document how populations have changed over time through rates of mortality and recruitment.

Oak Stand Demographic Structure

The field work to describe the current structure of black oak populations was divided into two separate field studies. One part surveyed black oak stands Valley-wide to document how and if population structure varied over the entire landscape. For this part we chose to randomly locate 48 0.1 hectare circular demographic plots distributed evenly amongst different soil types with the goal of documenting black oak demographic structure across the entire spectrum of soil types. The soils data was intersected with the vegetation data to determine where they overlapped. The soils data was provided by the Natural Resources Conservation Service (NRCS, 2006). The minimum mapping unit in Yosemite Valley was one acre. There were 12 soil mapping units (types) represented within the study area. These 12 soil types intersected with the four black oak vegetation types to yield 48 soil-vegetation intersections. We then randomly located 24 plots within areas where soils and black oak dominant vegetation types intersected, and 24 plots within areas where soils and black oak subdominant vegetation type intersected (see Table 1). Spatial data intersection and generation of random locations was accomplished in ArcGIS 9.2 (ESRI). Soil is known and expected to be an important variable in determining the presence and abundance of a given plant species. Soil polygons also represent a stable terrain unit that will remain unchanged over time, even as the distribution and abundance of individual species and species associations may change and so provides a convenient method of comparing plant species over space and time.

Field crews used Trimble GeoXT, ProXT, or Recon GPS units to locate each random plot center. In two cases, the random plot center was not in an area with black oaks, but the remaining 46 did have black oaks in the immediate vicinity. The two plots that did not contain black oaks were not sampled. Each 0.1 hectare circular demographic plot was laid out with the random X,Y coordinate as the plot center, and a radius of 17.8 meters. Four transects were laid out in the four primary compass directions (N, E, S, W). Along each of these transects was placed a 2 x 4 meter subplot to assess vegetation cover (Figure 2). Random values between 0 and 13 were used as the starting point for each subplot that shared one long side with the transect line and extended two meters out and 4 meters along the transect line.

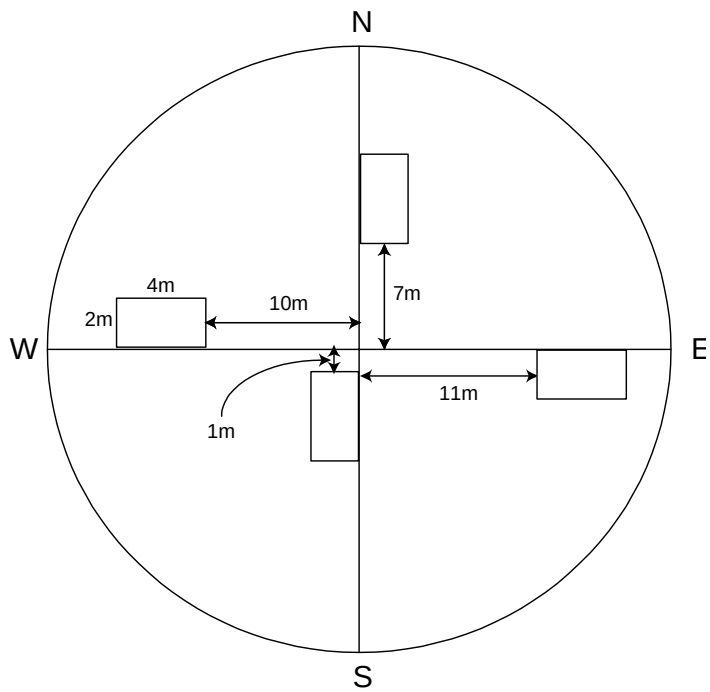

Figure 2: Black oak demographic circular 0.1 hectare plot. Plot radius is 17.8m.

Within each of the 2 x 4 meter subplots, all vegetation and ground cover was visually assessed and placed into one of seven Braun-Blanquet cover classes:

Cover Classes

0 = not present
+ = sparsely present; cover very small (less than 2%)
1 = Plentiful but of small total cover (2-5%)
2 = 5-25% cover
3 = 26-50% cover
4 = 51-75% cover
5 = greater than 75% cover

Within each of the four two by four meter subplots, all black oak seedlings and saplings less than three meters in height were inventoried. In all demographic plots, all black oaks taller than breast height (1.3 meters) were inventoried and their DBH (diameter at breast height, ~1.3m) measured.

In each 0.1 hectare plot, field crews walked along both the East and West transects and recorded the height, distance from transect, number of leaves, and any mammalian browsing evidence for the closest black oak seedling (<1 meter height) at each one meter interval. (17 intervals for each transect). The DBH of each black oak greater than 3 meters in height within entire 0.1 hectare plot was recorded. Finally, all woody species within the plot were counted and placed in one of four categories: <1m; 1-3m; 3-10m, and >10m in height. Four to six photo points were also taken with a digital camera.

Densities of seedlings, saplings, and adults in the plots were compared to many physical and biological factors to explore possible relationships that may explain any

variation in the demographic variables. Variables were chosen that were believed a priori may explain differences in black oak demographics. These variables included: soil type, mapping vegetation, number of black oaks per plot, distance to the Merced River (or large tributary), height above the Merced river, distance to nearest building, number of times burned since 1970, shrub cover in plot, rock cover in plot, total canopy cover, and the number of overstory pines per plot. Simple linear regression and analysis of variance (ANOVA) was used to explore and test relationships between the black oak demographic variable (dependent) and all the explanatory variables (independent). Demographic variables were also compared between the two vegetation types (black oak dominant and subdominant) using ANOVA to test for differences.

Roadsides

The second component of the demographic analysis focused on populations or stands of black oaks along roads with the goal of detecting any differences with distance from road. The roads within Yosemite Valley were intersected with the vegetation data to get those segments of road that passed through areas that contained black oak. Along these sections of road, 20 random points were generated. Those 20 points became the center of a four plot system, each plot 2 meters wide by 20 meters long. Two plots were placed on each side of the road. Each pair of plots at each location included one plot immediately adjacent to the road shoulder (that strip adjacent to the road that is disturbed to some degree), while the second plot was parallel to the first but 12 meters farther from the road (10 meters separated the borders of each plot of the pair) (Figure 3). This was repeated on the other side of the road.

The 20 locations were selected within areas that were mapped as black oak dominant or black oak subdominant, and thus we expected to find oaks at all locations. Random locations were then selected along all sections of existing road that intersected the vegetation polygons that had been mapped as containing black oaks.

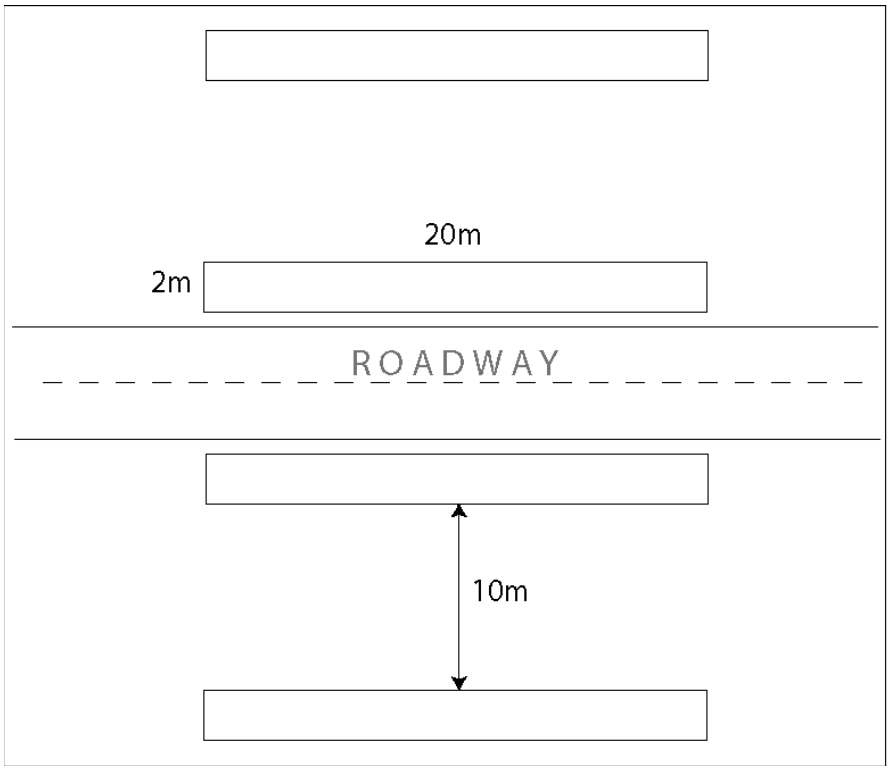

Figure 3: Schematic diagram of roadside demographic plot layout. Four plots were place per location: two on the north side, and two on the south side.

Field crews again used GPS receivers to locate each random location along the road system. At each location, the four temporary plots were set up. Within each of the four plots for the road effect survey, all adult black oaks were recorded and all seedlings and saplings were inventoried and placed into one of three height categories: <1m; 1-2m; >2m. A total of 80 subplots were surveyed in this part of the field study: four plots at each of the twenty randomly selected locations along roads in the study area. Differences in seedling, sapling, and young adult densities in plots were compared through ANOVA.

Temporal Analysis

In addition to the field work to describe current conditions across the distribution of black oaks in the Valley, we conducted a temporal analysis of black oak distribution and adult mortality and recruitment within selected black oak stands in the study area. Historical aerial photography (DDE 1944, 1:20,000 scale, black and white) from 1944 was provided by Pacific Western Aerial Surveys and scanned at 800 dpi. The scanned raw images were then georeferenced and georectified in ArcGIS 9.1 using georectified NAIP (National Agriculture Inventory Program) digital ortho photoquads as the base map.

This 1944 photography was then compared to the 2005 NAIP color DOQ imagery to assess changes in both the extent of identifiable pure black oak stands and to determine the stand mortality and recruitment rates where individuals within the population could be distinguished. Using the 2005 imagery and 1937 Yosemite vegetation map as a guide,

monospecific (or nearly monospecific) stands of black oaks were mapped in both 2005 and 1944. Only three locations within the study area qualified as being monospecific black oak stands that could be easily assessed for temporal changes.

The only practicable method to assess the change in black oak cover from 1944 to 2005 was to first map black oak stands in 1944 where black oak was clearly the dominant (though not the only) species present in a stand. Through photographic interpretation of the 1944 black and white aerial photographs, nine separate black oak dominated stands were mapped, ranging is size from 0.9 hectares up to 104 hectares. Black oaks are the dominant (though not only) broadleaf species in the study area and are easily distinguished in the black and white photographs from conifer species based on grayscale darkness, canopy shape, texture, and shadowing. It was difficult, however, to distinguish black oaks in the 1944 photographs from other broadleaf trees such as canyon live oak and black cottonwood. These two species are present in the Valley and do intermix with black oak in at least some of the locations.

The nine 1944 black oak dominated polygons were then intersected with the 1997 vegetation data to find overlap with the 1997 mapped black oak vegetation types. These intersections were used as the units to assess the temporal change. We placed a regular grid of points with equal 25 meter spacing over the digital aerial photographs and used the points to estimate percent cover within each intersected polygon (e.g. black oak in 1944 and California Black Oak Forest Alliance in 1997). So, for example, if there were 50 grid points that were contained within one of the overlapping black oak polygons, and 25 of them intersected with any part of the canopy of black oaks, then the polygon was said to have a 50 percent cover of black oaks.

Due to the difficulty in following the fate of individual trees between 1944 and 2005 in most locations where black oaks either intermingle with pines or where they form a forest or woodland of overlapping or adjacent canopies, just two locations were evaluated for adult mortality and recruitment. The black oak adults in these two locations, one if El Capitan meadow and the other south of the Valley school, were mostly distinguishable from other individuals – in many cases the canopies did not overlap. All trees in the two locations were field mapped in 2008 using aerial photo printouts of the two groves. Individuals from 1944 were mapped from aerial photo interpretation where individual oaks could be distinguished from pines and from other oak individuals. Population density and population mortality and natality rates were then derived by comparison of mapped populations in the two locations. The rates were again compared for statistical significance with ANOVA, assuming equal variances.

Results and Discussion

Oak Stand Demographic Structure

Figures 4-6 illustrate the demographic makeup of these individuals in the 0.1 hectare circular plots. The data indicate that there is a relative absence of the smaller size categories in all locations sampled – particularly those trees with a DBH of less than 20 cm. A peak in frequency occurs in the 20-40 cm DBH size category, with a steady decline in frequency in larger size classes.

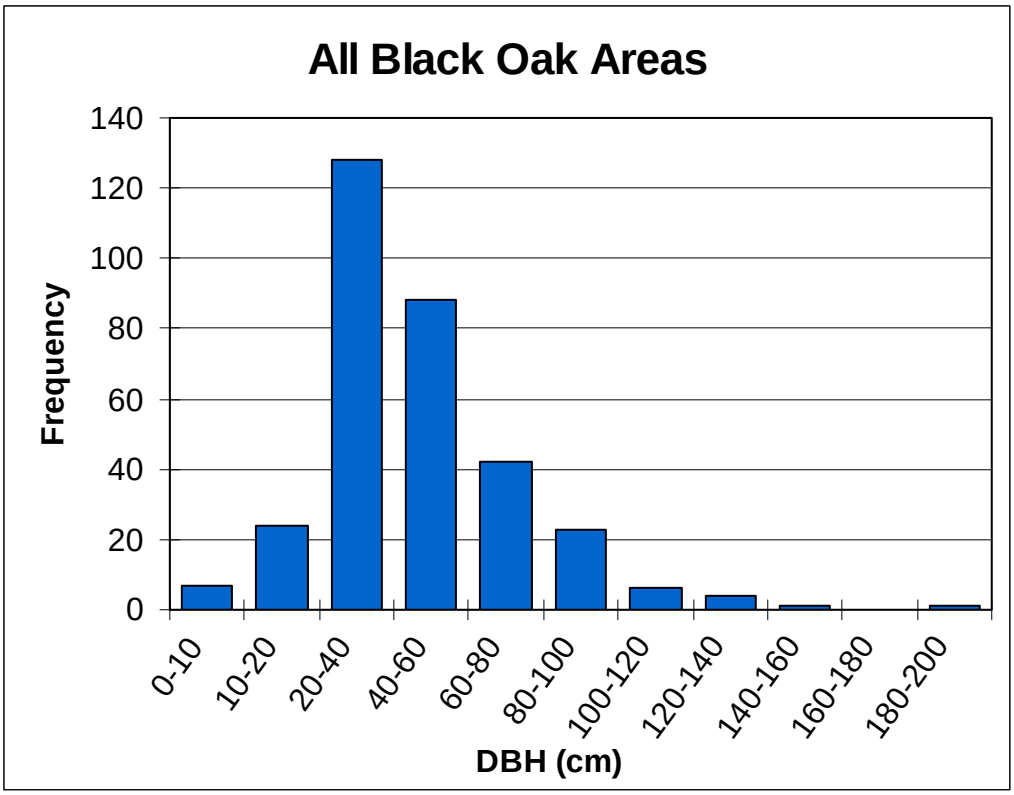

Figure 4: Histogram of the diameter at breast height (DBH) of all black oaks greater than 1.3 meters in height in all demographic plots (n = 46)

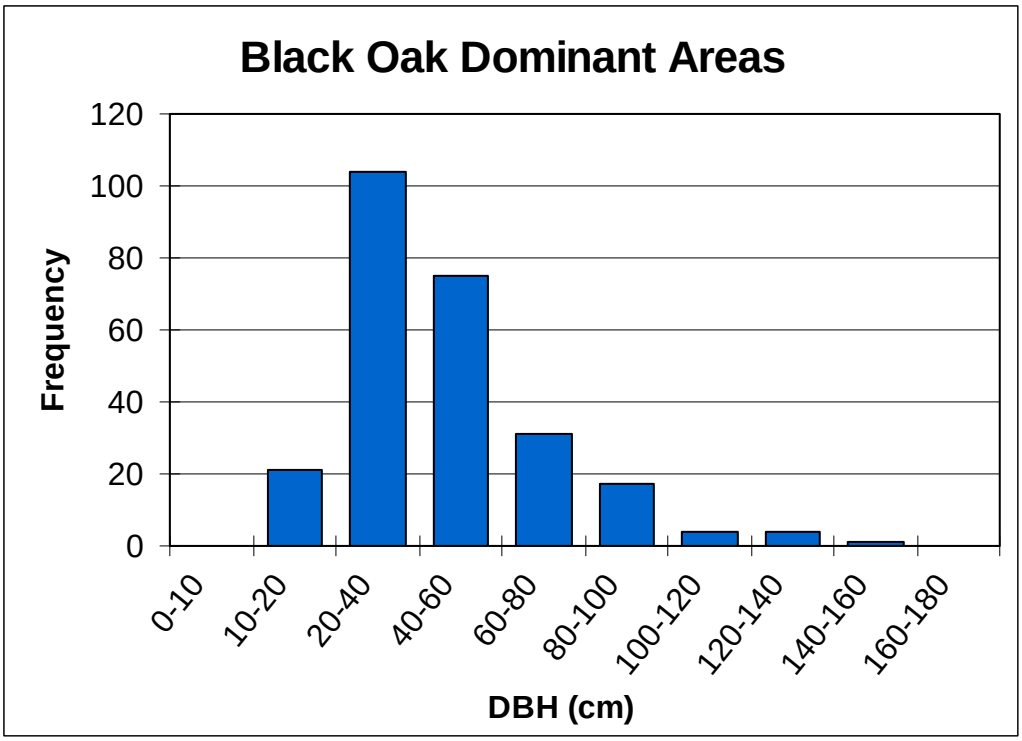

Figure 5: Histogram of the diameter at breast height (DBH) of all black oaks greater than 1.3 meters in height in demographic plots located in areas where black oaks were the dominant tree species (n = 23)

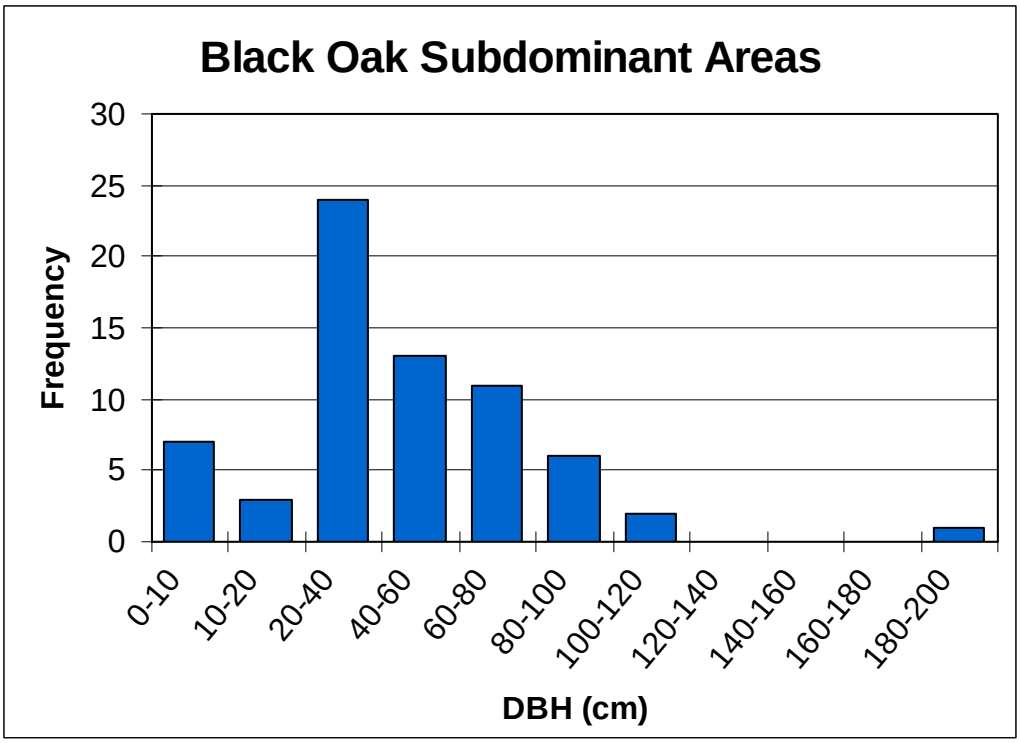

Figure 6: Histogram of the diameter at breast height (DBH) of all black oaks greater than 1.3 meters in height in demographic plots located in areas where black oaks were a subdominant tree species (n = 23)

Ripple and Beschta (2008) inventoried black oak stands in Yosemite Valley and measured the DBH of over 3000 individuals, finding that the large majority of individuals were older than approximately 80 years, though a small percentage of individuals were younger. In the current study we found a similar situation with demographic structure. Ripple and Beschta (2008) cored 27 black oaks form the floor of Yosemite Valley and determined a relationship between DBH and age:

$$Age = 5.35(DBH)^{0.795} + 11 \quad (r^2 = 0.77)$$

We measured the DBH of 325 trees in the 46 plots. Based on the above relationship, we found a mean age of 121 years, and a range of 18 to 347 years (Figure 7). According to Ripple and Beschta (2008), they found a drop off in black oak recruitment beginning in approximately 1920, a time when mountain lion hunting in the Valley was instituted. From 1920 until 2006, a period of 86 years, 79 individuals of the 325 that we measured were recruited into the Valley populations.

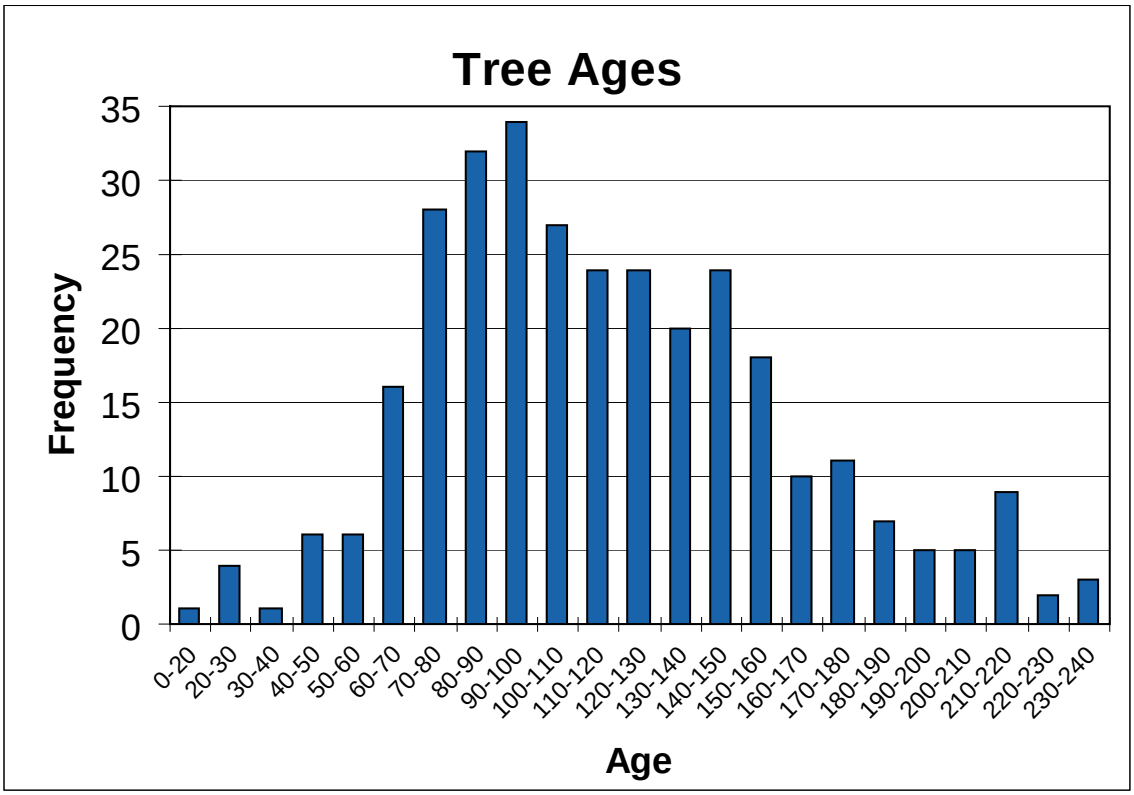

Figure 7: Frequency of 10-year age classes for all 325 adults black oaks inventoried. Age classes greater than 240 years not included.

In each plot, all black oak adults (> 3m in height) and all saplings (1-3m in height) were inventoried. The numbers of seedlings per plot was extrapolated from the surveys in the four 2x4 meter subplots. Eleven of the 46 demographic plots had no seedlings. Overall, the percentage of seedlings to the total number of oak individuals (seedlings + saplings + adults) was 63%. The mean percentage of saplings to the total number of individuals was 4.3%; there were 12 plots that contained at least one sapling, while 35 plots had none. The mean percentage of adults to the total number of individuals was 33%; there was at least one adult in all but two of the plots. Table 2 summarizes the demographic makeup of the plots.

Table 2: Proportions of seedlings, saplings, and adults in the demographic survey plots.

	Seedlings	**Saplings**	**Adults**
# plots with size class present	36	12	45
Mean % of total # of individuals	62.7	4.3	33.0
Ratios	Seedlings:Adults	Saplings:Adults	
Mean	7.1	0.28	
Range	0 - 40	0 - 4	

A typical demographic structure of a population of trees would have many seedlings, fewer saplings, and even fewer adults and take the form a reverse "J." The structure of most of the black oak populations sampled demonstrated a deviation from this expected pattern; saplings were less abundant than adults and much less abundant than seedlings. The mean ratio of saplings to adults was 0.28. As the sapling stage is the critical stage in the population dynamics of many oak species, the densities of saplings were regressed against a number of variables that may influence their survivorship.

The numbers of saplings per plot was regressed against soil type, vegetation type, distance to river, nearest road, and nearest building, height above the Merced River, number of times burned, number of black oak adults per plot, number of overstory pines, shrub cover, and rock cover (ground). There was no relationship between sapling density and any of the independent variables. None of these factors explained a significant proportion of variation in the number of black oak saplings per plot. See Table 3 for a summary of these factors. The same was true when seedling density per plot was regressed against all the variables individually.

Table 3: Summary of variables that were tested for a relationship with the number of black oak saplings per plot.

Variable	Mean	Range
Soil type	NA	Xeric – Mesic
Vegetation type	NA	Dominant – Subdominant
# black oak adults/plot	6.9	0 - 32
Distance to River	227m	24 – 613m
Distance to nearest road	161m	18 – 796m
Distance to nearest building	2286m	16 – 6100m
Height above Merced R.	14.1m	0.9 – 108m
# times burned	1.1	0 – 5
Shrub cover in plot	+*	0 – 4*
Rock cover in plot	1*	0 – 2*
% total canopy cover	44%	5 – 80%
# overstory pines/plot	8.4	0-31

* Cover classes for shrubs and rock estimated for 4 subplots. Classes: 0 = no cover; + = 1-2%; 1 = 2-5%; 2 = 5-25%; 3 = 26-50%; 4 = 51-75%; 5 = >75%.

A multivariate analysis of all factors investigated to compare pairwise correlations found only a few weak relationships ($r^2 > 0.5$). Some of these had no relevance to the study focus, such as percent rock cover increased with distance of plot from the Merced River. Perhaps only one weak correlation is worth mentioning: the greater the distance of the plot from the nearest road, the greater the number of overstory trees (all species) though the relationship is not strong ($r^2 = 0.504$).

Dominant Vs Subdominant

Analysis of variance (ANOVA) tests were run on demographic variables to compare black oak dominant to black oak subdominant plots. The mean DBH of adults in those plots where black oaks have been floristically classified as dominant was 61.3 cm versus 48.5 cm where they have been classified as one of the subdominant species; the difference is marginally not statistically significant ($p < 0.06$). All other woody species were inventoried in each plot. The mean number of overstory (> 10m) pines per plot was 6.7 for black oak dominant areas and 10.0 for black oak subdominant areas. This difference, however, was not statistically significant ($p < 0.06$). When the densities of seedlings, saplings, and adults are compared between the two types of black oak woodlands/forests, there are some significant differences (Table 4). Adult density in black oak dominant plots was 11.2 versus 2.8 in black oak subdominant plots, a significant statistical difference ($p < 0.0001$). Seedling densities were also statistically different: 57.8 (dominant) and 15.0 (subdominant). However, the density of saplings was not statistically different even though the sample size was small.

Table 4: Means (and standard deviations) of adult, sapling, and seedling densities in black oak dominant and subdominant plots. Probability that means are actually the same given under the *Difference* column. ANOVA assumes equal variances.

Variable	**Dominant**	**Subdominant**	***Difference***
Adult density	11.2 (8.6)	2.8 (2.3)	P < 0.0001
Sapling density	0.7 (1.4)	0.8 (1.3)	P < 0.89
Seedling density	57.8 (50.4)	15.0 (18.8)	P < 0.0007
Overstory conifers	6.7 (7.3)	10.0 (7.6)	P < 0.06

Existing Oak Restoration Project

We attempted to check the status of various past attempts to plant black oak seedlings in order to document the success rate (or tree mortality rate) of the efforts. Unfortunately, detailed records were not maintained on the numbers and locations of the plantings. We do know that there were several locations where hundreds or even thousands of young black oak seedlings were planted: Ahwahnee meadow, south of the Yosemite Valley school baseball field, next to Sentinel Bridge, near Happy Isles, and Lower River Campground. In all, thousands of seedlings were planted. Some of the seedlings were protected from deer browsing with above ground caging (using hogwire), though the exact number of seedlings originally projected is not known. Many of the cages were removed in subsequent years. Many of the seedlings were also planted with a hardware cloth (galvanized aluminum) cage around the root system. An arborist discovered that the hardware cloth was restricting the growth of the roots and an attempt was made to partially dig down around the roots of many or most of the seedlings to remove the hardware cloth. It is unknown to what extent the hardware cloth contributed to the deaths of seedlings.

The result of all the plantings was perhaps a few dozen seedlings that survive today, a grim result. This would put the survival rate at less that 5%. This implies low

seedling survival even when they were protected both above ground from mammals and below ground from rodents.

Roadsides

We sampled for differences in black oak population demographic variables at 20 different locations along roads. Plots were rejected if black oak adults were not in the vicinity (within ~25m), and/or fell within a vegetation type that did not contain black oaks. Out of a maximum total of 80 plots, 21 were rejected, leaving 59 that were sampled. We compared the numbers of individuals/plot in each of the three size classes between the plots next to the road (Near plots) to those plots 20 meters farther from the road (Far plots). Only the numbers of saplings (1-2m in height) differed between the near and far plots (Table 5).

Table 5: Mean numbers of individuals in each size class, by location and their statistical differences. Total number of plots = 59. Differences tested by ANOVA; an asterisk indicates statistical significance at the 5% level.

Size class	**Near (n = 31)**	**Far (n = 28)**	**Prob**	**ANOVA**
<1m	7.74	10.75	0.498	
1-2m	2.03	0.39	0.037	*
2-5m	1.19	1.07	0.762	

In order to test the hypothesis that roadsides in some locations may be providing a refuge from deer browsing, plots were first identified as being likely candidates for refugia or not. Refugia candidate plots were located along strips of vegetation that were squeezed between the roads and other physical barriers such as the Merced River or a steep cliff. The actual degree to which the barriers on either side of these potential refugia sites were actually preventing or reducing access by deer was not directly examined, and so the effectiveness of the barriers in making the refugia are unknown. Therefore, this comparison is more exploratory rather than a definitive analysis of site differences. Table 6 includes details of the comparison of the numbers of black oak individuals in the three sizes classes between refugia and non-refugia sites. While the number of seedlings (<1m) and saplings (1-2m) were the same, there was a significantly higher number of young adults (2-5m) in the refugia sites versus the non-refugia sites. This would indicate that in the refugia sites, saplings are more likely to survive into young adulthood. The fact that the numbers of saplings (1-2m in height) were the same would tend to not support the refugia hypothesis, though the numbers may be described as weakly different (4.11 vs 0.74, $p<0.133$). There appears to be a general trend in numbers as size class increases in the refugia sites, a trend not seen in the non-refugia sites. This would indicate an elevated survival rate seedlings and saplings in the refugia sites.

Table 6: Mean numbers of individuals in each size class in potential refugia versus non-refugia sites. Differences tested by ANOVA; an asterisk indicates statistical significance at the 5% level.

Size class	Refugia (n = 9)	Non-refugia (n = 50)	Prob	ANOVA
<1m	9.55	9.48	P < 0.98	
1-2m	4.11	0.74	P < 0.133	
2-5m	1.28	0.33	P < 0.007	*

Temporal Analysis

The spatial intersection of the mapped black oak stands between 1944 and the 1997 digital vegetation map resulted in 19 areas of common intersection (polygons). These polygons were evaluated for black oak cover change from 1944 to 2005. Table 7 summarizes the results of the temporal change in black oak cover between 1944 and 2005 in the areas examined. Although some locations experienced increases in cover and some experienced decreases in cover, many remained unchanged. Overall, there was no canopy cover change in the aggregate over the 61 year period.

Table 7: Black oak cover change between 1944 and 2005 for 19 sites containing black oaks in Yosemite Valley. Cover is fractional percent of the polygon defining each site.

Vegetation Type	1944 Cover	2005 Cover	
Black Oak Forest Alliance	0.48	0.40	
	0.78	0.78	
	0.71	0.71	
	0.91	0.61	
	0.92	0.80	
	0.53	0.79	
	0.37	0.47	
	0.78	0.89	
	0.75	0.81	
Black Oak/Bracken Fern Forest	0.34	0.35	
	0.21	0.17	
	0.46	0.34	
	0.26	0.30	
	0.52	0.48	
	0.57	0.67	
	0.56	0.51	
	0.68	0.59	
	0.36	0.50	
Black Oak-Incense Cedar Association	0.43	0.40	
Mean	0.559	0.556	P = 0.97
Variance	0.044	0.041	

Beyond changes in canopy cover, we were interested in examining the changes in population density as well as individual mortality and recruitment (population birth) rates so that we could determine if population densities were stable, increasing, or declining. Due to the nature of most black oak stands and mixed forests in the Valley, there were only two locations were we could have confidence in discerning individual trees in both 1944 and 2005 aerial imagery: the woodland adjacent to El Capitan meadow ("El Cap") and the woodland south of the Valley School ("Schoolyard"). For this comparison, only mature trees were compared. It was difficult to determine the species of trees with a small canopy size (~< 5 meters diameter) and so these were excluded from the analysis.

A perimeter for the two woodlands was delineated in order to compare the two times. Table 8 details the population metrics for the two locations compared. In both woodlands, there was a decline of tree density over the 61 year period. In the schoolyard woodland, there was a 12 percent decline in population size as a result of the loss of 19 individuals over the 61 year period. No new individuals were recruited into the adult population over this time period. In the El Cap woodland, there was also a net loss of trees over the 61 year period. However, there was also some recruitment into the greater than 5m canopy diameter size – 9 trees or three percent of the population size – that added adults into the population. The deaths of 26 individuals over the same period resulted in a net loss of 17 individuals or 5.7 percent of the population.

Table 8: Population changes in El Cap and Schoolyard woodlands

Woodland	**# in 1944**	**# in 2005**	**Recruitment**	**Mortality**	**Size change**
El Cap	299	282	9 (3.0%)	26 (8.7%)	-17 (5.7%)
Schoolyard	153	134	0	19 (12.4%)	-19 (12.4%)

El Cap woodland area = 10.6 ha; Schoolyard woodland area = 5.5 ha.

General Oak Status

According to the 1997 vegetation map, there are only 8.9 hectares of black oak dominated stands in Yosemite Valley. This represents only 0.7% of the approximately 1,342 hectares of the Valley from Pohono bridge east up to Happy Isles and Mirror Lake. However, black oaks are found in much of the conifer dominated forests in the Valley where they are a minor component. Therefore, black oak dominated stands represent an extremely small part of the Valley ecosystem.

Conclusions and Recommendations

Contemporary Stand Structure

The stand structure of each of the demographic plots we inventoried was essentially equivalent: sufficient adults, many to no seedlings and few to no saplings. This type of demographic structure has been seen in populations of oaks species throughout California (Tyler et al., 2006) in most but not all locations. We can conclude that some factor, or combination of factors, beginning approximately 85 years ago

(~1920) has resulted in a reduction in the rate of recruitment that has persisted to this day. This change began in approximately 1920, then accelerated in the subsequent 40 years, and has resulted in an ever increasing mean size and age of the black oaks within populations in the Valley as the populations mature and few new individuals enter adulthood. As figure 7 illustrates, the reduced number of trees in the younger ages will translate into a very small population of older adults as that generation matures and the older generations die. If the pattern of greatly reduced recruitment continues, then the future of black oaks in much of the Valley will be one of significantly lower numbers.

A healthy and persisting population of trees would be composed of many seedlings, fewer saplings, even fewer young adults, and fewer still older adults. This is the model of plant populations that are persisting in the long-term. Each year many seeds are produced, many of which sprout to produce seedlings, but then factors work to cull that seedling cohort such that most do not survive into the sapling stage. Not all saplings then survive into adulthood. The plots surveyed clearly showed populations skewed toward older adults with few saplings and young adults. Most plots still had many seedlings as would be expected, but the bottleneck appears to be survivorship between the seedling and sapling stage. Some factor is significantly reducing this rate below sustainable levels.

We explored a number of variables that we thought a priori might explain some of the variation in the numbers of seedlings, saplings, and adults in plots throughout the Valley. Factors such as distance to nearest building, road, or trail that might explain some type of direct or indirect human effect had no relationship with plot demographic dependent variables. No physical factors, including general soil type, soil moisture regime, distance to river, height above river, burn history, or the amount of rock substrate had any relationship with the demographic variables. Furthermore, no biological elements that we examined explained any of the variation in black oak demographics: vegetation type, density of black oak adults, density of conifers, shrub cover, and total canopy cover. These results suggest that the factor that is causing the skewed black oak stand demographic structure is nothing inherent about the locations themselves and the physical and biological makeup of the locations, but rather something that is operating Valley wide and appears to equally affect all sites despite all their biophysical differences.

Others have taken a look at black oaks in the Valley in the past, finding some conflicting information and making some interesting observations. Heady and Zinke (1978) surveyed vegetation in Yosemite Valley and they state in their report that black oaks were present in all size categories, although their data shows that there were very few individuals in the sapling size (0.3 – 1.8m in height). They found that black oaks showed more browsing evidence than most other tree species, but the authors concluded that the browsing level was not excessive and would not be detrimental to tree survival. Gibbens and Heady (1964) attempted to document the direct and indirect effects of humans and their activity on vegetation in the Valley, attributing the observed lack of black oak reproduction to deer browsing. Angress (1985) inventoried Valley vegetation and found that although black oak seedlings were abundant, there were few sapling sized oaks. Fritzke (1997) drew the conclusion that the observed lack of black oak recruitment was the result of increased browsing by rodents and deer which both had become relatively overabundant due to the lack of predators in the park. However, she does not support this assertion with data. As to the observed lack of black oak recruitment, she

also lays some blame on human trampling and destruction. The Schoolyard black oak woodland was fenced off to keep out visitors and restored in 1988 (Fritzke, 1997). However, not a single sapling has been natually recruited into this population in the 18 years following the restoration. This fact would disfavor the direct human causes for lack of recruitment. However, deer and other animals have had free access to this site over this period of time.

It is possible that we are seeing a trophic cascade of effects in the Valley if in fact, the top predators have been removed. In insular systems where a top predator is missing, research has found a trophic cascading effect on some species of local plants favored by the herbivores (e.g. McLaren & Peterson, 1994; Terborgh et al., 2001; Ripple & Beschta, 2006). Perhaps Yosemite Valley, or even the greater park, is also insular in nature where top predators are kept in check through behavioral avoidance such that they are effectively removed from the system (at least partially), or that their influence is significantly reduced. We would have to establish that the carnivores are actually absent, which we have not done. The pattern of negative impacts on certain plants, such as we have observed with black oaks, fits the model of a disrupted trophic cascade, but it is unknown if the predator is truly absent or in low enough densities to have limited influence on the herbivore of the trophic system.

It is possible that Yosemite Valley contains an altered trophic system where an artificially high deer population exerts a highly elevated browsing pressure on plants, including black oak seedlings and young saplings, reducing their survivorship. The exact mechanism by which the deer population may have grown to abnormally high densities in the Valley and the larger park is unknown. Whether it is the result of an effective exclusion of mountain lions by humans as posited by Ripple and Beschta (2008), or through lack of hunting, or through the altered behavior of bears, is uncertain at this point. However, the data and analysis in this report does show that the reduction in the rate of black oak recruitment did occur simultaneously with or soon after the reported eradication of mountain lions in Yosemite, and so appears to support the trophic cascade theory. Other factors that we did not closely examine may play a role in elevating the density of deer.

There have been many anecdotal accounts of deer browsing seedlings and eating acorns in Yosemite. Within a set of plots he established, Dixon (1944) observed mule deer in the Valley pull up as many as 80 percent of the black oak seedlings in order to eat the attached acorns. Heady and Zinke (1978) observed that black oaks in the Valley showed more browsing evidence than most species. Gibbens and Heady (1964) concluded that the limited black oak reproduction in the Valley was the result of excessive deer browsing.

A popular argument to explain the lack of black oak recruitment is that the infilling conifers are shading them out and killing many oak seedlings and saplings before they can reach adulthood (e.g. Angress, 1985). It is thought that the faster growing conifers outcompete the oaks for sunlight, eventually killing the oaks before they can reach adulthood, and even killing established adults. This infilling by conifers has been promoted by the lack of fire, since fire as part of the system was essentially excluded from the Valley when the traditional annual burning practices of the Miwok inhabiting the Valley were curtailed, then stopped after 1855. Angress (1985) attributes the lack of black oaks greater than one meter tall to shading by conifers. However, Gibbens and

Heady (1964) document that in about 1920 a vista clearing concept was promulgated for the Valley and the overgrowth of conifers and brush was reduced. If conifers were removed for a period following 1920, then we would expect to see a pulse of new oak recruits dating to this time. But our findings clearly show that the opposite is true: black oak recruitment declined from 1920 onward.

Other evidence tends to weaken the hypothesis that black oaks have declined due to invasion by conifers. The largest two black oak woodlands, the Schoolyard site and El Capitan meadow, have few conifers, but they have also experienced little to no recruitment of new individuals since 1944. In particular, the schoolyard black oak woodland restoration site has seen no infilling of conifers during the 18-year post restoration time during which there was no new recruitment of black oaks into the sapling stage. Clearly, at least in these two sites, shading out by infilling conifers can not be blamed for the lack of black oak recruitment. While shading by conifers can likely be ruled out as a factor in suppressing oak recruitment, the lack of conifer recruitment into these stands is at least partially due to a policy of cutting down conifer saplings in these areas.

Is infilling by conifers shading out black oaks and leading to their decline? An argument can be made for the apparent persistence of black oaks in the greater landscape whether they are locally dominant or a subdominant component of the mixed forest. Oaks are apparently not disappearing in mixed forests where they are surrounded by conifers. Although the density of black oaks in areas where they are a subdominant species was significantly less than their density in areas where they are the dominant species (2.8/plot versus 11.2/plot), the number of conifers within these two general vegetation types was not significantly different (6.7/plot versus 10.0/plot). If infilling of conifers are really shading out black oaks we would expect about the same density of black oak adults in the two vegetation types since conifer density is about the same, but this is not the case. Other factors appear to be at work to allow black oaks to continue to dominate some locations rather than others, even though conifers are present in roughly equal densities in the two vegetation types. This observation does not support the theory that infilling conifers are shading out the black oaks. Rather, the data suggests that a factor is working at the Valley scale rather than at the stand or site scale to reduce oak recruitment Valley-wide.

To support the idea that an altered trophic system is reducing oak recruitment in the Valley, we would have to find evidence that deer are abundant and mountain lions are not, or at least that mountain lions are not killing deer in enough numbers to reduce their high population densities. There is conflicting evidence about the population densities of mule deer in the Valley. Gibbens and Heady (1964) documented that deer were trapped and removed from the Valley starting in the early 1930s and continuing until 1941 in order to reduce the browsing pressure on local plants. We do not know how thorough or effective this effort was and so we can not conclude whether or not this evidence supports or undermines the trophic cascades theory. Colby (1953) observed that deer appeared to be much more abundant in 1953 compared with his first visit to the park in 1894 which he attributes to greater access to meadows that used to be fenced off and grazed by cattle and sheep.

Instead of the view that the mule deer population in the Valley is abnormally high (or dense) because this location has few to no resident mountain lions to cull the

population, perhaps deer are adjusting their behavior and actively entering the Valley to avoid predation by cougars that are more abundant elsewhere. The behavior of some mammals in the presence of humans and human activity has been shown to be altered in relation to their predators. Back in 1910 during a visit to Kenya, John Muir observed and concluded that most of the large herbivorous mammals on the Kenyan plains had learned that the closer they are to railroad lines, the safer they are from attack from either humans or lions (Branch, 2001). In Grand Teton National Park and surrounding lands, Berger (2007) examined moose behavior over a ten year period and discovered that female moose selectively chose birth sites near roads, shifting these sites away from their predators, the brown bear, which are averse to auto traffic and actively avoid roads. In contrast, he found that, independent of bear distribution, nonmothers did not change their behavior; neither did mothers in areas absent brown bears. This is an interesting aspect of the ecology of roads and road systems where there is a human—predator—prey interaction. In most cases mammals actively avoid roads (Forman et al., 2003).

On a broader scale, deer have been found to be more abundant within parks and other reserves, possibly exhibiting a predator avoidance behavior where the protected area is surrounded by private and/or public lands where hunting is permitted (Porter & Underwood, 1999). It is certainly possible that deer are congregating in Yosemite in greater numbers due to the in park hunting ban that has been in effect since the 1890s.

Is there really an artificially high density of deer in Yosemite Valley today? The answer to this is unknown since the park does not monitor the herd size in any way. Anecdotal evidence certainly suggests that today deer are abundant in the Valley, while the picture for mountain lions is even less clear. In occasional years, there have been dozens of sightings of cougar in the Valley by visitors. However, we are uncertain whether each encounter represented a different individual or if the same individual was seen dozens of times the same summer. Furthermore, even though one or more mountain lions may occasionally inhabit the Valley, there is little data to support the idea that they are having an effect of the deer population.

Certainly, it appears that deer are ever present throughout the Valley at all times of the day. If, for the moment, we are to assume that the Valley has an overabundance of deer, what effect would we predict they would have on plants, and on black oaks specifically? The answer to this question lies in the broad literature that has documented the negative effects of an overabundant deer population on many plant species. The effect of abnormally high deer densities on the composition and structure of forests throughout the world has been so pervasive and significant that some regard these mammals as keystone species (Stromayer & Warren, 1997; Waller & Alverson, 1997; Russell et al., 2001). When white-tailed deer were introduced into a fenced off portion of a biological reserve in Michigan in the 1970s, they overwhelmed the local carrying capacity and therefore had strong and persistent negative impacts on the vegetation (McCullough, 1979). Cote et al., (2004) conducted a review of the literature concerning the effects of overabundant deer herds on local vegetation and they found a worldwide phenomenon – significant negative effects of deer on many forest species in North America, Europe, Asia, and New Zealand.

Following a period of relatively low deer densities in Europe and North America, restrictive hunting laws have lead to a dramatic increase in deer densities over the past 75 to 150 years (McShea et al., 1997; Fuller & Gill, 2001). For example, in Virginia, white-

tailed deer increased from statewide population size of 25,000 in 1931 to about 900,000 by the early 1990s (Knox, 1997). It is unknown whether deer densities in North America seen today are greater or less than those found historically prior to European settlement, but some evidence suggests that today's herds are larger than they've ever been (McCabe & McCabe, 1997). Alverson et al., (1988) estimate that in the mixed coniferous forests of Wisconsin, deer densities currently exceed pre-European settlement deer densities by a factor of 2 to 12. The state of California has not tracked an accurate estimate of the size of the state's deer population, but using hunting permits and kill records as proxies, the number of deer in the state appears to have expanded from a low of 375,000-450,000 in 1910 to approximately 800,000 today (CDFG, 2004), higher than at any time in the past.

Deer impacts have been documented not only in the United States (Stromayer & Warren, 1997; Waller & Alverson, 1997), but also in many parts of the world including New Zealand (Stewart & Burrows, 1989), Japan (Shimoda et al., 1994), and Europe (Fuller & Gill, 2001; Cooke & Farrell, 2001). In these regions, deer populations are at or above historical levels. A high density of deer in forests and woodlands can have a negative impact on the survival of tree seedlings. In some places, excess deer browsing has resulted in the failure of some tree species to recruit new individuals into the young adult stage because over browsing has resulted in the killing or stunting of seedlings (Stewart & Burrows, 1989; Cooke & Farrell, 2001; Fuller & Gill, 2001; Gill & Beardall, 2001; Rooney, 2001). Studies have documented local recruitment failure of eastern hemlock (*Tsuga canadensis*) and regional decades-long recruitment limitation due to overbrowsing of seedlings by deer that has resulted in changes in the population size and structure of this species in the forest (Frelich & Lorimer, 1985; Alverson et al., 1997). Others have found that deer had a negative impact on large seedlings and small saplings, and thus limited recruitment of eastern hemlock at a regional scale in the Upper Great Lakes area (Rooney et al., 2000). Northern white cedar (*Thuja occidentalis*) trees are experiencing widespread recruitment failure in North America (Rooney, 2001; T.P. Rooney, S.L. Solheim, and D.M. Waller, unpublished data) and are a favored food of deer. This phenomenon has been at least partially explained by excessive deer browsing.

Research on the influence of deer and other large herbivore browsing has found that certain species of trees seem to be especially sensitive to browsing. Deer browsing can significantly slow or completely eliminate recruitment of seedlings and saplings of some species. This has been found to be true of oaks in Georgia (Bratton & Kramer, 1990; Strole & Anderson, 1992), Massachusetts (Healy, 1997), and Pennsylvania (Trumbull et al., 1989), yew in the Great Lakes region (Frelich and Lorimer, 1985), hemlock (Hough, 1965; Mladenoff & Stearns, 1993; Alverson & Waller, 1997), northern white cedar (Rooney, 2001) and other woody plants (Stewart & Burrows, 1989).

While it appears that black oaks in Yosemite Valley have been declining in density for the last 80-90 years, we have little information to corroborate this trend in areas outside the Valley. However, some long-term research from two plots in Yosemite that are in the black oak elevation zone but outside the Valley, has tracked the recruitment of saplings and adult mortality from 1991 to 2006. During this time period, there was no new recruitment of saplings and a steady mortality of adults (VanMantgem, pers. comm.). Adult mortality ranged between 2.47 and 3.81 percent annually. Although this is a small sample size, it does suggest that the situation for black oaks outside the Valley is similar to the situation in the Valley, in at least some locations.

In our efforts to explore all factors that might explain the current structure of black oak populations in the Valley, we also considered changes in the hydrology of the Valley. The Merced River and its tributary streams have a long history of manipulation by Euro-American settlers from the time of their arrival in 1855. Milestone (1978) examined the history of changes to the stream system of Yosemite Valley and documented that the Merced River and many of its tributaries have experienced significant management actions in the past century or more. Most of these have involved manipulation of the main Merced River channel including bank stabilization and gravel harvesting. However, many of the tributary streams have undergone at least some channel rerouting or confining. It is uncertain whether, if examined together, all the channeling of tributary creeks has had a long-term effect on soil moisture levels and the larger-scale hydrological regime of the Valley. Since these stream alterations have not occurred at the same time, but rather have been spread out over a century or more, it would be difficult to link ecological changes to changes in hydrological regime.

One event significantly altered the hydrology of the Merced River in 1879. In this year, boulders in the river channel at the El Capitan moraine (just east of Bridalveil straight) were blasted, resulting in a river channel bottom that was 5-6 feet lower than previously. Before their removal, the boulders acted to restrict flow and effectively damned up the river during spring runoff, creating a temporary lake upstream from this point that flooded meadows and forests. There is no other major human-induced hydrologic change that occurred in the time around 1920, when a step change in oak recruitment Valley-wide occurs. Furthermore, even if the boulder removal had a delayed effect, the temporary lake only extended approximately 2 miles upstream of the moraine. Ten miles of the Merced River transect the study area, leaving a full eight miles that would have been directly unaffected by the removal of the river boulders. Therefore, this hydrologic event does not appear to be responsible for the black oak demographic structure we see today.

Although it is uncertain how and how much the hydrological regimes of the Merced River and its tributaries have been altered through manipulation, it is possible that the hydrological processes have been changed significantly. The frequency and severity of flooding in the Valley may have been affected by the human manipulation of channels such that floodplain inundation and surface flows during high water events have been curtailed. In the California central valley, populations of Valley oak (*Quercus lobata*) in floodplains adjacent to large rivers have been documented to have larger proportions of seedlings and saplings than populations found in more upland sites (Knudsen, 1984). It is speculated that frequent flooding of the adjacent floodplain culls the local population of rodents (e.g. gophers, squirrels) that are known to be effective predators of oak acorns and seedlings (Adams & Weitkamp, 1992; Tyler et al., 2008). Flooding could effectively temporarily remove a factor that reduces the recruitment of new individuals into the local population. Although Yosemite Valley has continued to experience large scale flooding events in the past 100 years, the effect of these events on the rodent population is unknown. Even with stream channelization, the Valley has flooded on many occasions, including the most recent 1997 Valley-wide flood event. This event did not appear to result a cohort of new black oak recruits.

Roadsides

The results from the surveys of black oaks along roadsides suggest that although the densities of seedlings and young adults appear to be unaffected by proximity to the road, the density of small-sized saplings has a strong relationship with distance from the road. The plots next to the road had a significantly greater number of saplings than within the plots 12m from the road. This would indicate that the rate of survivorship from the seedling to sapling stage is elevated closer to the road and would support the theory that roadsides are acting as a refuge from deer browsing. Other factors may also explain this difference such as rain runoff carried into the adjacent roadside, or a fertilization effect from car exhaust.

The influence of water runoff to augment soil water available may be a factor in the elevated seedling to sapling survivorship. However, studies have shown that the effects of road traffic on vegetation within the adjacent roadside are almost exclusively negative as many pollutants (including heavy metals, PCBs, and hydrocarbons) that come from the road surface and from autos are carried into the roadside (Kobringer, 1984; Federal Highway Administration, 1996). The pollutants accumulate in the roadside soil, resulting in stunted vegetation and a vegetation composition composed of pollutant tolerant and disturbance loving annuals and perennials in the zone closest to the road (Trombulak & Frissell, 2000; Forman et al., 2003). Research has indicated that pollution and disturbance in the roadside zone may outweigh the potential benefits of augmented water from runoff, leading to reduced tree growth adjacent to roads (Iqbal & Shafiq, 2000). A positive effect of water on roadside vegetation growth has been only found in desert environments (Holzapfel & Schmidt, 1990) where water augmentation would be significant. A link between NO_x fertilization (from car exhaust) and enhanced roadside vegetation growth has only been documented in one case (Angold, 1997).

A more widespread systematic survey of roadside oak recruitment would be needed to more fully understand the link between roads and recruitment. The authors have identified many sites along roads where there are high densities of oak saplings, but most of these were not included as part of the unbiased survey. An examination of these sites may reveal factors which may be causing the elevated recruitment.

Refugia

We have observed several locations in the Valley where there are relatively high black oak sapling and young adult densities. All of these sites are adjacent to roads. None of these sites was captured in the plot sampling in this study. Ripple and Beschta (2008) examined the structure of black oak populations in Yosemite Valley in locations where they presumed deer could not easily access (refugia sites) and in areas where deer had easy access (non-refugia sites). They compared the number of individuals recruited since 1920 into these ostensible refugia sites with non-refugia sites and found a highly significant difference. While the non-refugia sites showed a substantially reduced rate of new recruitment since 1920, the refugia sites had a much higher rate of recruitment in the same time period. The authors apparently used the incidence of browsed flower buds on evening primrose plants (*Oenothera elata*) as evidence that deer were accessing a site, though this species was not present in all locations (including non-refugia sites). In those non-refugia sites that had evening primrose, 98% of the plants showed evidence of deer browsing. Their refugia sites were also narrow strips of vegetation squeezed between the

Merced River and either Northside or Southside Drive; the width of these strips is generally less than 20 meters. Although the authors did not directly determine that deer were not accessing the refugia sites and that deer were regularly accessing the non-refugia sites, their results do offer a potential case of the effects of altered trophic systems and the effects of trophic cascades on plants (oaks).

The present study also identified several of the roadside demographic plots that may be within one of the ostensible refugia areas squeezed in between the road and either the Merced River or a steep granite wall. In this case, the roadside near and far plots were considered as individual plots rather than plot pairs. The data show that there was no difference in the density of seedlings between the nine refugia sites and the 50 non-refugia sites. There also was no statistical difference between small sapling density between refugia (4.11) and non-refugia (0.74) sites ($p < 0.133$), even though the densities were substantially different (due to the high variance in the refugia sites). There was a statistically significant difference in the density of young adults (2-5 meters tall) between refugia (1.28) and non-refugia (0.33) sites ($p < 0.007$). This evidence points to the conclusion that although acorns produce abundant seedlings in all areas examined, in the refugia sites more seedlings are making it into the sapling and young adult stages compared to the non-refugia sites.

A cursory observation of potential refugia sites that are thin strips of vegetation squeezed between Northside Drive and the Merced River reveals an abundance of black oak saplings and young adults. What is it about these locations that is different from most locations in the Valley? Is there a road effect of some sort, or are these places really acting as refuges from deer browsing? Answers to these questions would point us in the right direction in attempting to understand the ecology and persistence of black oaks in the Valley.

Temporal Analysis

The aerial cover of black oak stands, either pure stands or those dominated by black oaks, saw no overall change from 1944 to 2005 (61 years). However, we know that individual oaks have been dying in at least some of the stands. In light of the changes in individual mortality and natality in those stands, the absence of change in cover can likely be explained by an increase in individual canopy size over the 61 year period. Although the number of individuals has declined over the 61 year period in the places we closely examined, each extant individual grew in size and so covered more aerial ground. If the same trend continues, black oak cover will be expected to begin decreasing at some point as extant individuals continue to either grow in size or die. Individual size will reach a maximum, at which point, losses of individuals will begin to more than offset the growth in canopy size of the other extant individuals. Based on tree coring and age estimation of black oak individuals in Yosemite Valley (Ripple & Beschta, 2008), it appears that black oaks in Yosemite Valley have a maximum life span of between 200 and 350 years. If current trends continue, we can expect most black oak dominated stands to be extirpated within the next 100 to 250 years.

We were only able to examine population metrics for two woodlands, though these are the two largest black oak woodlands in the Valley and are located in places of high visitor visibility. The El Cap woodland has seen an overall loss of individuals since 1944, though there has been a small number of new individuals recruited into the

population over the same time period. In 1944 many of the trees were small in size compared to the 2005 canopy sizes. Although we did not directly measure and compare canopy sizes, this woodland has likely experienced significant growth in average individual canopy size over the 61 year period of examination. As the trees continue to mature, a larger percentage will reach "old age" and begin to die in greater numbers. As the youngest individuals in this population are at least approximately 60 years old, this population would completely disappear within 300 years, assuming no new recruitment.

In comparison, the Schoolyard woodland did not experience any new recruitment into the adult population, only losses. This woodland experienced a mortality rate of 12.4 percent over the 61 year period, representing a 0.2% loss in population per year. There was no new recruitment of individuals into this population since 1944. Most individuals appear to be entering "middle age" or "old age." Thus, with no new recruitment, this population will completely disappear within the next 250 years.

We did not examine other oak woodlands or forests, though the authors have observed evidence that the trend is the same in many places in the Valley – a decline in population size. While the rate of decline found in the two woodlands we examined is not critical, it does highlight a potential disturbing trend that will require further attention.

A Holistic View

There are several possible explanations for the shift in demographic population structure that began to take place after approximately 1920. These include: 1) changes in the local trophic system resulting in overbrowsing by deer; 2) changes in the physical characteristics or system of the Valley such as hydrologic, edaphic, or fire regime; 3) a shift in climate, 4) a shift in the direct human management of the Valley; or, 5) a change in another biological entity or ecological function. Although we did not comprehensively research the literature and the park's historical record to test the other theories, we have come across no strong evidence that would support a relationship between explanations two through five and the decline of black oak recruitment. There have been some very significant changes – fire regime, hydrological regimes and function, human hunting – but none of these appear to correlate well temporally with the pattern of reduced recruitment in black oak populations. The only apparent factor that we examined that could explain the timing of the shift in black oak recruitment is overbrowsing by an overabundant deer population. An overabundant deer population in Yosemite Valley is an assumption based on limited evidence. The mechanism that has created this assumed overabundance may be due to mountain lion exclusion, prohibition of hunting, or other factors. Evidence would certainly suggest that the first explanation cited above is a valid theory, though not fully supported as yet. We do not rule out that the other factors listed (or others not specifically mentioned) could have played some role in creating the patterns we see today.

The evidence we collected confirms that the recruitment of new individuals into extant black oak populations was drastically reduced from historic levels in approximately the year 1920. Since that time, recruitment of new individuals has occurred at a relatively slow rate, leading to populations across the Valley that are deficient or absent trees younger than 85-90 years old. The largest cohort or age group is the group that is 80-100 years old. Older and younger trees are progressively fewer in number. This demographic structure does not reflect a healthy and persisting population.

Some factor has been reducing the survival rate of seedlings and saplings such that there are few young adults. This research supports, but does not prove the theory that alteration of the trophic system of the Valley has lead to the current demographic structure of black oak populations.

Some evidence, mostly anecdotal, suggests that mountain lions were actively removed from the Valley beginning about 1920, the same time we see a change in the age class structure of black oaks. No change in other physical or biological factors occurred around 1920. The fire regime was altered around 1850; the hydrology of the Valley has been consistently and progressively altered from 1851 through today; hunting of deer was prohibited in the early to mid 1890s. It is evident from the history of fire management, general Valley management, and the impacts of a high density of annual visitors, that the natural balance within Yosemite Valley may have been lost. This research suggests that a disruption of the natural trophic system (predator – herbivore – plant) may be at least partially to blame. In addition, what we are likely seeing today in the Valley is the return of the ecological and functional system to the days prior to intense management through the use of fire (by Native Americans).

The history of fire in the Valley has been significant and varied. The 1997 Vegetation Management Plan (USDI, 1997) describes this history and draws the conclusion that the recent decline of black oak woodlands, not only in Yosemite Valley, but throughout the entire park where they historically occur, can be attributed to fire suppression and loss of the intensive Native American burning regime. This may be somewhat overstating the decline and its causes. As Gibbens and Heady (1964) concluded, the extent of black oak woodlands had declined significantly since the Miwok were displaced from Yosemite beginning in the 1850s. However, Reynolds (1959) concluded that aboriginal burning caused the extension of black oak dominance in areas where burning was applied as a management tool. So the change we have seen occur in Yosemite Valley since 1860 may be the process of returning to a dynamic state that existed prior to intensive aboriginal burning. Furthermore, as conifers have filled in within the once open black oak woodlands, the numbers of black oak trees did not necessarily change, only their relative dominance. Due to the relative infrequency of lightning strikes in the Valley, fire suppression in this location may not be as critical to the dramatic change in forest cover documented since 1860.

The current Fire Management program at Yosemite attempts to burn in the Valley to thin out conifers. They also attempt to save the legacy (older) black oaks by cutting conifers around them and moving slash and other woody debris away from the trees prior to burning an area. Black oaks are adapted to survive fire even if the entire tree above ground is killed. The year following a high intensity fire that kills the above ground portion of the tree, it will aggressively resprout from its base, sending up multiple new shoots. With a large resource base stored in the root system, these shoots can grow rapidly. A close inspection of some of the park's recent large high intensity fires such as the Ackerson and A-rock fires that burned in the zone containing black oaks finds that most if not all oaks that were killed have resprouted. In much of the area burned, oaks currently appear to be the dominant tree species by cover.

If the goal of the prescribed burning in the Valley is to restore the area to a more open meadow and woodland/savanna mosaic that existed during the years when the Miwok heavily managed the landscape, then burning large portions of the valley and

protecting oaks would be the methods to use. However, if it is just to restore fire to the system, then actively clearing conifers around oaks prior to burning may not be necessary since fire will kill the conifers but not the oaks that will resprout and quickly come back.

It is worth discussing here the possibility that the reduced oak recruitment that we are seeing today may be part of a natural cycle of long-term black oak ecology. Perhaps successful oak recruitment into the sapling stage (the current bottleneck) requires a set of environmental conditions that do not occur often, perhaps every 50-200 years. And perhaps we have not seen those right conditions come together for 80-90 years. It is possible that oaks experience infrequent punctuated recruitment pulses during good times and that the factors that create these times have not occurred in decades. However, the current demographic structure of the black oak populations we studied does not indicate past punctuated recruitment, but rather a relatively steady rate throughout the last 200 to 250 years.

If one walks through the Valley, one notices that most locations have numerous black oak seedlings (if adults are nearby), but no saplings. But, occasionally we encounter small pockets of saplings. It is possible that black oak recruitment into the sapling stage requires special conditions – the right combination of moisture, sunlight, nursery areas, nutrients – that are very patchy and infrequent across the Valley. These small zones may also move around in time, forming a patchwork of oaks of different sizes. Since black oaks can live upwards of 300 years, not much new recruitment would need to take place to maintain the same density of adult trees over time.

It is also possible that the relatively pure black oak stands in the Valley today (Schoolyard woodland, El Capitan meadow, south of the Ahwahnee), are an artifact of aboriginal management. These stands have not seen significant recruitment of new conifers or oaks in the past 60 years, though it is likely that conifers have been purposefully removed. Perhaps oak seedlings are overbrowsed and do not survive into adulthood, and young conifers are targeted for removal to maintain the sylvan beauty of the black oak woodlands. It is possible that at least some of the relatively monospecific oak woodlands that exist in the Valley today are artificial, and we are attempting to maintain these artificial creations through much effort.

There is no current comprehensive Valley-wide plan to manage black oaks, or even to manage vegetation that addresses all the issues. Two vegetation management plans for Yosemite have been issued: one in 1985 and another in 1997. The 1997 Vegetation Management Plan (USDI, 1997) describes the desired conditions for California Black Oak woodlands and forests within the park. The goals include: 1) …maintain the dominance of valued species (such as black oak), through the localized exclusion of conifers and understory growth; 2) Maintain natural species diversity within an acceptable range of variation; 3) Maintain variability that includes both woodland (open canopy) and forest (closed canopy); and, 4) Maintain variability that includes both pure and mixed stands. The 1997 plan concludes that at that time black oak woodlands (25 – 60% canopy cover) covered only about 10 percent of the area they covered in the 1860s. This analysis was based on comparisons of photos taken in 1866 and again in 1943 and 1961 as shown in Gibbens and Heady (1964), though those authors did not come to that conclusion. What is clear from the repeat photography is that the relative dominance of black oaks, and the woodlands and savannas dominated by them, had diminished considerably since 1866.

What is the long-term management goal for vegetation and wildlife in the Valley? To what end are we burning and attempting to maintain oak groves? In the face of a changing environment, in particular with changing climate, what can we expect to be achieved through vegetation management? At the very least though, Yosemite National Park needs to develop a comprehensive vegetation management plan for the park and in particular for Yosemite Valley. In light of vista management, fire management, vegetation management, visitor management, cultural resource management, and wildlife management, all of which may be in conflict to some degree, a conversation amongst all interested parties desperately needs to occur. However, the actions taken will depend upon whether park management wishes to maintain a static state that may have been created by an earlier management regime, or restore the natural processes that may have been interrupted. However, it is likely impossible or at least highly improbable that both these goals can be achieved.

Therefore, it should be decided what the Park wishes to establish within the entire park and within the Valley. Does management staff wish to return the Valley to the state it was as it existed during the time of intensive Native American management? Or does management staff wish to return the park and Valley to its state as it existed prior to the arrival of Native Americans? On top of this we have a changing climate that will further stress the system and work to change it in ways that are yet to be fully understood. What then is the best approach? Management staff needs to consider many factors in making the best decision in regards to black oaks: 1) How important is it to maintain the extant black oak stands? 2) Will it even be possible to maintain these stands in the current and future environment? 3) Should and will fire be used more intensively as a management tool in Yosemite Valley? 4) Is the goal of the current fire management program to restore the natural (pre-human) or aboriginal fire regime? 5) How will the apparent lack of recruitment by black oaks be addressed? 6) If deer densities are in fact abnormally high, and this overabundance is negatively impacting black oaks, can and should deer populations in the Valley be culled?

This last question is one that has long been an issue in protected areas, especially in national parks. The National Park Service has long grappled with the issue of deer and ungulate overabundance and its effects. The idea of culling deer and other ungulate populations in parks has long been anathema to park managers. Although the NPS is charged with protecting and enhancing resources within parks, park managers may fail to perceive that within parks we may have created an artificial system and that deer overabundance may be a manifestation of dysfunctional and disrupted natural systems and processes. Park management should understand the consequences of any potential deer overabundance and all the costs to other resources that it entails. The “Leopold Report” (Leopold et al., 1963) attempted to provide a comprehensive review of wildlife management in national parks. The report concluded that the fundamental goal of parks should be to create or maintain as well as possible, natural conditions that existed prior to European settlement, and allow natural processes to proceed untrammeled. However, the report did make one exception – for ungulates – because of a need to keep ungulate numbers in balance with their forage vegetation through culling. This recommendation caused significant debate throughout the Park Service and implementation of the recommendation has proved politically untenable.

Porter and Underwood (1999) provide an excellent review of the history and issues of deer overabundance and management in national parks. The authors argue that the NPS has failed to find a solution to the problem of overabundant deer in parks that is acceptable to many of the constituent parties because each party does not have a comprehensive understanding of all components of the system. Just like blind men each touching a different part of an elephant and disagreeing on what it is, the constituents engaged in the debate over deer management in parks are touching (seeing) different parts of the system or problem. Too few have "seen" the entire problem or system and as a result there is no common agreement on the nature of the problem. This same allegory could be also applied to the management of black oaks in Yosemite.

To be sure, more research and an adaptive management approach to black oaks would be a place to begin. Unfortunately, the restoration project begun in 1989 has fallen prey to lack of attention and so it is difficult to determine the success or failure of the project. First it should be determined if continued restoration to maintain certain black oak dominated woodlands is a goal. If so, perhaps it would be more cost effective that a smaller, yet more closely watched and managed, effort be established to encourage the recruitment of natural or planted seedlings. An adaptive management program would establish some long-term plots that would document some experimental manipulations aimed at addressing some of the unknowns or assumptions regarding black oaks and their recruitment.

We probably do not fully understand the past and current factors that are affecting black oak population dynamics in Yosemite Valley. Although evidence would suggest that one possible hypothesis to explain the current demographic patterns of black oaks is a result of overbrowsing by an overabundance of deer, it is still unclear what has caused this overabundance or even if there is an overabundance. Furthermore, we do not assume that deer browsing is the one and only factor affecting black oak recruitment and population dynamics and that should deer populations in Yosemite Valley be reduced, everything will turn out fine for black oaks. The results of the 1990s oak restoration project attest to this. There may be other factors at work such as climate change, climatic variation, insects, disease, plant-plant interactions, and even black oak autoecology that can be working singly or in combination affect black oaks.

We can conclude that today we are witnessing the results of decades and even centuries of varied management in Yosemite. The black oak stands today may be ephemeral in nature for various reasons. What if these relatively pure black oak stands are dynamic in space and time? What if the Native Americans selectively burned and cut down pines in a rotating fashion to create pure stands of black oak that then matured, and then slowly died. These former oak woodlands may have then been allowed to be invaded by conifers and in time became mixed conifer and black oak forests. What if black oaks really need to be a subdominant component of a pine dominated forest or woodland environment to exist or persist? What if they do best over the long-term as a component of the mixed forests rather than as a monospecific stand? Certainly, anecdotal evidence suggests that there is much more recruitment of black oak saplings in mixed forests in at least some locations where black oaks are not the dominant species compared to those locations were black oaks form a more or less monospecific stand.

Much still is to be learned. An adaptive management program would use available information to begin management actions. New information would inform the plan and

alter it as necessary. If Yosemite National Park determines that the current makeup of black oaks in the Valley is something to be preserved, then an adaptive management program would be integral to that goal. Below we provide several recommendations for future management and research.

Recommendations

The results of this research and a review of the literature supporting the theories presented to explain the current demographic structure and suppressed recruitment in black oak populations in Yosemite Valley lead us to some natural recommendations for future management and research.

Management

1. Park management and the Resources Management and Science Division at Yosemite should decide what the long-term goals are for preserving and even enhancing black oaks and the prominent black oak woodlands in Yosemite Valley. This should include data collection to enable sound decision making (see below in the Research section). The discussions and decision making process should include costs and benefits to any restoration efforts proposed.
2. The Resources Management and Science Division, the Fire Management Program, the USGS Yosemite Field Station, and all other interested parties need to hold a discussion on what the long-term resource objectives are for Yosemite Valley. There appear to be potentially conflicting and ill-informed management objectives. Is the goal to re-establish the aboriginal burning/fire regime? Or is it to establish a “natural” fire regime? How does the goal for preserving/enhancing black oaks and black oak woodlands fit into the fire management goals? Is the goal for black oaks to maintain the oak woodlands of Yosemite Valley in their current state (static), or to preserve or re-establish the natural processes that regulate oak and deer populations across the broader landscape? Managing for both these goals would be unreasonable or impossible. What actions would be necessary to achieve these goals? Considering that the current black oak stands may be the result of aboriginal management, then a continuation of Native American management practices would probably be necessary in order to maintain those stands; they burned large portions of the Valley each year.
3. Take a close examination at the efforts and results of the other black oak restoration sites in Yosemite Valley. How successful or unsuccessful were these sites? What can be learned from the process? Since only a very small fraction of the originally planted seedlings have survived to this day, lessons can be learned.
4. If the goal is to maintain the size and density of the prominent oak woodlands – the Schoolyard stand, El Capitan meadow, south of the Ahwahnee – then more active, but perhaps less intensive restoration may be needed. We would recommend that a small number of locally grown oak seedlings be planted in these areas and protected both above and below ground. This effort would be repeated for several sequential years. It may not make sense to plant hundreds of

oaks all at one time. A smaller number of planted oaks would be easier to maintain over time. Their survivorship could be monitored on an annual basis. Many studies have investigated the factors that affect oak seedling survival and the prescriptive management efforts required to ensure a high level of seedling survival. See Tyler et al. (2008) for an excellent example. The fact that only a very small fraction of the over 500 oak seedlings that were planted in 1988 have survived, even when protected from deer browsing, tells us that the factors affecting oak recruitment are complex.

5. Re-examine the policy of cutting down conifers to "protect" black oaks either as part of or exclusive of the fire management program. This may do nothing to enhance the long-term survivorship of individuals and may even have a negative impact on the long-term persistence of black oaks in the landscape. Field research would be required to test various hypotheses in regards to black oak survivorship in mixed forests and woodlands in both the presence and absence of conifers and under different burning regimes (see below).
6. Synthesize the park's current understanding of mule deer populations in Yosemite Valley and the park.
7. Monitor deer behavior in relationship to humans in the Valley. This would shed some light on whether or not they tend to congregate in high human density areas as a behavioral avoidance of mountain lions.
8. Establish a program to monitor the intensity of deer browsing on oak seedlings and saplings throughout the Valley on a long-term basis.

Research

If the issue of preserving black oaks and the black oak stands in Yosemite Valley is deemed of high importance, then some field research and analysis of results would be necessary for several reasons. First, hypotheses would have to be tested to more fully understand the dynamics of oak seedling survival, demographic rates, the effects of fires and other management practices, deer herbivory, deer behavior and population dynamics, and mountain lion behavior and population dynamics. Not all of these issues would require field work and data collection. A review of the available literature could provide insightful information. However, if resources are available, the following research would be useful.

1. In order to fully understand the effect of deer browsing on black oak seedlings and saplings, further research is needed both in Yosemite Valley and in other locations in the park and outside the park. This would provide a larger picture of how variations in black oak population dynamics and seedling survival vary with deer density and browsing pressure. This research should be long-term in nature in order to include interannual variations that work on a scale greater than one or a few years. This research could include experimental manipulations and possibly deer exclosures.
2. Design and implement research that will analyze the intensity of deer browsing on oak seedlings and saplings throughout the Valley on a long-term basis. This effort could quickly assess a set of plots a few times each year and give a clearer picture of the spatial and temporal variability of browsing pressure on black oaks.

3. Take a close examination of the size and persistence of the Valley deer population and how it varies in space and time. This would help solidify the assumptions made about its size and structure.
4. If possible, it would also be extremely beneficial to document both the frequency of mountain lion observations in the Valley as well as the numbers of deer they are killing. This information will help to confirm or disprove some of the assumptions made about the disruption of the local trophic system and its effect on black oaks.
5. For the fire program, we would recommend a policy of testing the effect of prescribed burns on mixed forests and black oak woodlands, using controls to track the fate of black oaks of all sizes in burned and unburned plots over time, again focused on long-term monitoring.
6. Though rigorous field research, test the hypothesis that oaks are being shaded out by infilling and overtopping conifers. This can be accomplished by monitoring the long-term survival of black oak adults that have adjacent conifers to those that have had conifers removed from within their canopy extent.
7. It would be useful to examine deer behavior in relationship to humans in the Valley. Evidence collected in the field could establish whether or not deer are exhibiting altered behavior around humans as an avoidance behavior of mountain lions.

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