RE-OAKING SILICON VALLEY

Building Vibrant Cities with Nature

SFEI AQUATIC SCIENCE CENTER

SAN FRANCISCO ESTUARY INSTITUTE & THE AQUATIC SCIENCE CENTER

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Building Vibrant Cities with Nature

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(cover and also appearing on this page) Valley oak in Joseph D. Grant Park, San Jose, California. *(Photo by Allie Caulfield CC BY 2.0)*

CONTENTS

Coast live oak. *(Photo by Corin Royal Drummond CC BY 2.0)*

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In this report, we investigate how re-integrating components of oak woodlands into developed landscapes — "re-oaking" — can provide an array of valuable functions for both wildlife and people. Re-oaking can increase the biodiversity and ecological resilience of urban ecosystems, improve critical urban forest functions such as shade and carbon storage, and enhance the capacity of cities to adapt to a changing climate. We focus on Silicon Valley, where oak woodland replacement by agriculture and urbanization tells a story that has occurred in many other cities in California. We highlight how the history and ecology of the Silicon Valley landscape can be used as a guide to plan more ecologically-resilient cities in the Bay Area, within the region and elsewhere in California. We see re-oaking as part of, and not a substitute for, the important and broader oak woodland conservation efforts taking place throughout the state.

1 • INTRODUCTION

Before 1900, native oaks graced many of California's now-urbanized valleys. These hardy trees had an unusual ability to thrive on hot, open plains through California's long dry season and frequent drought. Oak woodlands (and savannas with more open canopies) played a foundational role for native wildlife, forming the base of a complex and varied set of food webs involving hundreds of terrestrial vertebrate species, thousands of native insect species, and many associated native plants (Giusti et al. 2005, Swiecki & Bernhardt 2006).

The oaks supported people too. Indigenous Californians have relied on their nutritious acorns as a staple food for thousands of years (Mensing 2006). Broad oak canopies provided the original architecture of many California landscapes, such that early Mexican and American towns were often integrated into oak woodlands to take advantage of their shade and beauty (Mensing 2006, Jepson 1910, Bartlett [1854]1965). Oakville, Oak Knoll, Oakland, Thousand Oaks, Oakley, and many other oak-centric place names reveal the legacy of oak woodlands.

Valley oak near San Jose depicted on postcard from 1905. *(Photo courtesy California Room, San Jose Public Library)*

(top) Landscape painting of Native Americans camped under oaks. *(Photo "Under two great oak trees are two tipis with seated Indians in right foreground; one Indian walking in center; other Indians and tipis in distance." Signature (LL): R.G. Holdredge)*

(bottom, left) Native Americans relied on acorns as a staple food crop. Here, Mrs. Freddie, a Hupa, leaches acorn meal in a sand basin. *(Photo courtesy Phoebe A. Hearst Museum of Anthropology, University of California at Berkeley)*

(bottom, right) Two large acorn granaries, Railroad Flat, Calaveras County. Northern Miwok. *(Photo courtesy Yosemite Online Library)*

By the early 1900s, agricultural conversion of many of California's most fertile valleys had eliminated many oak woodlands. During the 20th century, urban expansion joined agriculture as a dominant threat to oak woodlands. Near the turn of the 21st century, California followed the rest of the world into yet another era: for the first time in human history, over 50% of the earth's population now live in cities (United Nations 2010). The footprint of cities has grown as human populations have increased, and the pace of urban expansion has rapidly accelerated over the past several decades.

As population growth, increasing temperatures, and climate extremes place new demands on our infrastructure, efforts to improve urban resilience will become increasingly necessary. At the same time, there is also strong interest in using urban green spaces and green infrastructure to improve human well-being. These trends highlight a need to identify activities that synergistically enhance both ecological and human health.

Today, we are beginning to envision the next generation of urban trees. Much of the state's urban forest – planted 50-75 years ago – is nearing the end of its lifespan (Bernhardt & Swiecki 2014). Over the next two decades, local communities will create yet another urban forest, planting the trees that will shape the aesthetic character, sense of place, human health, and biodiversity of the mid-and late 21st century California cities. What visions will guide the forest of the future? Might California's native oaks – largely gone for a century – have a greater role to play in the coming century? This report begins to explore that question, focusing on Silicon Valley, the changes that have occurred in that region, and the opportunities within the urban landscape to restore lost elements of oak woodlands.

By the early 1900s, most of Silcon Valley's oak woodlands had been converted to orchards or vineyards. *(Photo courtesy Visual Instruction Department Lantern Slides Collection (P 217), Special Collections and Archives Research Center, Oregon State University Libraries)*

Native oaks, such as the coast live oaks shown here in a median and traffic circle, often thrive in urban settings, producing shade in the summer and reducing runoff in the winter. *(Photos by Shira Bezalel)*

ABOUT THIS DOCUMENT

In this report, we investigate how we might integrate components of oak woodlands into an urban setting in order to create healthy populations of oaks that support oak-associated wildlife and create benefits for people. This report draws from the Landscape Resilience Framework and the Vision for a Resilient Silicon Valley Landscape (Beller et al. 2015, Robinson et al. 2015), which delineates seven dimensions of resilience: setting, process, connectivity, diversity/complexity, redundancy, scale, and people, along with the key elements of each. We draw on this framework to evaluate the potential benefits of oak ecosystems, and to develop specific re-oaking guidance likely to contribute to landscape resilience.

In this report, we describe how oak ecosystems support ecological functions, using both historical and contemporary oak woodlands as models. Focusing on Silicon Valley, we use historical and contemporary data to quantify how these structural and compositional elements have changed over time. Based on these analyses, we propose a set of guidelines for maximizing the benefits of re-oaking to native biodiversity and suggest next steps for application and translation into management plans.

We use the term "re-oaking" because we focus specifically on the oak ecosystems that have been lost from many urbanized areas of California, but the concept could be applied to historical ecosystems in other urbanized areas. Here, we ask how urban greening activities focused primarily on benefits to people might achieve a broader set of benefits, with an emphasis on how ecological functions could be restored to cities by integrating a variety of different types of actions. Our approach builds on other urban conservation-oriented programs, which often promote activities within a single type of landscaping that can improve benefits for particular species of wildlife (e.g., backyard gardens for butterflies).

While building an ecological foundation for re-oaking is an important first step, we anticipate that subsequent steps will be needed. We do not address in detail many of the infrastructure and planting considerations that would be required to carry out a particular project. While we touch on other ecosystem services that re-oaking can offer, such as the potential for carbon storage, temperature modulation, and water regulation, we do not explore these in depth. We also discuss urban forest management issues only briefly, which are addressed elsewhere (for example, see Costello et al. 2011). Therefore, expertise in urban forestry, landscape architecture, and environmental horticulture should be used alongside the guidance provided here in the development of re-oaking programs.

In this report, we explore a variety of potential benefits of re-oaking to people, ecosystems, and wildlife. In Chapter 2, we describe the ecological functions provided by oak woodland ecosystems with an emphasis on how oaks support food webs and biodiversity. We explore the potential ecological benefits and risks of re-oaking, and highlight some wildlife species that could be appropriate choices for additional habitat support in urban areas. In Chapter 3, we quantify how oak woodlands have changed through time, highlighting which elements of oak woodland ecosystems have changed in Silicon Valley, and which remain similar in the urban landscape. In Chapter 4, we provide guidelines that summarize our main findings and direct specific actions that can be taken within re-oaking projects to improve ecological functions. In Chapter 5, we briefly address some of the concerns raised, and we conclude with a brief discussion of next steps that can move re-oaking from theory to practice.

DEFINITIONS

RE-OAKING is an approach to reintegrating oaks and other associated native trees and vegetation within developed California landscapes to provide valuable functions for wildlife and people. We emphasize re-establishing the composition, structure, and configuration that allow oak woodlands to support ecological functions given changes caused by development and expected shifts in climate.

ECOLOGICAL FUNCTIONS are all the ways that ecosystems support life, including nutrient cycling, the flow of energy and materials through foodwebs and across landscapes (including the movement of organisms), and physical and structural features that provide habitat for flora and fauna.

LANDSCAPE RESILIENCE is the ability of a place to sustain desired ecosystem functions over time and under changing conditions. A resilient landscape supports the recovery and persistence of native species and natural communities, yet also allows for ecological transformation and adaptation.

OAKS AND THE EVOLVING URBAN FOREST

Given the foundational role of oaks in many California ecosystems and their extensive loss in many now-urban landscapes, reincorporating elements of oak ecosystems in California cities has the potential to improve the ecological resilience of cities, contribute to regional conservation in areas around cities, and provide benefits for people. Since plants and animals are most well adapted to the climate and environment where they evolved, species that adapted to local conditions are more likely to be able to cope with extremes when they occur, including drought, heat, and fire (Kawecki & Ebert 2004, Meineke et al. 2013). A broad set of ecological literature has also found that in contrast to non-native plants, native plants are more able to support native wildlife, enabling better support for ecological functions and biodiversity (e.g., Burghardt et al. 2009, Isaacs et al. 2009, Threlfall et al. 2017). These general patterns are no less true in oak woodlands, where a shared evolutionary history has resulted in a diverse flora and fauna that are adapted to use and depend on oaks (Pearse & Hipp 2009). Thus, oaks are likely to provide greater benefits to native wildlife than do ornamental, non-native trees. Finally, local adaptation can increase the benefits of a tree to people, both directly and indirectly. For example, in a dry climate, a locally adapted tree can provide greater direct benefits such as reduced water use and increased drought tolerance (Giménez-Benavides et al. 2007, Jump et al. 2008). Economic benefits can accrue via reduced costs if trees are less likely to need maintenance or replacement. Drought-adapted trees are also likely to be more resilient to future climate shifts than many of the urban trees currently in use (Knops & Koenig 1994, Roloff et al. 2009, Costello & Jones 2014).

As we anticipate drier and warmer conditions in the coming decades, trees that may have been appropriate in the wetter mid-20th century may make less sense today. Urban forests will be increasingly important for their temperature-modulating role, yet will be subject to more challenging climatic conditions, placing a premium on drought tolerance. Some of the most common urban trees come from wetter regions and are not likely to fare well in the face of limited water in the coming years (Bernhardt & Swiecki 2014, Costello & Jones 2014). Others create maintenance or nuisance issues and are being replaced. Our native oak species, which are long-lived and occur along a broad climatic gradient to the south, may perform better in some of these settings than many of the most common urban trees.

HOW CAN PEOPLE BENEFIT?

Oaks deliver a number of ecosystem services, or benefits, that are important for people. Some of these services, such as shade and air pollution reduction are not specific to oaks. However, oaks do out-perform other species in the production of other important services. For example, over 45 years, a coast live oak street tree will sequester more carbon than many other common urban trees including sweetgum, London planetree, and magnolia (the three most common street trees in Silicon Valley; Fig. 5, Table 1). Carbon sequestration by urban forests can help to capture some of the carbon dioxide produced by the burning of fossil fuels; an important component of reducing green house gas emissions.

Coast live oak (*Quercus agrifolia*) in particular is also superior to many other non-native street trees in reducing runoff because it retains a dense canopy during the winter. In one study comparing a coast live oak to a pear tree, the oak retained about 15% more precipitation in its leaves and canopy, reducing the amount of water that reached the ground (Xiao et al. 2000). Reducing runoff is important in cities because the swift flow of water over paved surfaces can increase flooding and erosion, while impairing water quality in streams, wetlands, and the Bay. In addition, the oaks native to Silicon Valley consume less water than many other common street trees, including coast redwood which is popular in Silicon Valley today despite being rare on the valley floor historically (Costello & Jones 2014, Fig. 5). The vegetation of native oak woodlands, including the herbs and shrubs that thrive near oaks, generally requires less irrigation than much of the landscaping commonly employed in the region today. Increasing drought-tolerant vegetation and trees can substantially reduce the costs of irrigation, particularly during dry years.

Cultural services, such as aesthetic value and the provision of recreational experiences, are also important. Since the first European explorers entered California, travellers have remarked on the beauty of California's oak trees, and oak woodland ecosystems are one of the most beloved habitat types in California. One measure of this is the premium homeowners pay in California to live near oak woodlands. A study in southern California found a 12% increase in average home price when comparing houses adjacent to oak woodlands to those at a distance of 1,200 feet from a nearby oak stand (Standiford & Scott 2001). Some cultural services

Table 1. Total carbon storage, annual carbon sequestration, and size and height for coast live oak and the 10 most common street trees in Palo Alto, Mountain View, and Cupertino (See fig. 5). Values represent total carbon storage (Kg/tree), annual carbon sequestration (Kg/tree/year), diameter at breast height (inches), and tree height (feet) for trees at age 45 years. Data taken from The Tree Carbon Calculator (CTCC; Center for Urban Forest Research).

Common name	Total CO_2 stored (kg/tree)	Annual CO_2 sequestration at year 45 (Kg/tree/yr)	Diameter at breast height (inches)	Tree height (feet)
Coast live oak	6,813	325	26.7	41.9
Coast redwood	6,689	358	37.2	94
London plane	3,204	146	23.1	54.1
Callery pear	2,683	81	20	39.4
Sweet gum	2,280	94	21.6	56.4
Velvet ash	2,236	134	20.2	48
Camphor tree	770	46	13.8	28.3
Magnolia	753	52	15.3	33.3
Ginkgo	574	34	13	35.6
Chinese pistache	568	17	12.4	33

may also come from the wildlife that benefit from re-oaking activities. For example, many people enjoy watching birds (Wenny et al. 2011), and the economic value of opportunities to bird watch have been estimated to range from $34 to $135 per day (LaRouche 2003).

Re-oaking also has the potential to reduce the biotic homogenization of cities (Groffman et al. 2014) by creating a more locally-based ecosystem that is unique to our climate and geography. While diversity is often high, plants in cities tend to come from a fairly limited number of families, and fill fewer functional roles beneficial for other organisms compared to those in the surrounding native ecosystem (Knapp et al. 2012). For example, the same set of turfgrass, horticultural plants, and street trees are frequent choices throughout the United States, and some urban wildlife (including pigeons, crows, and house sparrows) are common to cities worldwide, contributing to overall trends of biotic homogenization (McKinney 2006, Groffman et al. 2014).

Thus, restoring elements of oak woodland ecosystems to urban environments could make California cities less similar to cities in other parts of the world, reinforcing a distinctive identity and adding character that could complement local landscapes and architecture. Making cities more distinct can also increase the sense of place and attachment that people feel towards their local environment. This type of attachment is not only beneficial for human well-being but can also motivate environmental stewardship and engagement in conservation activities (Gomez-Baggethun et al. 2013). Current landscaping choices reflect a broad set of values, perceptions and aesthetic appeal, and re-oaking would need to be implemented in ways that are consistent with residents' values and interests. A growing movement towards planting native species suggests there may already be some appetite for a change in practices (Brzuszek et al. 2007, Zadegan et al. 2008). As urban forests are expanded, re-oaking can provide a new framework that may better accommodate the need for changes in priorities and perceptions over the coming decades.

Oaklandish, a fashion line and retail store, promotes pride and attachment to the city of Oakland using symbols that showcase the oak tree. *(Photo by Thomas Hawk CC BY-NC 2.0)*

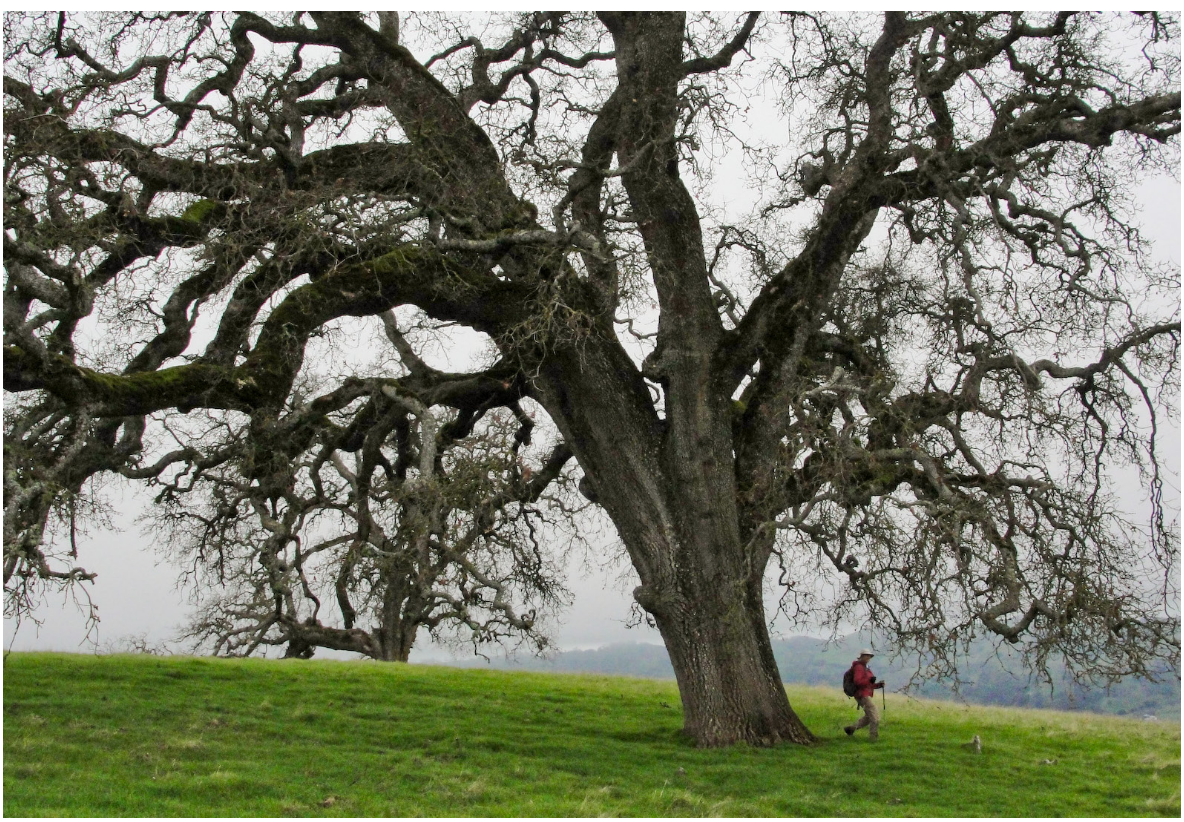
2 • ECOLOGICAL FUNCTIONS

Valley oak with leaf litter in a residential yard, Palo Alto. *(Photo by Dee Shea-Himes)*

INTRODUCTION

Oak woodlands are one of the most diverse habitat types in California, with over 300 species of terrestrial vertebrate wildlife (Guisti et al. 2005), 370 fungal species, and almost 5,000 insect species found in them at some time during the year (Swiecki & Bernhardt 2006). Currently covering roughly 8.5 million acres or 8% of California's land area, oak woodlands are found throughout the state (Gaman & Firman 2006). Their extent has been much reduced from the 19th century as agricultural and urban areas have expanded (Mensing 2006). The defining characteristic of these landscapes are the oak trees, including over 20 species in the genus *Quercus*. Interspersed with the oaks are other trees, including buckeye *(Aesculus californica),* madrone *(Arbutus menziesii),* several species of manzanita *(Arctostaphylos spp.),* wild cherry *(Prunus ilicifolia),* and California bay laurel *(Umbellularia californica).* Trees grew in varying densities, creating savanna-like open areas where grassland and chaparral plant communities dominate. Under the trees, upwards of 2,000 species of herbaceous plants also thrive (Meadows 2007).

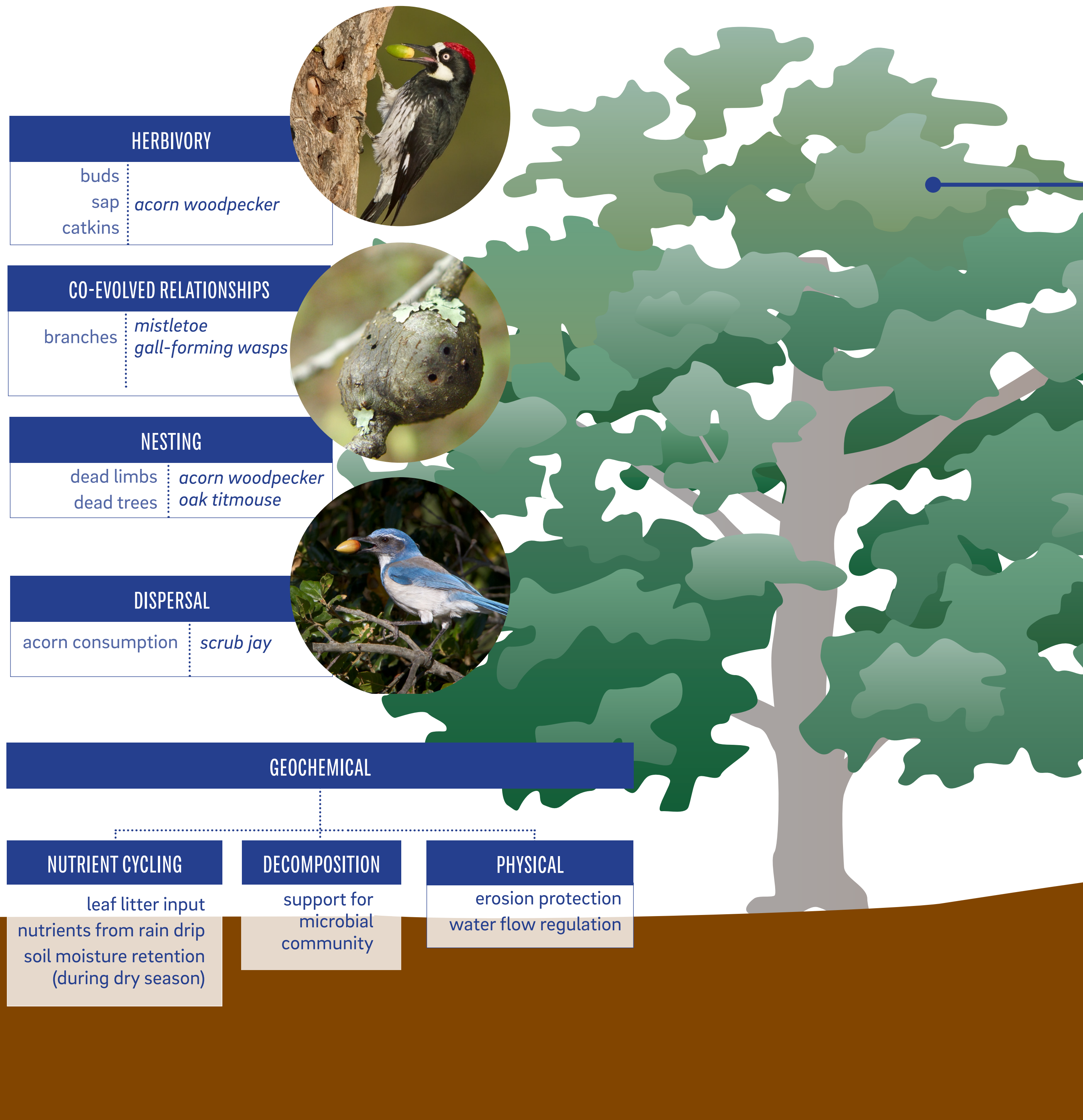
In California ecosystems, oak woodlands support a number of important ecological functions. Oak trees in particular create habitat to an extent that is not easily replicated by other trees. A shared evolutionary history has resulted in a large number of species that are specialized to depend on oaks (Pearse & Hipp 2009). In the next pages, we describe the types of ecological functions supported by oak woodlands, including nutrient and hydrological cycling and support of food webs and wildlife. In addition, we highlight how wildlife also contribute to oak woodland ecosystems. We emphasize that ecosystems depend on a variety of different ecological functions, and are therefore unlikely to emerge from initiatives that focus on single species or taxa. While restoring fully functioning ecosystems to cities may be difficult, adopting a holistic approach with a goal of supporting multiple types of ecological functions will not only lead to greater biodiversity but is also more likely to improve ecological resilience.



(Photo by Miguel Vieira)

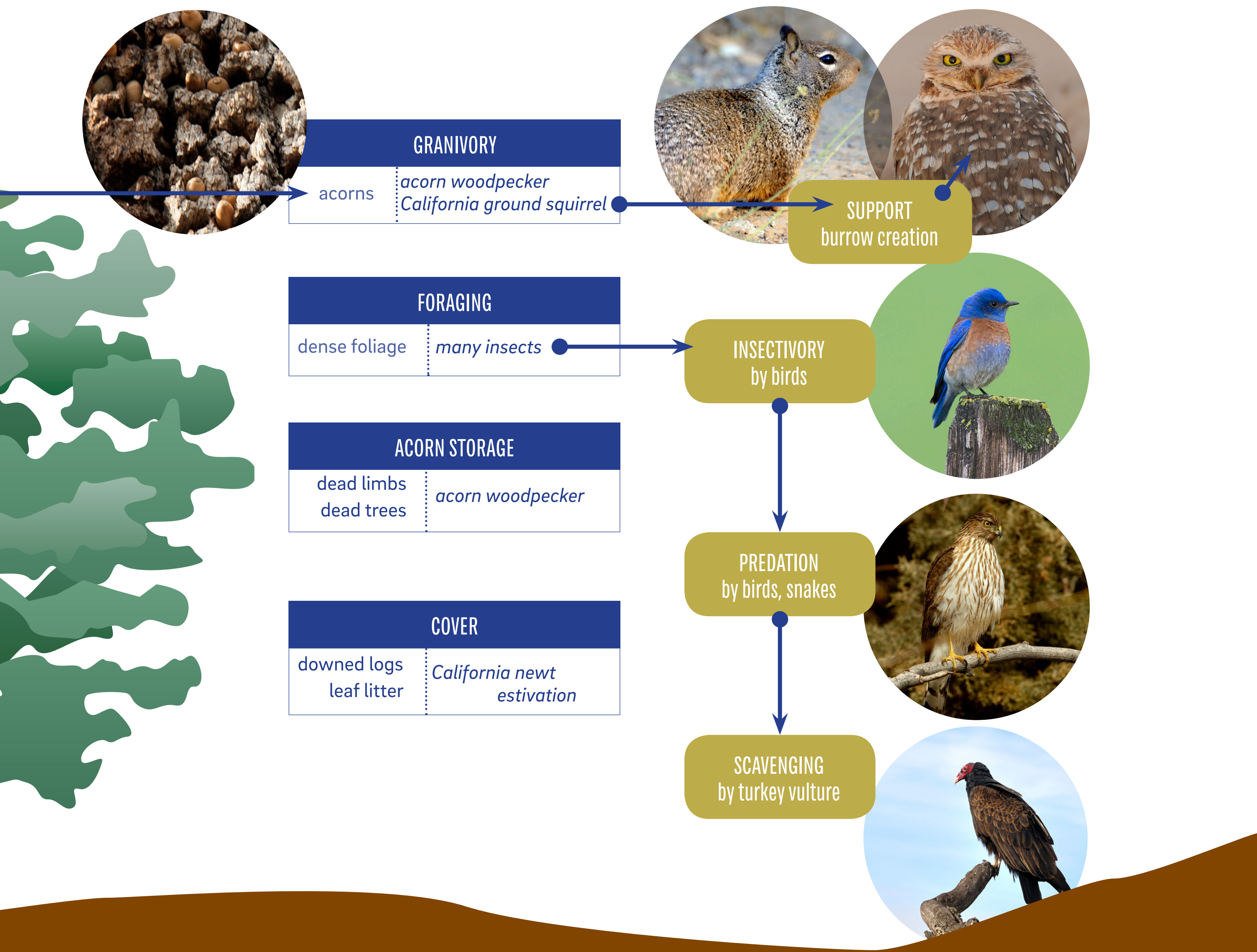
ECOLOGICAL FUNCTIONS

Oaks contribute to the support of many ecological functions and physical processes, including hydrological processes and nutrient cycling, production of biomass, uptake of carbon and nitrogen, and decomposition of leaf litter. Oak trees generate large amounts of leaf litter that increase soil organic matter under trees, creating islands of fertility compared to surrounding open areas (Dahlgren et al. 2003). Other functions are related to the structural and physical properties of oak trees. For example, the dense tree canopy provides cover for birds, and dead limbs are used as nest cavities and by arboreal ants. Downed branches and leaf litter act as cover for small mammals, reptiles, and amphibians. Finally, oak woodlands support a complex food web, enabling the flow of energy from primary producers to higher trophic levels. Materials generated in oak woodlands also flow across landscapes, including the movement of animals and the dispersal of seeds.



We focus here on the structural and compositional properties of oaks and oak woodland ecosystems because these are the features that support ecological functions. For example, the presence of many large old trees in oak woodlands provides ample excavation opportunities for cavity nesting birds, and leads to the accumulation of dead wood under trees that can create habitat for wildlife. Similarly,
a complex mixture of understory vegetation, stands of trees, and open areas dominated by herbaceous vegetation and woody shrubs increases resources and creates many niches for animals, broadening the set of species that can utilize oak woodlands.

Conceptual diagram highlighting some of the important ecological functions played by oaks. Some functions are provided directly by oaks. For example, oaks create habitat for many animals, and their leaves and acorns are consumed by herbivores and birds that disperse and consume acorns. Oaks also support a food web, including secondary and tertiary consumers. For example, insects that live in oaks support a community of insectivorous birds that are in turn consumed by predatory raptors and mammals.



(*Acorn woodpecker photo: Steve Zamak; oak gall photo: Franco Folini CC BY 2.0; scrub jay photo: Steve Zamak; acorn granary: Erica Spotswood; ground squirrel photo: Don DeBold CC BY 2.0; burrowing owl photo: Jeri Krueger, USFWS CC BY 2.0; Western blue bird photo: Gregory Smith CC BY 2.0; Coopers hawk photo: USFWS CC BY 2.0; turkey vulture photo: Don Debold CC BY 2.0*)

Oak gall. *(Photo by Franco Folini CC BY 2.0)*

FOOD WEBS

California oaks form the base of a rich and varied food web. Many of the more than 800 species of insects that feed directly on the tissues of the trees are specialists that can tolerate the high levels of tannins produced by oaks. For example, of the 150 species of gall-forming *Cynipid* wasps, most are associated with oak trees, and valley oaks (*Quercus lobata*) in particular have around 35 different species that specialize on them (Cornell 1985, Weld 1957 cited in Washburn 1984). These types of galls, as well as the larvae inside them, form their own small food web; they are parasitized by other insects and preyed upon by woodpeckers and small rodents (Yahnke 2006). Some wasp larvae also produce a honeydew, which attracts ants, who in turn tend galls and help deter parasites (Washburn 1984). This diverse community of insects and other arthropods are a food source for a variety of insectivorous birds that forage for insects on oak trees including oak titmice (*Baeolophus inornatus*), brown creepers (*Certhia americana*), and white-breasted nuthatches (*Sitta carolinensis*).

Among the many functions that oaks provide, one of the most important is acorn production. Acorns are consumed by numerous species, including acorn woodpeckers (*Melanerpes formicivorus*), scrub jays (*Aphelocoma californica*), and California ground squirrels (*Otospermophilus beecheyi*) (Giusti et al. 2005). In turn, many other species that prey on animals that consume acorns are also beneficiaries. For example, acorn woodpecker and scrub jay eggs and nestlings are preyed upon by snakes and birds of prey, such as Cooper's hawks (*Accipiter cooperii*), sharp-shinned hawks (*Accipiter striatus*), northern pygmy owls (*Glaucidium gnoma*), and gopher snakes (*Pituophis catenifer*; MacRoberts & MacRoberts 1976, Koenig & Mumme 1987). Oaks are also a key host for mistletoes, which produce fruit that are consumed by a number of birds. In particular, western bluebirds (*Sialia mexicana*) rely upon mistletoe berries as a primary source of nutrition during the winter (Dickinson 2005).

The different native oak species found in the region provide complementary contributions to the oak woodland food web. For example, coast live oaks (*Quercus agrifolia*) maintain leafy vegetation year-round, providing important resources to insects and insect-gleaning birds in the winter when the deciduous valley oak (*Quercus lobata*), blue oak (*Quercus douglasii*), and black oak (*Quercus kelloggii*) have dropped their leaves (Root 1967, Mauffette & Oechel 1989). Where coast live oaks are common, valley oaks may be especially valuable for their larger acorns (Howard 1992, Steinberg 2002) with lower tannin content (Koenig & Heck 1988), different gall-forming wasp communities (Washburn 1984), and deeply-dissected bark that supports insects (Tietje 2005, Costello et al. 2011). In addition, oaks are "masting" species, which means the size of their acorn crop varies widely among years. The environmental factors that trigger masting vary among oak species, and valley, coast live and blue oak tend to produce large crops in different years than black and canyon live oak (*Quercus chrysolepis*; Koenig et al. 1994, Koenig & Knops 1995, Koenig et al. 2015). Collectively, the presence of multiple oak species in the same woodland can create redundancy in the supply of resources, increasing the resilience of oak-dependent wildlife to seasonal and year-to-year variability.

(top, right) Mistletoes in a valley oak. *(Photo by Erica Spotswood)*

(middle and bottom, right) Cedar waxwings consuming mistletoe berries. *(Photo by Steve Hagerty)*

Mistletoe's relationship to California oak trees

Mistletoe is a flowering evergreen woody plant that colonizes tree branches. Technically a hemiparasite, mistletoe relies only partially on host resources. Mistletoe plants use branch limbs as structure from which to establish and gather minerals and water, but otherwise make their own food through photosynthesis. Mistletoe plants can kill tree limbs, leaving dead branches that provide important wildlife habitat. Less commonly, entire trees with many mistletoes can be killed, particularly during drought or other periods of stress (Swiecki & Bernhardt 2006). While oaks provide the foundation of a rich and varied food web, mistletoes enhance diversity by acting as a secondary keystone species (Watson 2001). In California, oak mistletoe *(Phoradendron villosum)* inhabits most common oak species and some other woody plants. Mistletoe can be found in over 50% of trees on a given site. Its presence varies depending on the location and the species of oak, and where it occurs, its distribution is usually clumped (Thomson 1983).

Mistletoe flowers and nectar attract a diversity of insects, some of which act as pollinators, enabling the production of fruit. The great purple hairstreak butterfly depends on oak mistletoes and other *Phoradendron* species as hosts on which to deposit its eggs (Thacker 2004). The fruit and foliage support many insects, birds, and some small mammals that forage and nest within protective mistletoe thickets (Watson 2001). This resource is so important that trees with higher mistletoe loads support larger and more diverse avian communities on average (Pritchard 2016). Animals also spread the mistletoe fruit from tree to tree, enabling colonization and expansion of the plant's range. Thus, mistletoe builds upon and enhances the foundation for diversity provided by oaks.

WILDLIFE

Wildlife in oak woodlands perform particular functions that contribute to the overall ecosystem, and some species also facilitate the presence of others. For example, the cavities excavated by woodpeckers are used by many other birds and small mammals (Giusti et al. 2005). Other species, such as western bluebirds and cedar waxwings (*Bombycilla cedorum*), consume fruit and facilitate the spread of fruit-bearing trees and shrubs, including toyon (*Heteromeles arbutifolia*), madrone, manzanita, and mistletoe. Bees and some butterflies are critical for pollination of trees and shrubs such as buckeye and manzanita. Some species influence the distribution of oaks themselves, facilitating the dispersal and spread of trees by moving acorns across the landscape. For example, scrub jays, acorn woodpeckers, and California ground squirrels cache and disperse acorns, and scrub jays in particular play an important role in the natural recruitment of oaks (Tyler et al. 2006).

Many species of wildlife utilize oak woodlands at particular times of the year. However, some species are oak specialists, and are much more dependent on oaks than others. For example, acorn woodpeckers and many species of insects are entirely dependent on oaks and are rarely found outside of oak woodlands. Others are found in or near oak woodlands as well as in other habitat types. These species are often associated with the grassland and chaparral areas adjacent to, or interspersed with, oak woodlands. Examples include white-breasted nuthatches, western bluebirds, wrentits (*Chamaea fasciata*), spotted towhees (*Pipilo maculatus*), California ground squirrels, California mouse (*Peromyscus californicus*), coyotes (*Canis latrans*), bobcats (*Lynx rufus*), and pallid bats (*Antrozous pallidus*).

Because each species fills a particular ecological role, higher biodiversity generally leads to greater ecological function across many types of ecosystems (Cardinale et al. 2012). Therefore, it is likely that the creation of habitat patches in urban areas using re-oaking would lead to gradual colonization by wildlife. Each new arrival has the potential to create opportunities for new species that can follow, ultimately leading to increases in biodiversity that accumulate over time.

(opposite, top) Acorn woodpecker storing an acorn in a granary tree. **(opposite, bottom) White-breasted nuthatch** at nest feeding insects to young. *(Photos by Steve Zamek)*

(this page, top left) Western bluebird emerging from nest in a cavity. **(top, right) Scrub jay** with an acorn. *(Photos by Steve Zamek)*

(**this page, bottom**) **This crab spider *(Diaea livens),*** an oak specialist, is found primarily in coast live hoak woodlands. *(Photo by Sean McCann)*

ECOLOGICAL BENEFITS AND RISKS

Re-oaking has the potential to restore lost ecological functions to cities where oak woodlands once thrived. This could have many benefits, including supporting native animal populations (Tietje 2011), increasing biodiversity in re-oaked areas, and supporting other ecological functions such as nutrient cycling and decomposition (Dahlgren et al. 2003). Re-oaking can also benefit oak populations that have suffered significant declines in the 20th century (Bolsinger 1988, Tyler et al. 2006, Pulido et al. 2015). Oak woodlands are threatened statewide by urbanization (Gaman & Firman 2006) and conversion to agriculture (Bolsinger 1988). In addition, individual oak species are also susceptible to sudden oak death (e.g., coast live oak; Rizzo and Garbelotto 2003) and a low rate of recruitment that is likely exacerbated by factors such as livestock grazing, competition with annual grasses, herbivory and acorn predation (Tyler et al. 2006). Therefore, establishing oaks in urban areas may help ameliorate statewide declines in both valley and coast live oaks, and should be conducted in coordination with continued preservation and restoration of oak woodlands in nearby undeveloped lands.

Valley oaks in particular can benefit from re-oaking in the developed lowlands where they have been largely extirpated. Unique to California, valley oaks are the largest and most long-lived oak in North America (Tyler et al. 2006). With their graceful form, they are focal points of many existing landscapes and an iconic California image, featured in postcards and on wine labels. Yet they are also one of the most impacted of California oaks, with continuing decline from development and recruitment failure (Tyler et al. 2006). Since many of the state's best locations for valley oak savanna are now agricultural or urbanized, re-oaking may contribute to the recovery of valley oak populations by increasing population size, reducing fragmentation and genetic isolation, and increasing genetic diversity. Given the challenges in rural areas and preserves, valley oak regeneration may have a greater chance of success in developed areas where the potential for more active management can reduce mortality during critical life stages (Tyler et al. 2006, McLaughlin & Zavaleta 2012). If new valley oaks are sourced with appropriate combinations of local and more distant genotypes (drawing a modest proportion, 5-20%, from hotter and drier settings; Aitken et al. 2013), re-oaking can contribute to re-establishing populations with healthy genetic diversity, propagating

Valley oak overlooking Redwood City, California. *(Photo by JKehoe CC BY 2.0)*

locally-adapted genotypes while increasing climate resilience with strategic supplementation from genotypes adapted to projected future conditions.

Re-oaking may also help facilitate adaptation of local ecological communities to climate change. Models of vegetation change in response to projected climate scenarios indicate that oak woodlands and savannas are likely to expand in many parts of the Bay Area as conditions become drier and warmer (Ackerly et al. 2015, McIntyrea et al. 2015). Increasing the distribution and diversity of native oaks within the region in areas with little existing native vegetation today can help seed and maintain more climate-adaptive native communities in the valley and surrounding hills. Improving habitat connectivity across developed areas may also be important to facilitate movement of native species between protected climate refugia in the hills to promote migration toward newly-suitable areas. (Heller et al. 2015).

However, there is some risk that creating habitat in cities could negatively impact wildlife both in cities and in adjacent open spaces. Ecological risks include risks to wildlife that may be attracted to urban oaks, as well as risks to the oaks themselves. Because urban plant and animal populations are contiguous with those in adjacent areas, one can affect the other. Here, we briefly highlight some of the most important risks to oaks and other urban and regional wildlife populations.

One risk posed to oaks by re-oaking is the potential for transmission of pathogens and pests. Of particular concern in cities are microscopic water molds in the genus *Phytophthora* that cause diseases, including root rot, stem cankers, and blights on fruit and leaves. Many herbaceous plants and trees native to California are susceptible to these pathogens, which often cause mortality. Spread of root rot in nurseries is a primary vector for transmission, and infected plants that are established in the field can have long lasting impacts on the establishment site (Phytosphere Research 2015).

Another concern is *Phytophthora ramorum*, an introduced pathogen that causes the often-fatal disease Sudden Oak Death (SOD). The spores of *P. ramorum* are found on the leaves of host trees, particularly bay laurel. Spores spread from host trees to susceptible oaks during rain storms (Grunwald et al. 2012). Whereas valley and blue oak are not usually affected by SOD, coast live oak, California black oak, canyon live oak and tanoak (*Notholithocarpus densiflorus*) are among the most susceptible species (Sweiki & Bernhardt 2013). In areas invaded by *P. ramorum*, SOD has become the most common cause of mortality in susceptible trees (Sweiki & Bernhardt 2013). In urban settings, the most significant risk to oaks is the potential for spread from California bay laurel to oaks, and between oaks which may occur if trees are spaced close together (Swiecki & Bernhardt 2013, Grunwald 2012).

Re-oaking could also lead to the loss of unique native oak genotypes. This could occur if oak populations in cities are created by mixing genes from many locations, creating genetic types that could swamp locally-adapted genotypes in areas surrounding cities. Many oaks are capable of hybridizing with each other (Costello et al. 2011). For example, coast live oak can hybridize with interior live oak (*Quercus wislizeni*) and black oak (Dodd et al. 2004), and valley oaks hybridize primarily with blue oak, though relatively infrequently (Craft et al. 2002). Urban centers often bring oak species into close proximity that do not typically occur in nature, creating novel opportunities for hybridization. This process may already be occurring with a variety of native plants, including oaks, that are sourced from areas beyond the local watershed and planted in cities and suburbs. While re-oaking could exacerbate this issue, it could also potentially be an improvement, if oaks and understory natives were carefully sourced from appropriate genetic types as part of re-oaking.

Re-oaking could also directly affect native wild animals in a variety of ways. For example, urban centers can concentrate wildlife populations, facilitating interactions between individuals of the same species, and between wildlife and domestic animals (Rosewald & Gehrt 2014). Higher densities and increased contact can increase the probability of disease transmission (Rosewald & Gehrt 2014). Native animals attracted to re-oaked areas might also be vulnerable to a number of stressors, including predation by domestic animals, competition with urban-associated wildlife (e.g., raccoons, crows, European starlings, and rats), and road and window fatalities. Urban habitat patches may create ecological traps - areas that appear to be attractive habitat but where the risk of mortality is high (see stressors described above). An ecological trap could steadily draw individuals that are attracted to these patches out of open spaces adjacent to cities, depleting regional populations (Battin 2004). Finally, genetic changes in urban populations (Alberti 2015) may lead to the spread of novel genotypes into wildland areas.

Despite the potential risks, there remains substantial potnetial for re-oaking to provide a number of ecological and social benefits. Nevertheless, a central challenge is that there is substantial uncertainty surrounding the risks, particularly with respect to the effects of re-oaking on wildlife. For example, it is unclear which species will be most negatively affected, and under which conditions. Therefore, we recommend developing a strategy for re-oaking with both the risks and uncertainty in mind. Projects can also reduce risk by targeting focal wildlife that are likely to be at low risk from urban stressors and genetic contamination, and by adopting in-parallel design and conservation measures aimed at reducing risk to both oak trees and associated wildlife (See guidelines, Chapter 4).

(right) *(Photo by Feliciano Guimaraes CC BY 2.0)*

(opposite page) *(Oak seedling photo: Brian Washburn CC BY 2.0; Valley oaks photo: JKehoe CC BY 2.0; Acorn woodpecker photo: Alan Hack CC BY 2.0)*

FOCAL SPECIES

Throughout this report, we have focused on how oak woodlands support ecological functions, and on how restoration of some of the structural and biological properties of oaks and forests may restore some of the functions that have been lost from urban areas. It is likely that by improving ecological function, native wildlife support will also increase. However, restoring trees and understory will not be sufficient for all oak woodland wildlife, since many species have specific habitat requirements that need special attention. Additionally, many people may be interested in how to improve habitat for particular wildlife species. In these cases, we recommend choosing focal species, targeting those that are least likely to be at risk for negative effects. While there is little information on the urban tolerance of California's oak woodland wildlife, recent syntheses from studies across the world have revealed several attributes that appear to consistently enable species to tolerate urbanization (Evans et al. 2010, Evans et al. 2011, Sol et al . 2014). Attributes include a generalist diet and habitat requirements, species that do not nest on the ground, non-migratory behavior, high annual production of offspring, and high dispersal ability. One caveat is that the majority of current research on this topic is from birds, and the factors leading to tolerance or avoidance of urban areas are much less well understood for other wildlife groups.

Here, we propose a few species that we believe could benefit from re-oaking in Silicon Valley. These species are already present in urban areas, and are likely to be at minimal risk because all are fairly generalist in their dietary requirements, are good dispersers, and are not ground nesters. In addition, because these species can facilitate the presence of other wildlife, a focus on them could benefit native biodiversity more generally. These species also highlight how the integration of tree planting with understory planting could attract wildlife that rely on both resources. Finally, each of these species is charismatic in its own way, which could facilitate public engagement and could motivate groups like homeowners with backyard gardens.


(Photo by Steve Zamek)

ACORN WOODPECKER • Acorn woodpeckers are common in oak woodlands throughout California, Arizona, New Mexico, Mexico, and Central America. During much of the year, woodpeckers consume both insects and acorns. They rely most heavily on acorns during the fall and winter when insects are scarce. While they are tolerant of urbanization, and birds are spotted occasionally in Silicon Valley, established colonies are rare. Birds live in small family colonies of 2-15 birds on territories 4-22 acres in size that they defend year-round. For more on acorn woodpecker ecology and habitat requirements, see in depth section on acorn woodpeckers (pages 24-25).

(Photo by Steve Zamek)

OAK TITMOUSE • The oak titmouse is a common year-round resident in oak woodlands throughout California. Oak titmice are usually found in pairs within territories ranging from 4.2-6.4 acres that are defended year-round. Common in our region, the bird is also fairly tolerant of urbanization. The oak titmouse consumes mostly insects and vegetation from the leaves, branches, and trunks of oak trees. Titmice are secondary cavity nesters and will use natural cavities as well as those excavated by woodpeckers. They will also readily use nest boxes; nest-box programs may reduce the need for cavities in live trees in urban areas. This species has been found to be more abundant in oak woodlands with denser canopy cover of 40-70% (Tietje et al. 1997). However, titmice can also benefit from a mixture of shrubs under trees (Tietje et al. 1997). Additionally, chaparral habitat elements may also be beneficial; nesting success and use of nest boxes has been found to be higher in nest boxes located in chaparral habitat adjacent to oak woodlands compared to nest boxes within oak woodlands (Milligan & Dickinson 2015).

MOURNFUL DUSKYWING • The mournful duskywing (*Erynnis tristis*) occurs with oaks, often in riparian areas and chaparral, and is routinely observed in cities in the Bay Area and Sacramento Valley (Shapiro & Manolis 2007). It requires the tender young growth at the shoot tips of oak leaves for egg laying, and often lays eggs on young trees and saplings. Mournful duskywings have been recorded using both coast live oak and valley oak, as well as cork oak and black oak from the eastern United States. They require nectar from flowers, and adults visit many flowers such as tall verbena (*Verbena bonariense*), milkweeds (*Asclepias* sp.), dogbanes (*Apocynum* sp.), yerba santas (*Eriodictyon* sp.), mints (*Mentha* sp.), coyotebrush (*Baccharis pilularis*), and California buckeye. In gardens it is partial to butterfly bush (*Buddleia* sp).

(Photo by Alan Schmierer)

(Photo by Alan Schmierer)

CALIFORNIA SISTER • The California sister (*Adelpha californica*) is common throughout California where oak trees grow (Shapiro & Manolis 2007), and is tolerant of urbanization (A. Shapiro pers. comm.). Its host plants are oak trees, especially live oaks. Adults have generalized nectar preferences, and will visit California buckeye, thistles (*Cirsium* sp., *Carduus* sp, and *Silybum* sp.) and coyote brush. California sisters also visit rotting fruit, sap, and mud puddles, and could benefit from maintenance of puddles in urban areas (A. Shapiro pers. comm.).

IN DEPTH: THE ACORN WOODPECKER

Acorn woodpeckers are a particularly good target wildlife species for re-oaking due to their tolerance of urbanization and ability to facilitate other species. Acorn woodpeckers also have specific habitat requirements that may not be met without special attention, and they can be sensitive to urbanization when key habitat elements are missing (Rottenborn 1999). Here, we highlight how these requirements can guide specific activities that could be included in re-oaking projects in an urban landscape.

The acorn woodpecker is a conspicuous and gregarious woodpecker with striking plumage that is best known for its habit of hoarding acorns in granary trees. Their diet is fairly broad, and though they require acorns, they also consume sap, oak catkins, fruit, flower nectar, and insects (Koenig et al. 1995). Acorn woodpeckers are already present at some urbanized sites in Silicon Valley (Koenig et al. 1995, Blair 1996) and because they are fairly tolerant of urbanization, large patches of open space are not necessarily required to support local populations (W. Koenig pers. comm.). In addition, acorn woodpeckers are good colonizers and are likely to find oak resources anywhere within 20 miles of a source population (Koenig et al. 1995).

Acorn woodpekcers. *(Photo by Steve Zamek)*

Acorn woodpeckers live in small colonies of 2-15 birds on territories that they vigorously defend year-round. Acorns are a critical resource, though reliance on them varies throughout the year (Koenig et al. 1995). Woodpeckers stock acorns in the fall in preparation for winter when insects are scarce. During the winter months, woodpeckers rely almost exclusively on acorns. With the return of warm weather in the spring, adults feed insects to their young while continuing to consume acorns themselves (Koenig et al. 1995). Acorns are typically gathered from multiple trees within territories that range in size from 4 to 22 acres, with an average of 17 acres (corresponding to a circle of roughly 1,000 feet; See guidelines in Chapter 4).

Woodpeckers are typically found in oak woodlands with fairly open canopies. Though the ideal canopy cover is unknown and may vary geographically, they have been recorded in woodlands with densities in the range of 30-40% (Landres & McMahon 1983), often on the edges of denser woodlands bordering open savanna (Scofield et al. 2010). The number of oak trees within acorn woodpecker territories is highly variable throughout the state, and it is probably not possible to specify an exact number of trees required to support a colony (W. Koenig pers. comm.). However, territories with more trees are likely to produce larger crops of acorns. Groups with larger acorn crops in their territories in the fall are more likely to have acorns remaining into the spring when breeding occurs. With a larger store of remaining acorns for adults in spring, the most successful groups are able to feed more insects to their young, leading to higher breeding success (Stacey and Ligon 1987, Koenig et al. 1995).

Acorn woodpeckers can also benefit from having a diversity of oak species within their territories. Acorn crops are highly variable from year to year, and while valley, blue, and coast live oak are often fairly synchronized, they tend to produce bumper crops in different years than California black and canyon live oak (Koenig et al. 1994, 1995, 2015). Therefore, a bumper year for one oak species can occur during a lean year for other species (Koenig et al. 1994). Higher oak diversity has been found to be associated with higher numbers of acorn woodpeckers (Roberts 1979, but see Bock & Bock 1974) and lower year-to-year variation in bird abundance (Koenig & Haydock 1999), presumably because groups are more stable when the resource supply is more even across years (Koenig & Haydock 1999).

Acorns scattered on the ground after a productive year for coast live oaks, Briones Regional Park. *(Photo by Erica Spotswood)*

Since 2013, an acorn woodpecker colony has been consistenly recorded by citizen scientists in the Plaza de Cesar Chavez in downtown San Jose. This photo, taken in 2007, suggests the colony was present well before its first record on the citizen science website eBird. A palm tree serves as a granary. *(Photo by Tom Clifton CC BY 2.0)*

Acorn woodpecker territories are often centered around a single large tree (often dead, or with dying limbs) that is used for acorn storage, and can contain as many as 50,000 holes (Dawson 1923). These granaries are a critical resource and can be even more limiting than acorn crops for woodpecker populations (Koenig & Mumme 1987). Acorn woodpeckers usually select large trees for use as granaries, and will use both live and dead trees. Acorn woodpeckers also rely on large trees for cavity excavation of holes used for nesting and roosting (Koenig et al. 1995). The average size of granary trees has been documented at two sites to be 32- 58 inches (81-148 cm) diameter at breast height (Gutierrez & Koenig 1978). In Palo Alto, a comprehensive survey of all oaks reveals that only a small proportion of oak trees are this large in size (Fig. 2). Among street trees, the proportion of large trees is even smaller; inventories from the cities of Mountain View, Cupertino and Palo Alto reveal that only 3% of street trees are at least 32 inches in diameter (Fig. 2).

A variety of tree species can be used as granaries, though woodpeckers appear to favor trees with either soft wood or dead branches that are easy to drill into. Trees that meet these criteria include soft palms, pine trees, and dead trees or limbs of a variety of species. For example, on the Stanford campus (Burgess et al. 1982), woodpeckers have been recorded using Canary Island date palms and California palms.

Acorn woodpecker granary tree, Los Padres National Forest. *(Photo by Erica Spotswood)*

3 • CHANGE OVER TIME

INTRODUCTION

Many California cities were established in oak woodlands and savannas. In Santa Clara Valley, oak ecosystems were the defining feature at the time of European contact, covering thousands of acres from what is now Palo Alto to San José (Beller et al. 2010). These woodlands were also home to indigenous people, who lived in high densities in the valley for thousands of years (Keeley 2002). Native people frequently set fire to herbaceous vegetation on the valley floor and in the foothills, presumably to favor improved forage and game habitat (Mensing 2015). Over time, this practice likely would have favored grassland over shrubland understory, creating spatial heterogeneity that varied with local fire intensity. Valley oaks have high fire tolerance and can persist for hundreds of years, so the valley's oak woodlands and savannas were likely well established by the time of European arrival (Whipple et al. 2011).

Oak savannas and woodlands were so extensive that the valley was christened the *Llano de los Robles*, or Plain of the Oaks, by early explorers (Font 1775-6, in Bolton 1930). As late as the end of the 19th century, travelers and residents still marveled at the "enormous growth of large and magnificent oaks" (*San Francisco Chronicle* 1896) occurring "in such numbers...that I wondered [how] the farmers tolerated them" (Kenderdine 1898). While valley and coast live oaks were the dominant species, a diverse array of other trees were also present in lower numbers (see pages 28-29 for more detail).

The vast majority of these oaks – as high as 99% in some parts of the valley – were cut down in the late 19th and early 20th centuries to make way for orchards and expanding cities (Whipple et al. 2011). Exotic species arrived with the early Spanish explorers, and fire and grazing regimes were altered with increased European settlement (Rejmánek & Randall 1993, Whipple et al. 2011). With these changes, the valley was transformed in a short time from the *Llano de los Robles* into the highly productive agricultural region known as the "Valley of Heart's Delight." Just a few decades later, orchards gave way to expanding cities, and as a completely novel urban forest was planted, cherries, apricots, and other fruit trees were replaced with a wide variety of new tree species. The wholesale shift in the species composition that now defines the valley's urban forest has been accompanied by a near-total loss of herbaceous and shrubby vegetation. Occasional oaks have persisted and can still be found in the valley's streetscapes, parklands, and backyards.

In little more than a century, Silicon Valley's oak woodlands were felled, replaced with orchards, and then replaced again with a patchwork of urban trees. This section describes the structure and composition of the original oak woodlands and quantifies change over time by comparing historical conditions to the today's urban forest. Using data from the past and the present, we assess how oak trees and oak woodlands have changed through time. We focus on the structural and compositional elements of the trees and the forest because these elements enable oak woodlands to support exceptionally high biodiversity and a diverse array of ecological functions. Our findings reveal that while some changes have been profound, others are relatively minor, leaving opportunities for oak woodland functions to be incorporated into the urban landscape.

Towns often preserved oaks, which provided valuable shade in the summer heat. *(Photo # E598, "View of Morgan Hill" by Burton Frasher Sr., 1933, courtesy Frasher Foto Postcard Collection and Pomona Public Library)*

Silicon Valley at night. *(Photo by Vadim Kurland CC BY 2.0)*

OAK SIZE AND STRUCTURE

Before large-scale removal, Silicon Valley supported many more oaks—particularly valley oaks (Cooper 1926). Many of these trees were quite large; we estimate that roughly 20% of valley and coast live oak trees were 32 inches or greater in diameter (Fig. 2; see also Appendix 2). Dead trees would also have persisted on the landscape, and dead limbs would have been retained on trees, potentially for years before falling to the ground. Fallen logs and leaf litter would also have remained under trees until decomposition. Finally, galls and mistletoes were probably common, especially in valley oaks.

Where oaks remain in the urban landscape today, they still hold potential to support many ecological functions. However, several structural characteristics have been modified by humans. For example, while a similar proportion of valley oaks are as large today (over 32 inches in diameter) as in the valley historically, coast live oaks and street trees of all species appear to be smaller on average than the Valley's historical trees (Fig. 2). Urban trees often lack structural features that provide critical habitat elements for wildlife in oak woodlands outside of cities. Dead limbs and trees are often removed because they threaten pedestrians, houses, and cars. Clearing under trees also removes leaf litter, and the ground under urban oaks is often bare or covered in turf grass. While data on galls and mistletoes in urban settings are lacking, anecdotal observations suggest that urban valley oaks often support oak galls, but rarely mistletoes, possibly due to removal and maintenance.

(Photo by Dee Shea-Himes)

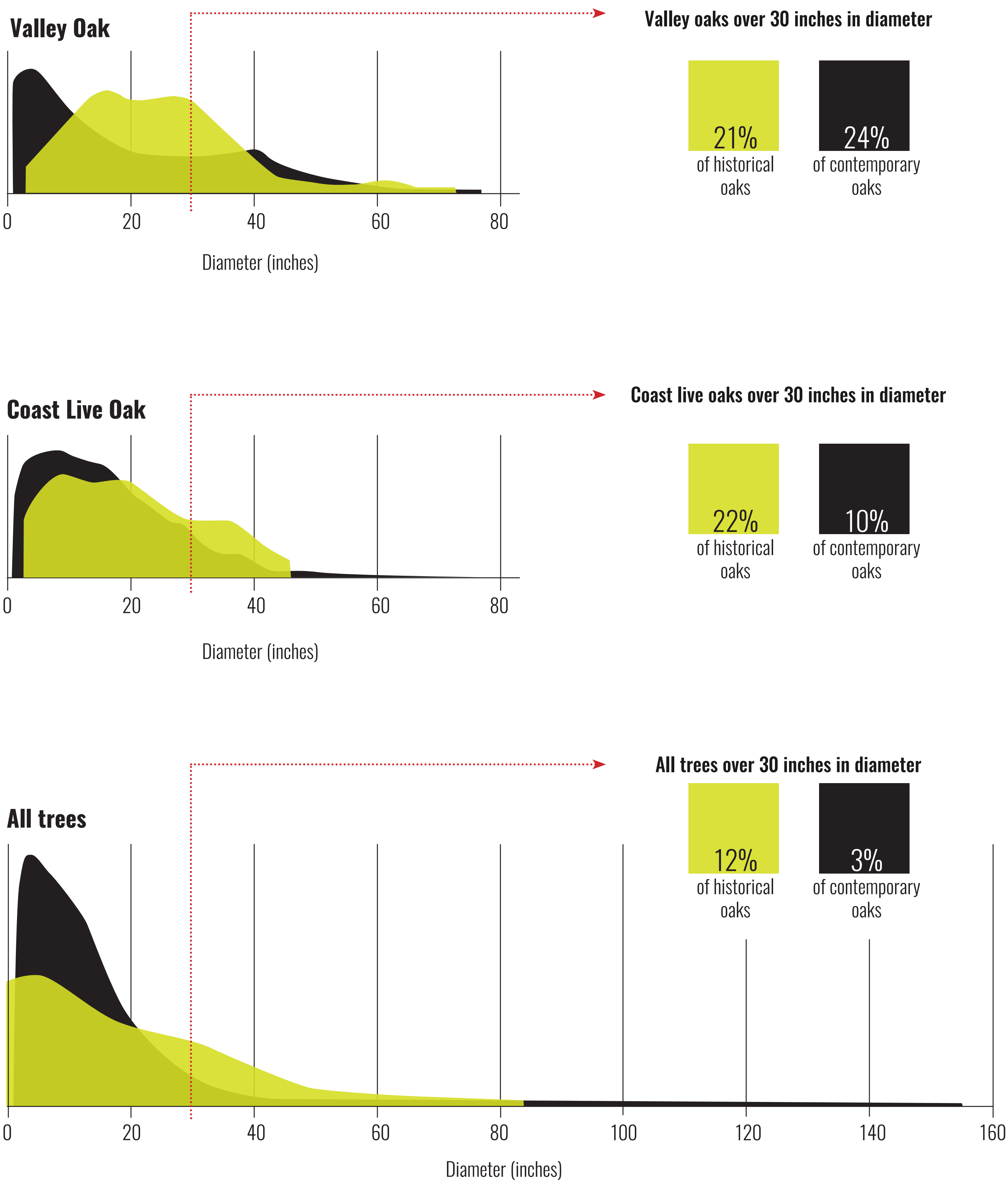


Fig 2. A comparison of the historical and current distribution of oaks in the region reveals that while contemporary valley and coast live oaks are similar in size to historical oaks, the modern urban forest has fewer large oaks (over 32 inches in diameter at breast height), and fewer large trees of all species, to support the ecological functions that oak woodlands provided before landscape transformation. Historical data is from western Santa Clara Valley General Land Office records. Modern tree data for oaks is taken from an oak survey in Palo Alto. Data for comparison across all trees is from street tree inventories in the cities of Palo Alto, Mountain View and Cupertino. See Appendix 2 for methods and data sources.

(top) Oak grove near Palo Alto, 1904. This photo, taken from Bryant Street east of Coleridge Avenue, shows Embarcadero Road (in foreground) and the oak woodland behind it to the northwest. Unlike much of western Santa Clara Valley's oak lands, this grove was composed of predominantly live oaks; only a few valley oaks are visible (not yet in leaf). *(Photo by Unknown 1904, courtesy Palo Alto Historical Association)*

(middle) composite of top and bottom photos.

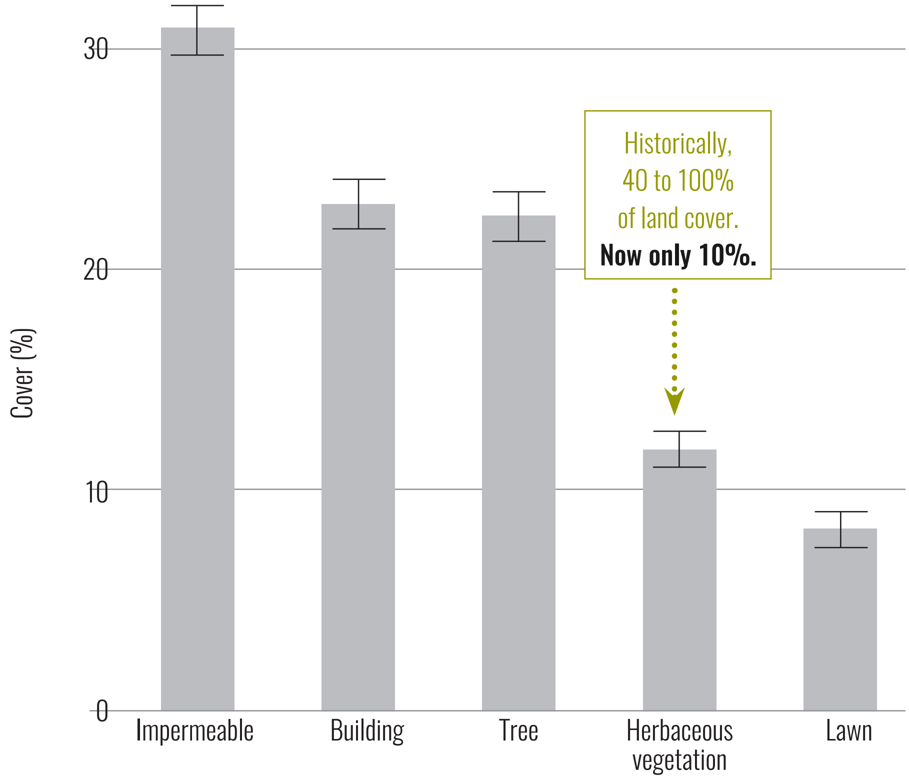
(bottom) Along Camino Real in Palo Alto. *(Photo courtesy Google Street View)*

FOREST STRUCTURE

Silicon Valley's oak woodlands included both dense woodland areas with canopy cover of 25-60%, and more open savannas with canopy cover of 0-25% (Beller et al. 2010). In the open areas, an herbaceous layer made up of wildflowers, perennial bunchgrasses, and perennial shrubs accounted for the remaining cover (Jackson and Bartolome 2007, Minnich 2008, Beller et al. 2010). Beneath and between oaks, herbaceous vegetation added vertical structure and habitat complexity.

The extent of urban tree canopy cover across the Bay Area today is not inconsistent with that of a natural oak woodland. While canopy cover varies both within and among cities, as of 2002 most cities in the region had a tree canopy cover of around 30%, with higher canopy cover in much of Silicon Valley (Simpson & McPherson 2007). Therefore, large increases in canopy cover should not be required in order to achieve some of the ecological functions associated with oak woodland communities.

While overall canopy cover in the cities of Silicon Valley falls within the general range of oak woodlands of the past, a dramatic shift has occurred in the herbaceous layer of vegetation. In the Silicon Valley of ca. 1850, herbaceous and shrubby vegetation made up between 40% and 100% of the land cover (Beller et al. 2010). Herbaceous vegetation is now largely absent, forming 10% or less of the total land cover (Fig. 3). In its place are impervious surfaces, buildings, and lawns. In addition, the vertical structure created by herbaceous vegetation (both directly under trees, and in the spaces between them) is often missing from the urban landscape. Trees planted in planting strips, in tree wells, and over irrigated lawns often lack any herbaceous vegetation other than turfgrass that could add habitat value for oak-associated species. Where present, herbaceous vegetation is made up of a diverse mixture of horticultural and other exotic species with a very different species composition than the historical landscape.



(top) Native wildflowers. *(Photo by Dee Shea-Himes)*

Fig 3. An analysis of the modern land cover in Mountain View reveals that while modern tree canopy cover is comparable to the historical landscape, the herbaceous vegetation layer has been reduced. Historically, tree canopy varied from 0-60%. Native annual wildflowers, perennial bunchgrasses and shrubs filled in the spaces between trees, occupying between 40% and 100% cover. In the contemporary landscape, buildings, lawns and impervious surfaces take the place of a formerly diverse mixture of grassland and chaparral vegetation. For an explanation of data sources and methods, see Appendix 2.

FOREST COMPOSITION

Silicon Valley was historically dominated by native oak trees, with other oak woodland-associated species forming a smaller proportion of trees. Oaks comprised around 80% of all trees on the valley floor, excluding riparian woodlands (Figs. 4 & 5). Total tree species richness was likely around 20 species (Fig. 4), including valley oaks, coast live oaks, black oaks, sycamores (*Platanus racemosa*), wild cherries, madrones, California bay laurels, and buckeyes. Herbaceous and shrubby plants growing adjacent to and under oaks included native perennial bunchgrasses and annual wildflowers (partially as a result of native fire management practices), blackberry (*Rubus ursinus*), poison oak (*Toxicodendron diversilobum*), toyon, scrub oak (*Quercus berberidifolia*), coffeeberry (*Frangula californica*), nightshade (*Solanum santi*), and honeysuckle (*Lonicera hispidula*) (Cooper 1926, Beller et al. 2010).

Native oak woodland species are rare in the modern urban landscape of Silicon Valley, forming just 4% of contemporary street trees (Fig. 4). Of these, most are either valley or coast live oaks; other oak woodland species make up less than 1% of the urban forest (Figs. 4 & 5). Today's urban trees are far more diverse than a typical oak woodland. For example, street tree inventories for the cities of Palo Alto, Mountain View, and Cupertino include nearly 400 different tree species. The shift in valley oak prevalence is particularly remarkable. While valley oaks were the most common tree in the mid-19th century Valley, representing 60% of the non-riparian trees, they represent less than 1% of over 82,000 street trees today; a decline of over 99%. While both valley oak and coast live oak – the predominant components of the native oak woodlands – are quite uncommon in Silicon Valley cities today, their relative proportion has also shifted so that there are now many more coast live oaks (21% historical, 3 % today) than valley oaks (54% historical, 0.5% today). Most street trees are not native to the region and many are indigenous to temperate deciduous forests elsewhere in the world. In addition, there has also been a dramatic shift in patterns of dominance. For example, the most common street trees in Silicon Valley account for no more than 8% of total trees. Historically, just three species (valley oak, coast live oak and California black oak) accounted for approximately 80% of all trees (Fig. 4).

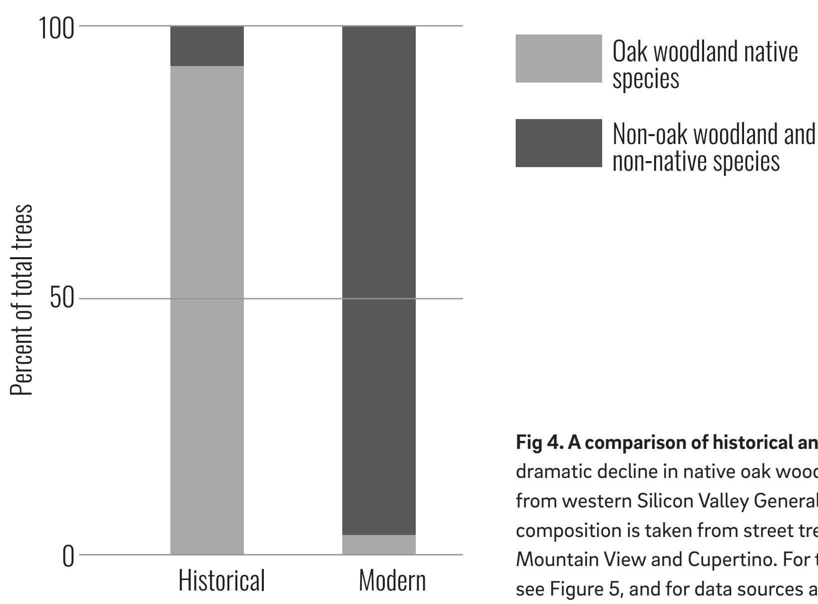


Fig 4. A comparison of historical and modern tree composition reveals a dramatic decline in native oak woodland species. Historical data are taken from western Silicon Valley General Land Office records. Modern species composition is taken from street tree inventories of the cities of Palo Alto, Mountain View and Cupertino. For the list of oak woodland native species, see Figure 5, and for data sources and methods, see Appendix 2.

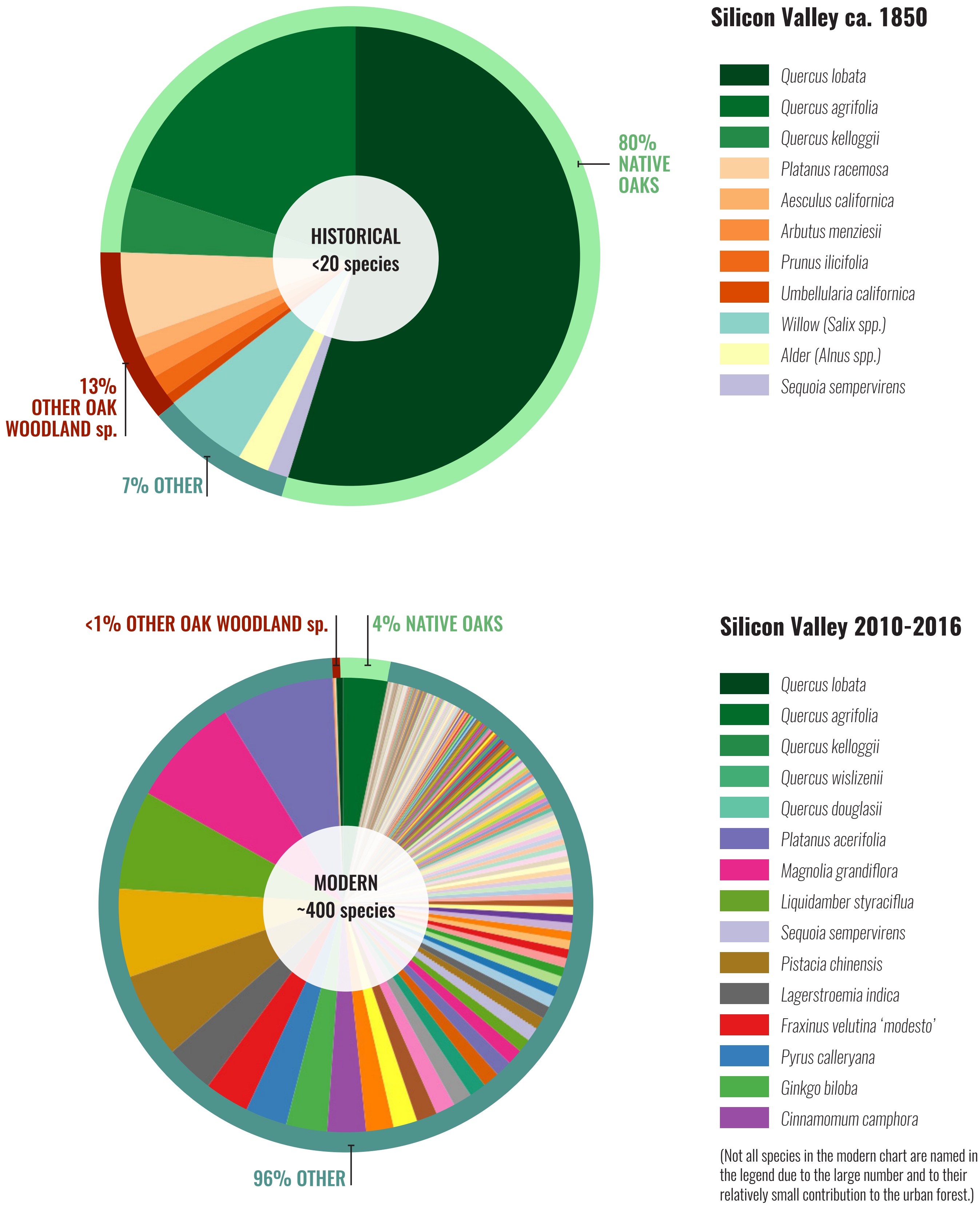


Fig 5. Shift in tree species composition ca. 1850 to present, showing a near total loss of native oak and oak-associated species. Dramatic increases in species richness have also occured, transforming the tree canopy from a woodland containing around 20 species to an urban forest with close to 400 species of non-native trees that have been imported from around the world. Historical data are taken from western Silicon Valley General Land Office records. Modern data are from street tree inventories of the cities of Palo Alto, Mountain View, and Cupertino. See Appendix 2 for description of data sources and methods.

Fig 6. Urban oaks in various settings. *(Photos by Robin Grossinger)*

(top row, left to right) Valley oaks along street in San Jose, Cupertino, and Berkeley; and at a mall in San Jose.
(middle row, left to right) Live oaks at a schoolyard in San Jose, in a front yard in Berkeley, along a street in Cupertino.
(bottom row, left to right) Live oaks alongside a park in downtown San Jose, along a median in Union City, and at plazas in Berkeley and Oakland.


EMERGENCY
Hospital
Garage

INTRODUCTION

The following pages summarize the main findings of this report into a set of guidelines that can be used when designing re-oaking projects. The guidelines are based on an analysis of the changes that have occurred in Silicon Valley with urbanization, and a synthesis of oak woodland ecology. We do not provide specific metrics, such as exact numbers of trees or amounts of herbaceous vegetation. Instead, these guidelines are intended to summarize key features of oak woodland ecosystems that enable support for biodiversity and ecological function. Implementation of the guidelines should enable projects to maximize their benefits to wildlife, maintain a healthy urban forest, and improve biodiversity.

The dramatic transformation of Silicon Valley leaves many opportunities within the urban landscape for elements of oak woodland ecosystems to be restored. Because the canopy cover of the urban forest is already comparable to historical oak woodlands, re-oaking would not require a substantial increase in tree numbers. Where canopy cover is low, additional trees could be added. Where canopy cover is already sufficient, native oaks and other associated species could replace other trees as opportunities arise, such as after tree mortality and during development or infrastructure upgrades. The species composition of the urban forest has undergone a dramatic transformation; with careful design large numbers of oaks and associated species could replace existing trees in appropriate settings without substantially compromising the diversity or character of the urban forest.

There are also a number of opportunities for increasing the amount of ecologically valuable herbaceous vegetation. For example, following multiple years of drought, interest in converting lawns to other types of less water-intensive landscaping has grown. Conversion of lawns, new development that includes extensive landscaping, and enthusiasm for native plants in backyard gardens are just a few of the opportunities where herbaceous vegetation could be added. Finally, oak trees themselves could be managed for wildlife. Some activities, such as leaving dead trees on the landscape and dead branches on trees, can present a safety hazard, and should only be attempted in open spaces where foot and vehicle traffic is minimal. However, other activities, such as leaving dead branches and leaves on the ground and mistletoe in trees are feasible in both commercial landscaping and backyard gardens.

RE-OAKING THE URBAN FOREST

Aim to increase the proportion of native oaks and other oak woodland-associated plants in the urban forest along streets and in residential yards, commercial landscapes, and other settings. The modern urban canopy is dominated by non-native species from all over the world, and California oak-woodland plants and trees are rare. Increasing their numbers can benefit native wildlife, restore lost ecological functions to urban forests, and reduce the biotic homogenization of cities by incorporating local species that are not found in other urban areas.

Plant multiple oak woodland species to increase native tree diversity and wildlife support, prioritizing species that are less common and in need of conservation, such as valley oak. In Silicon Valley, appropriate oak species include coast live oak, valley oak, black oak, blue oak, and interior live oak. Integrating other oak woodland-associated trees alonside native oaks can also increase diversity and habitat for wildlife. Some species to consider include toyon, madrone, manzanita, and California buckeye. These species vary in size and architecture and may be appropriate for sites that cannot support oaks.

Create re-oaking nodes where efforts can be concentrated. Aim for nodes of around 1,000 feet in diameter (15-20 acres) with a minimum of 20 oak trees, although more trees can also be beneficial. Each node would result in trees spaced on average 200 feet apart, and would have enough trees to potentially support a colony of acorn woodpeckers (Koenig pers. comm.). Concentrating efforts within nodes can provide greater benefits than planting isolated trees because many oak woodland wildlife species need multiple oaks in fairly close proximity for foraging, movement, reproduction, and other activities. Where possible, center nodes around existing large oak trees (diameter at breast height greater than 32 inches) to maximize functions in both the immediate and longer-term time frame.

Plant oaks of the same species close enough to pollinate each other within re-oaking nodes. For example, valley oaks can successfully pollinate one another if they are planted less than 500 feet apart (Sork et al. 2002, F. Davis pers. comm.). While 500 feet is a maximum for effective pollination within valley oaks, closer distances will often be preferable. Pollination is important because it enables the production of acorn crops which many wildlife species depend upon, and because it can facilitate natural recruitment of new oak saplings in areas that are not intensively managed.

Establish scattered trees and groves. Within a patch of oak savanna, trees need not be evenly distributed but typically occur in complex patterns with groves of multiple closely-spaced trees, open spaces, and scattered trees. Historically trees in Southern Santa Clara County varied in density from about 1 to 5 trees/acre (Whipple et al. 2011) and a range of densities will support the greatest diversity of wildlife. For example, close spacing will facilitate the movement between trees of the mourful duskywing (A. Shapiro pers. comm.) and oak titmice, whereas other wildlife prefer a mixture of open spaces with low canopy cover and chaparral or grassland vegetation.

Protect large trees (both oaks and other species). Compared to historical estimates, large trees are relatively rare in the contemporary urban landscape. These trees are particularly important for wildlife, and contribute disproportionately to some ecosystem services such as carbon storage. Because it will take time for new oak plantings to reach maturity and produce sizeable acorn crops, preserving existing large oak trees is important to maintain continuity of services and to have a diverse age-class structure in the future.

(Photo by Robin Grossinger)

MAINTAINING TREE HEALTH

Use primarily local genetic stock for re-oaking, with a small percentage (5-20%) of acorns from regions with hotter and drier conditions, to the extent possible given commercial availability. This approach will maximize the preservation of locally-adapted genetic diversity while increasing resilience to climate change (Aitken and Whitlock 2013).

Plant oak trees a minimum of 30 feet from California bay laurel trees to reduce the threat of transmission of sudden oak death between trees (Grunwald 2012, Swiecki & Bernhardt 2013). Distances should be increased to 50 feet in locations downhill or downwind from bay trees and this distance may also be needed in climates more favorable to *Phytophthora ramorum* spore production. Bay laurel abundance should be kept to a minimum, and limited primarily to riparian areas.

Adopt best management practices for reducing transmission of root rot fungi (*Phytophthora* sp.) in nurseries (See Phytosphere Research for an example in Appendix 1). These fungi can cause mortality of oaks and many other native trees and herbaceous plants. In addition, the fungi can also contaminate a site, leading to additional future mortality.

Select planting locations that provide the highest potential for successful establishment and growth of oaks, such as state, county, and municipal parks, golf courses, transportation corridors, schoolyards, and other sites wtih sufficient space for oaks. Follow recognized best practices for site preparation and planting. Provide appropriate care during the establishment period, such as irrigation, pruning, and staking.

Ensure planting stock is of the highest quality available. Avoid planting of trees that are overgrown or rootbound, structurally weak, diseased, and lack in the color, crown density, and vigor that is typical for the species.

Diagram of a re-oaking node in a residential neighborhood. Key features such as oak trees, understory vegetation, leaf litter, and downed logs can be integrated into yards and public rights-of-way. Ideal spacing, appropriate numbers of trees, and centering of nodes around large existing trees will help maximize the biodiverstiy benefits of re-oaking nodes. *(Understory vegetation and leaf litter photos; Dee Shea Himes, Acorn woodpecker photo; Steve Zamek, California hairstreak photo; Don Loarie CC BY 2.0, Downed log photo; Erica Spotswood)*

HERBACEOUS VEGETATION

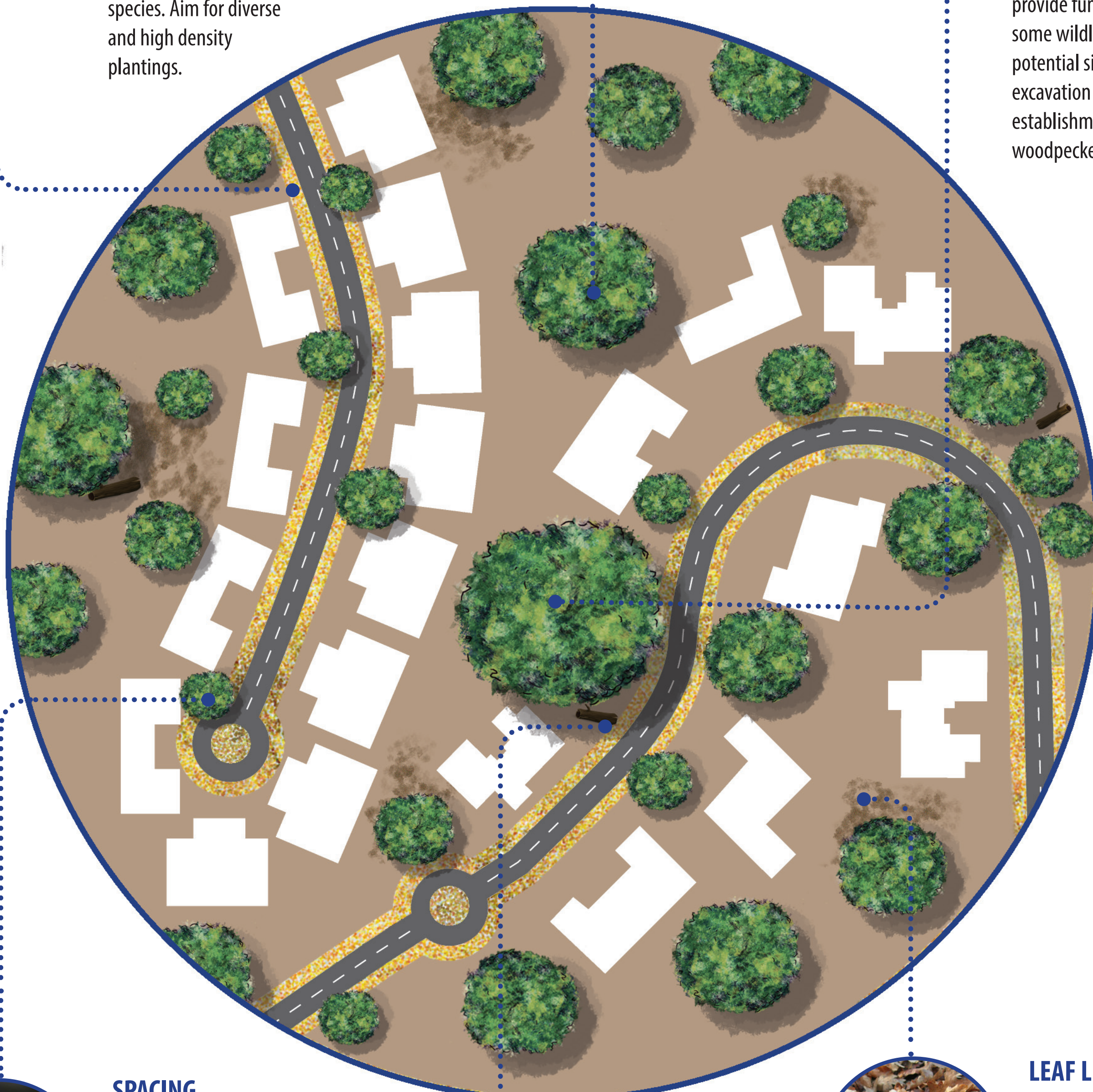
Create linear corridors of native wildflowers that bloom throughout the year to support a diversity of butterflies, including oak-associated species. Aim for diverse and high density plantings.

ACORN WOODPECKERS

Aim for around 20 oak trees within nodes of 15-20 acres. This number is likely sufficient to support a colony of acorn woodpeckers.

LARGE TREES

Where possible, center re-oaking nodes around large existing oak trees. These trees already provide functions for some wildlife and are potential sites for cavity excavation and granary establishment by acorn woodpeckers.



SPACING

Space oak trees no more than 500 feet apart to enable oak pollination and to support movement of wildlife such as the California hairstreak (*Styrium california*).

DOWNED LOGS

Leave downed logs on the ground where possible to support anthropods, amphibians, reptiles, and small mammals.

LEAF LITTER

Leave leaf litter on the ground where possible to allow decomposition and nutrient cycling to occur. This will improve soil health which can enable a more complex anthropod community to flourish.

INTEGRATING HERBACEOUS VEGETATION & SHRUBS

Plant native oak woodland herbs and shrubs under and near oak trees in order to add habitat heterogeneity and vertical structure that benefit a variety of wildlife.

Add native annual wildflowers, shrubs, and perennial bunchgrasses wherever possible in order to increase the cover of this valuable habitat element within the urban landscape.

Aim for mixtures of species that bloom in different seasons under and around oak trees in order to maximize access to floral resources throughout the year for native birds, bees and butterflies (Morandin & Kremen 2013).

Choose locally adapted genotypes from the same watershed for native plantings where possible.

INCREASING WILDLIFE HABITAT

Identify focal wildlife species that could benefit from re-oaking and are likely to have relatively low risk for negative impacts. Each species has its own specific requirements for food, shelter, and reproduction. These requirements are often missing from urban landscapes, which can prevent successful establishment by wildlife. Incorporating habitat features that can benefit focal species into re-oaking projects can increase the chance that these species will be able to survive and thrive.

Leave mistletoe clumps intact on trees where possible. Mistletoe berries benefit many wildlife, and the presence of plants does not harm oak trees at low levels of infestation (Swiecki & Bernhardt 2006).

Leave downed logs and leaf litter under trees where feasible. These important features can help support a community of decomposing organisms, increase soil fertility, and provide habitat for small mammals, reptiles, and amphibians.

Protect trees with existing cavities, and dead limbs with cavities in areas where vehicle and foot traffic is low. Cavities are used by many species of birds and mammals, and are re-used year after year by resident birds such as acorn woodpeckers and oak titmice that maintain

(opposite page, top) Native understory vegetation can be planted with trees to create landscaping that is both beautiful and functional. *(Photo by Dee Shea-Himes)*

(opposite page, bottom) Native annual wildflowers and bunchgrasses were common in oak woodlands throughout California historically and can be integrated into residential yards and landscaping. *(Photo by Dee Shea-Himes)*

(below) Many animals can benefit from water sources and puddles during the dry season. *(Photo by Sandy Harris CC BY 2.0)*

family territories for multiple years. While dead trees and limbs are important resources for wildlife, they can also bring hazards. Adopting a flexible approach to management can enable the benefits to be retained in places where the risk to people, vehicles and infrastructure is minimal. For example, parks and other open spaces may be able to maintain dead limbs and dead trees with minimal risk.

Protect existing granary trees. Granary trees are often used by multiple generations of acorn woodpeckers, and their removal can break up groups, leading to the loss of woodpecker colonies (Koenig et al. 1995). Consider the use of artificial granaries, which may be adopted where appropriate granary tree resources are not present. In locations where dead trees are actively used by woodpecker colonies, the top of the tree could be removed, leaving the stump in place (to a height of around 20 feet). Where feasible, this could minimize the threat of falling limbs.

Adopt measures aimed at reducing urban stressors for wildlife, such as bird-friendly window design and education of the public to reduce the numbers of outdoor cats. These measures can reduce wildlife mortality, ultimately enabling cities to support larger, more resilient wildlife populations in the future.

Encourage the use of nest boxes, which are used by many cavity-nesting birds, and can help alleviate competition for nest cavities in urban areas where retention of dead limbs on trees is not feasible. Identify wildlife species that may benefit in order to select boxes appropriate for particular species.

Consider maintaining mud puddles and other water sources (such as bird baths and backyard ponds with water that is not chemically treated). Mud puddles are used by butterflies and water resources are important for a variety of wildlife, particularly during the dry season.

Protect existing trees that contain cavities that are known roost and/or nest sites. These trees are important resources for acorn woodpeckers, as well as a variety of other wildlife.

(bottom left) Western bluebirds in birdbath *(Photo by JKehoe CC BY 2.0).* **(center) Tree swallow** on nest box. *(Photo by Don Debold CC BY 2.0)* **(right) Scrub jay in birdbath.** *(Photo by Jessica Merz CC BY 2.0)*

MAXIMIZING ECOLOGICAL BENEFITS

Target re-oaking design toward focal species that are likely to be at relatively low risk from urban stressors and genetic contamination. While few data are available for California oak woodland associates, regional and global syntheses identify groups that are likely to be at higher risk (Evans et al. 2010, Sol et al. 2014). In particular, extra precautions should be taken with certain wildlife groups. For example, ground-nesting birds and small mammals are highly sensitive to predation by domestic cats (Loss et al. 2013, Rodewald & Gehrt 2014) and ground-dwelling animals are more likely to be victims of road fatalities (Fahrig & Rytwinski 2009).

Adopt in-parallel design and conservation measures aimed at reducing risk to both oak trees and associated wildlife. Some examples include the adoption of bird-friendly window designs to reduce bird collisions and education campaigns that emphasize the value of keeping domestic cats indoors. Road fatalities can also be avoided by eliminating the placement of low perches near roads. Emphasizing conservation efforts aimed at increasing native wildlife populations in the areas surrounding cities can also be helpful since large population sizes can help buffer against genetic contamination while also benefiting regional conservation efforts.

(Photo by JKehoe CC BY 2.0)

EYE TOWARDS MANAGEMENT: ADDRESSING CONCERNS

All trees have the potential to produce both ecosystem services and disservices, and oaks are no exception. Some of these perceived or actual disservices may create conflict with urban forestry goals, while others affect the willingness of private citizens to plant or maintain oaks on their property. Because these issues could inhibit adoption of re-oaking programs, strategies for addressing common complaints are likely to be an important determinant of project outcomes. Some issues will require outreach to understand and overcome public perceptions. Others can be addressed by combining re-oaking with thoughtful urban forest management, or within the context of city-wide plans such as urban forest management plans. Here, we briefly outline some of the concerns that have been identified by the urban forestry community, and provide guidance for each. The list is not intended to be exhaustive, nor are the recommendations for addressing issues comprehensive. The guidance provided here is therefore only a start, and it is likely that more will be needed to develop effective and locally-tailored outreach and management plans.

Among the issues cited is that oaks produce relatively high levels of volatile organic compounds (VOCs). While this complaint is supported by science, oaks are far from the highest producers of VOCs. Studies of trees in enclosures have found that VOC emissions from the leaves of urban trees of varying sizes ranges from fewer than 1 microgram/hour (mcg/h) of VOCs to around 600 mcg/h (Wiedinmyer et al. 2004). Valley oaks emit around 3.4 mcg/h and coast live oaks emit 35-49 mcg/h. For comparison, many of the eucalyptus species common in the urban forest emit around 600 mcg/h (Wiedinmyer et al. 2004). VOCs react with common nitrogen oxides (NOx) compounds produced by fossil-fuel emissions in the presence of sunlight to produce ground-level ozone (Calfapietra et al. 2013); a key air quality concern in California. Ozone production is most problematic in areas of the state that already have substantial air quality problems, and may not be a significant issue in cities with less air pollution. However, trees also capture and mitigate air pollution, and the balance of production of VOCs relative to air pollution reduction benefits is an important factor to consider (Pataki et al. 2011). In addition, a shift away from vehicles powered by internal combustion engines (to electric cars, for example) over the coming decades could make VOC production by trees in cities less of a concern. Local air quality, existing street tree composition (including the presence of other trees that are high VOC producers), a comparison of the total benefits that the existing trees are providing compared to the total benefits those trees plus the proposed trees would provide, and numbers of proposed additional oaks are some of the factors that can be considered when evaluating the likelihood that a project will have substantial impacts on the production of ground-level ozone.

Another concern is that large-scale oak planting could reduce the tree species diversity of the urban forest. Urban forestry professionals strongly prioritize diversity in order to reduce the risk that pest outbreaks will lead to widespread mortality in street trees. To address this issue, we recommend an assessment of current levels of diversity during the planning phases of re-oaking projects. In Silicon Valley, for example, oaks are relatively uncommon, leaving room for substantial numbers of additional trees without a dramatic reduction in diversity. We also stress the importance of funding for pest research and monitoring, and for the development of best management practices around reducing the risk of spread of harmful pathogens and pests.

Re-oaking could also exacerbate conflicts between people and the wildlife that are attracted to oaks. For example, acorn woodpeckers can drill into the wood siding of people's homes to store acorns. While this behavior is usually not widespread, it can be a significant local nuisance. A number of techniques are available to deter woodpeckers from constructed features that draw interest, including strategically-placed netting in eaves of houses where drilling is most likely to occur (Salmon et al. 2006). To address this issue, we recommend thoughtful management that combines re-oaking with techniques such as woodpecker netting that reduce conflict between wildlife and people. In some cases, public outreach may also be helpful in changing perceptions about wildlife that are considered pests.

Other commonly cited issues that may best be addressed via public outreach and education are complaints that oaks are too large for many urban sites, that acorns are a nuisance, and that oak pollen is allergenic. Facing concerns about the large size of oak trees, it can be important to recognize the benefits provided by large trees (Lindenmayer et al. 2012). To address this issue, some urban forest managers use photos showing oaks at different ages to help the public understand that many backyards can accommodate oaks even at maturity. Furthermore, private properties are often excellent places for oaks because conflict with infrastructure such as sidewalks and roads can often be minimized. Similar outreach may be effective in alleviating fears about acorn production and allergies. While it is true that oak pollen can be allergenic for some people, there are many other trees, shrubs, grasses, and herbaceous plants that also produce allergenic pollen (D'amato et al. 2007), and it is not clear that tree pollen is the most potent producer of allergens. For example, grass pollen is the most common source of pollen-induced allergies in Europe (D'amato et al. 2007), and many of the most problematic grasses from the Mediterranean are also common in California. In addition, many non-native street trees common to our region produce allergenic pollen, including European ash, London planetree, stone pine, privet, olive, and several species of cypress, cedar and juniper (WHO/IUIS Allergen Nomenclature Sub-committee). Given the large number of other allergenic plants in California, it is unlikely that planting oaks will substantially increase the production of problematic pollen in cities.

Judgements about the magnitude of these issues are likely to depend on local context. For example, cities in areas with frequent drought may place a higher premium on drought-tolerant trees. Adequately addressing the full set of services and disservices is a key step in evaluating the tradeoffs associated with any project (Escobedo et al. 2011). Evaluating disservices is also important, because identifying the most problematic issues as well as the people most likely to be affected by them can allow projects to mitigate disservices in affected areas, thus reducing the possibility for backlash against tree-planting projects (Lyytimaki et al. 2009).

Valley oak in an urban park in Thousand Oaks, California, with supports to prevent limbs from falling. *(Photo by Randy Robertson CC BY 2.0)*

CONCLUSIONS: RE-OAKING IN THE FUTURE

The rapid and continuing transformation of Silicon Valley creates an unusual opportunity to recover some of the region's natural heritage by re-incorporating elements of oak woodland ecosystems. These changes could contribute to building landscape resilience in the region, increase biodiversity, and benefit people. Becasue oaks are relatively rare urban trees, their numbers could be augmented without substantially reducing the diversity of the urban forest, and re-oaking could be accomplished primarily by replacing trees as needed over time. We have focused primarily on Silicon Valley as a test case for how re-oaking might occur, but there are many other cities in California that replaced oak woodlands, and it is likely that similar approaches will apply to these places as well.

This report begins to develop a foundation for re-oaking, drawing on ecology, natural history, and historical ecology. However, additional scientific development could build upon this foundation. In particular, this report touches only briefly on how re-oaking might tailor recommendations to adapt to future predicted climate changes. Additional work can further evaluate which species and genotypes will be most appropriate over the coming decades. In addition, we have provided a short summary of some of the main ecosystem services and disservices provided by some oaks. However, additional development could synthesize a broader set of services and disservices for oaks and for other species in the oak woodland community, build scenarios to quantify how the urban forest of today would compare to changes that re-oaking could achieve, and provide a framework for evaluating the tradeoffs of services and disservices in a holistic way.

This report is a beginning, but more work will be needed in order to develop re-oaking into a full program that can be easily implemented. Anticipated next steps include developing more detail to address technical challenges, maintenance issues, and planting guidelines. Additional management and design guidelines will help facilitate integration into projects across a variety of sectors including urban forestry, horticulture, landscape architecture, open space planning, and community outreach.

(Photo by Miguel Vieria CC BY 2.0)

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APPENDICES

APPENDIX 1: USEFUL RESOURCES

Other useful sources of information related to urban forestry, arboriculture and horticulture, and oaks in the urban landscape.

Costello, Laurence Raleigh, Bruce W. Hagen, and Katherine S. Jones. 2011. Oaks in the Urban Landscape: Selection, Care, and Preservation. Vol. 3518. University of California Agriculture and Natural Resources, Richmond, CA.

http://ucanr.edu/sites/oak_range/Oaks_in_Urban_Landscapes/

This resource provides valuable information for management, conservation and recruitment to maximize both lifespan of oaks and their benefits in the urban landscape.

Giusti, G. A., D. D. McCreary, and R. B. Standiford. 2005. A planner's guide for oak woodlands. University of California Agriculture and Natural Resources, Richmond, CA.

http://anrcatalog.ucanr.edu/Details.aspx?itemNo=3491

This guide provides valuable information about oak woodland ecology and management, some of which can be applied to re-oaking practices in urban settings.

Little, Richard, T. Swiecki, and W. Tietje. 2001. Oak woodland invertebrates: The little things count. University of California Agriculture and Natural Resources, Richmond, CA.

http://anrcatalog.ucanr.edu/Details.aspx?itemNo=21598

This document provides information on the ecology of oak woodlands on a finer scale, useful for planning involving management of biodiversity.

Mccreary, D. 2011. Living among the Oaks: A Management Guide for Landowners and Managers. University of California Agriculture and Natural Resources, Richmond, CA.

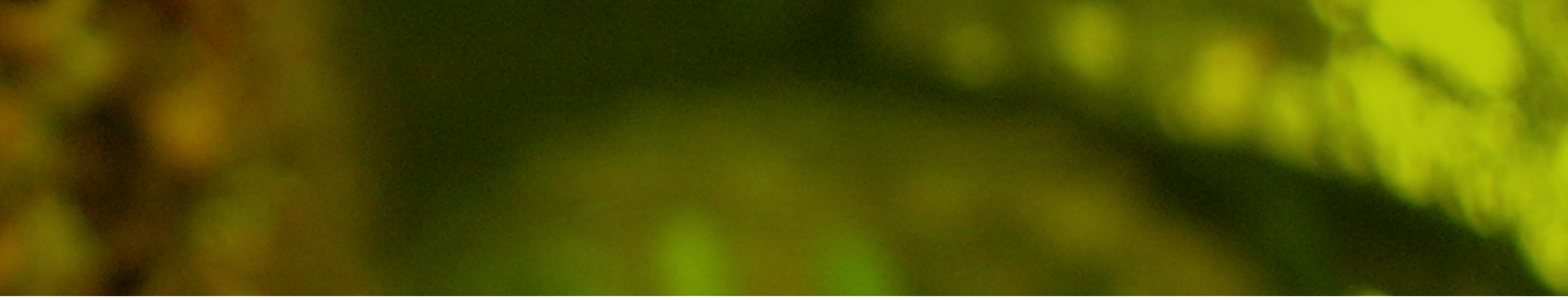
http://anrcatalog.ucanr.edu/Details.aspx?itemNo=21538

This guide provides management strategies and methods for land stewards targeting oaks.

Pavlik, Bruce M. P. Mvick, and S. Johnson. 1991. Oaks of California. Cachuma Press and the California Oak Foundation. Los Olivos, CA.

https://books.google.com/books/about/Oaks_of_California.html?id=Mz8lAQAAMAAJ

This resources provides an overview of California oak species, distributions, biology and ecology.



Phytosphere Research fungal root rot management guide

http://phytosphere.com/soilphytophthora/Issues_implications_Phytophthora_container_stock.htm

This website provides best management practices for reducing contamination of plants by root rot fungi in nurseries.

Ritter, Matt. 2011. A Californian's Guide to the Trees Among Us. Heyday, 2011.

https://www.amazon.com/Californians-Guide-Trees-among-Us/dp/159714147X

This book provides an overview of common street trees planted in California cities.

Standiford, Richard B., Pamela Tinnin, and Ted Adams. 1996. Guidelines for managing California's hardwood rangelands. University of California Agriculture and Natural Resources, Richmond, CA.

http://anrcatalog.ucanr.edu/Details.aspx?itemNo=3368

This guide provide valuable information about hardwood rangeland ecology and management, some of which can be applied to re-oaking practices in urban settings.

Swiecki, T. J., and E. A. Bernhardt. 2006. A field guide to insects and diseases of California oaks. Gen. Tech. Rep. PSW-GTR-197. Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, CA.

https://www.fs.fed.us/psw/publications/documents/psw_gtr197/

This resource provides a comprehensive overview to many of the threats to California oak trees in terms of pests and pathogens -- a potentially important resource for urban forest managers.

Urban forest master plans from Bay Area cities.

Mountain View Community Tree Plan	http://www.mountainview.gov/depts/cs/parks/community_tree_master_plan.asp
Palo Alto Urban Forest Master Plan	http://www.cityofpaloalto.org/gov/depts/pwd/trees/mgmt/ufmp.asp
San Diego Tree Guide	https://www.sandiego.gov/sites/default/files/legacy/street-div/pdf/treeguide.pdf
San Francisco Urban Forest Plan	http://sf-planning.org/urban-forest-plan
San Jose Tree Policy Manual	http://www.sanjoseca.gov/DocumentCenter/View/8968
SF Bay Area State of the Urban Forest	http://www.sanjoseca.gov/DocumentCenter/View/8968

These plans represent past, ongoing and future management plans to promote healthy urban forests and provide ecosystem services. They present opportunities to understand where re-oaking strategies may be congruent with or integrated with municipal management plans.

APPENDIX 2: METHODS AND DATA SOURCES

Table A1. The analysis of historical and contemporary change over time in size, structure and composition of trees is based on three data sources:

	General Land Office Public Land Survey	Palo Alto Oak Well Survey	Street tree inventories
Source	Beller et al. 2010, Powell 2008, White 1976.	Courington & the OakWell Volunteers, 2002: http://canopy.org/wp-content/uploads/OakWell_Survey.pdf.	**Cupertino:** http://gis.cupertino.opendata.arcgis.com/ **Palo Alto:** http://www.cityofpaloalto.org/gov/depts/it/innovation/gis.asp **Mountain View:** http://data.mountainview.opendata.arcgis.com/
Sample size (# of trees)	135 trees.	Total sample size = 8,901 trees, valley oaks= 1,399, coast live oaks = 7,459.	82,342 trees.
Time period	1851-1888.	1997-2001.	Inventories collected between 2000 and 2010.
Geographic extent	Western Santa Clara County.	Palo Alto.	Palo Alto, Mountain View, Cupertino.
Description	Survey by Land Ordinance from Ohio to the west coast initiated in 1785. Surveyors gathered tree cover data, species identity, and size for up to four bearing trees at each section corner within section grid cells measuring 1x1 mile, as well as line trees used to mark the section line between section corners.	All valley, coast live, and black oaks in the city of Palo Alto.	Street trees managed and maintained by the city. City inventory data publicly available.
What does it include?	Transect and bearing trees from grid sampling design.	All oak trees including those privately owned in residential yards.	Includes trees in front yard rights-of-way, parking strips, tree wells, medians, and city parks.
Caveats and limitations	Surveys probably underestimate the number of both large and small trees (White 1976). Sample size is very small and likely missed some of the larger trees and rare species. Some oaks were not identified to species.	Does not include any species that are not oaks.	Does not include backyard trees in private residences, or trees on private property owned by businesses.

Figure 2. Historical oak size data were taken the Public Land Survey data from Western Santa Clara County, including 182 valley oaks and 63 coast live oaks. Modern data for comparisons of valley and coast live oaks are taken the Palo Alto OakWell survey. Modern data for comparison across all species are taken from street tree inventories from the cities of Mountain View and Cupertino (n= 51,811). Palo Alto street tree data was excluded from the analysis of tree size because the city does not record trees above 48 inches in diameter (trees larger than this size are recorded as 48 inches).

Note that the absence of Coast Live oaks larger than 50 inches is most likely due to the small number of trees; it is likely that surveyors simply didn't encounter any very large trees, which are usually rare on the landscape. Furthermore, while it appears that the proportion of small trees may be larger today than it was historically, we caution against this conclusion because the historical data likely underestimated the number of small trees (White 1976).

Figure 3. The analysis of land cover types was conducted in June, 2016 and was taken from two neighborhoods in the city of Mountain View in zones that were historically oak woodland and oak savanna. Analyses were conducted using iTree Canopy and Google Earth imagery with 1,500 randomly dropped points in each neighborhood. Each point was classified visually by the category of land cover type (e.g. impermeable surfaces, building, tree canopy, lawn, or herbaceous vegetation). Herbaceous vegetation included any vegetation that was not clearly either lawn or tree canopy, including gardens, shrubs, open grassland vegetation, and ruderal vegetation in waste spaces. Impermeable surfaces included pavement, cars, sidewalks and roads. Standard errors were calculated for each category using the following:

N = total number of sampled points
n= total number of points within classification category (e.g.,10 tree canopy, building, etc.)
p=n/N
q=1-p
SE=square root of pq/N

See www.itreetools.org for additional documentation on iTree Canopy methodology.

Figures 4 and 5. Species composition comparisons are taken from Public Land Survey data and street tree inventory data (see data descriptions above).