Development of a Management Plan for Coast Live Oak Forests Affected by Sudden Oak Death in East Bay Regional Parks[1]

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Abstract

The East Bay Regional Park District maintains the largest urban park system in the United States, comprising over 45 000 ha, and more than 1900 km of trails, with extensive forests bordering residential areas. Sudden oak death (SOD), caused by the introduced oomycete *Phytophthora ramorum*, was first detected in a district park in 2001. Both increased fire risk and structural failure of large trees located near sites with heavy public usage are concerns for managers. Management requires reliable data about the location and severity of the disease. To produce disease incidence and risk maps, between 2008 and 2013 we placed 537 georeferenced 10-m radius fixed plots in oak-bay stands in five parks in the East Bay Hills in the San Francisco Bay Area. We recorded data for all woody vegetation and the disease status of coast live oaks. Between 6 and 17 percent of coast live oaks were symptomatic and 2 to 8 percent were dead with symptoms of SOD. Infection rates of 2.1 and 3 percent/year were estimated for Tilden Park and Huckleberry Preserve, respectively. Logistic regression analysis for Anthony Chabot Park identified two predictors of SOD incidence: topographic moisture indices and increasing coast live oak diameter at breast height (1.37 m; DBH). Model results for the other parks confirm that DBH is a significant predictor of SOD infection. Modeled results for the other four parks found consistently significant associations between symptomatic coast live oak and remote sensing derived tasseled cap greenness vegetation index values, and distance to stream channels.

Key words: coast live oak, East Bay Regional Parks, logistic regression analysis, management, mapping, sudden oak death

Introduction

The sudden oak death (SOD, caused by the introduced oomycete *Phytophthora ramorum*) epidemic has potential to significantly alter species composition, stand structure, ecosystem services, fire risk, and wildlife populations in susceptible forests. Coast live oak (*Quercus agrifolia*) is the dominant oak species in many hardwood forests in the Coast Ranges of California.

The East Bay Regional Park District (EBRPD) maintains the largest urban park

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system in the United States, comprising over 45 000 ha, more than 1900 km of trails, and numerous picnic grounds and campsites. The urban-wildland interface, much of which is composed of coast live oak-California bay laurel (*Umbellularia californica*) forests, lies adjacent to the cities of Richmond, El Cerrito, Berkeley, Oakland, and San Leandro. Sudden oak death was first detected in Wildcat Canyon Regional Park in 2001. The pathogen was already established in Marin County when the first mortality was observed in 1994 and the effects on impacted forests have been well documented (McPherson and others 2005, Rizzo and Garbelotto 2003). Due to the more recent establishment in the East Bay (Alameda and Contra Costa Counties), the disease has inflicted considerably less damage to date. A principal management concern is the effect of the death of large numbers of coast live oaks on fire risk and structural failure of large trees located near sites with heavy public usage. Reliable data for location and severity of the disease in coast live oaks is necessary to produce disease incidence and risk maps, which help to inform and prioritize management decisions.

In 2008, we found large numbers of coast live oaks showing the full range of SOD symptoms in a stand adjacent to a picnic site in Tilden Park. Symptomatic bay laurel foliar samples in the stand were confirmed positive for *P. ramorum* by the California Department of Food and Agriculture. Following discussions with EBRPD's IPM specialist, the late Nancy Brownfield, we proposed to define the extent and intensity of the disease in Tilden Park. The goal of this study was to apply what we had learned from long-term disease progression plots in Marin County to the East Bay forests, in which the pathogen was a more recent arrival, to help the park district develop approaches to managing their lands while there might still be time to be proactive.

This study was designed to determine where SOD was established and the extent of the damage, to project change at the stand level, and to evaluate the influence of environmental variables that might affect disease propagation. To accomplish these goals, we created detailed georeferenced maps of disease incidence and intensity.

Sudden oak death in coast live oaks progresses in identifiable stages (early stage – bleeding only; late stage – bleeding plus beetles, with or without the secondary fungus *Annulohypoxylon thouarsianum*; dead) (McPherson and others 2005, 2010). A major concern is the risk posed by structurally weakened coast live oaks. Once infected by *P. ramorum*, a large majority of coast live oaks are attacked by up to six species of ambrosia and bark beetles (McPherson and others 2008), with subsequent fungal introductions into the sapwood (McPherson and others 2013), leading to considerably increased likelihood of structural failure. Our work in Marin County showed that beetle attacks reduced median survival times of infected trees from about 8 years without beetle attacks to about 3 years after attacks (McPherson and others 2010). By introducing a temporal component, we could then apply a stage-structured approach to mapping and have greater ability to predict which locations are likely to show increased disease impact. Additional spatial information is beneficial to park managers because tree failure often occurs while foliage is still green, which untrained personnel may not recognize as posing a hazard. Larger coast live oaks tend to have higher infection rates than smaller trees, (McPherson and others 2005, 2010) and therefore pose a greater risk to park users. Such trees are frequently found in picnic areas, campgrounds, along roads, and adjacent to playing fields.

Monitoring plots were placed in Tilden, Wildcat Canyon, Redwood, and Anthony Chabot Regional Parks and Huckleberry Regional Botanic Preserve. These parklands generally lie to the east of the westernmost ridge in the East Bay Hills from Richmond to near Castro Valley, a distance of approximately 34 km (fig. 1). Except for a discontinuity between Tilden Park and Huckleberry Preserve, the coast live oak-bay laurel forest cover under EBRPD's jurisdiction is largely continuous. Park District vegetation type maps based on aerial photography and ground assessments were used to classify the dominant plant communities, which include eucalyptus stands, redwood forests, chaparral, and oak-bay forests.

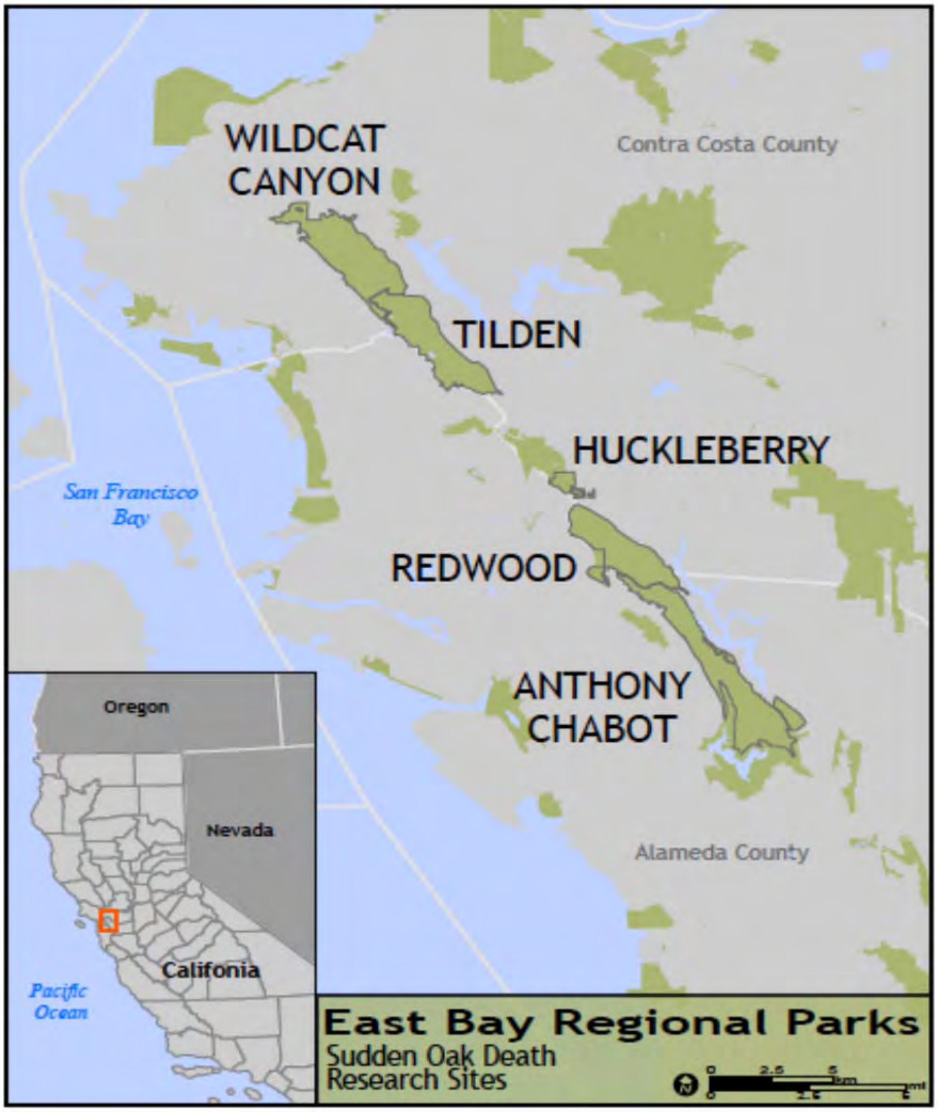

Figure 1—Monitoring plots were placed in the coast live oak-bay laurel vegetation type in five parks of the East Bay Regional Park District. These parks lie at the urban-wildland interface along their western boundaries.

Methods

Two sampling and plot distribution methods were used in the study. In Tilden Park and Huckleberry Preserve, where vegetation type and cover are highly variable, we employed the point-centered-population density estimation (PDE) method (Engemann and others 1994, Kelly and others 2008). This method allows for efficient sampling of isolated stands within a larger fragmented landscape. Sampling nodes were placed at 40-m intervals along transects established through oak-bay stands with a minimum length of 150 m from 2008 to 2010. The minimum length assured at least three sample nodes per transect. In each node, a center tree was selected and data were taken for the nearest mature coast live oak in each cardinal direction, for a maximum of four trees per sampling node. Only trees within 15 m of the center were included in a node to avoid overlap with other nodes. A 10-factor foresters' prism was used to estimate basal area by tree species.

The other three parks are not only larger, but the forest cover is considerably more extensive. We randomly placed plots in Redwood, Anthony Chabot, and Wildcat Canyon Parks based on the area of oak-bay habitat within each park. Numbers of plots per park were determined with well-known sample size formulas for estimating a population proportion (in this case the proportion of diseased trees) assuming we want our sample estimate to be within ten percent of the true, but unknown, population proportion with an alpha level of 0.05. To make these calculations we used the estimated proportion $\hat{p}$ and the variance of $\hat{p}$ from Tilden Park, which could be reasonably assumed to represent the level of disease in the other parks for the purposes of calculating sample sizes needed in the other parks. Plots were randomly assigned to the habitat type with GPS coordinates in 2011 and were restricted to sites with < 30 percent slope to improve access. In each 10-m radius fixed plot, a center, north, and south tree was tagged for permanent reference. Every woody stem $\geq$1.5 cm diameter at breast height (1.37 m; DBH) was recorded. Additional SOD symptom data were collected for coast live oaks (McPherson and others 2005, 2010). Each stem of a multiple stem coast live oak was counted as a tree because on such trees *P. ramorum* infections appear to be distributed independently (McPherson and others 2005, Swiecki and Bernhardt 2013). Regeneration data were collected for all woody seedlings and saplings by placing two 2 x 10-m belt transects aligned approximately north and south in each plot. These data (McPherson and others, unpublished) are not discussed here. In 2013 we revisited the Tilden Park and Huckleberry Preserve transects and converted each node to a 10-m radius plot to update the data and to standardize the data for analysis.

A logistic regression modeling approach was used to measure the association between coast live oak symptom status treated as a binary variable (symptomatic/asymptomatic) and a number of plot and landscape level environmental variables. We chose to conduct an analysis of Anthony Chabot Park as the model park. The probability that a coast live oak will become symptomatic was estimated for three distinct risk levels within the park (O'Neill 2014). Briefly, a combination of ground sampled plot-level variables and landscape level environmental variables based on GIS (Geographic Information Systems) software and remotely sensed image analysis were chosen as inputs to the model. Plot level variables included DBH and basal area for coast live oaks and two proven foliar hosts, bay laurel and madrone (*Arbutus menziesii*), and one associated host, beaked hazel (*Corylus cornuta*) (USDA APHIS 2012). Landscape level variables produced from GIS data included percent slope, aspect, a topographic wetness index - slope area ratio, total summer solar radiation, and distance to roads and trails, forests edges, and streams. Two vegetation indices, NDVI (Normalized Difference Vegetation Index) and tasseled cap brightness, greenness, and wetness, were derived from National Agriculture Imagery Program (NAIP) 4-band color infrared (CIR) tiles (NAIP 2014).

Results

Summed across the five parks, data were recorded for 8,179 coast live oak stems ≥1.5 cm. The coast live oak-bay laurel vegetation type accounts for 35 percent of the total area in the five parks (table 1). The total numbers of trees per park in the oak-bay vegetation type were calculated by assuming that vegetation in each plot (area = 315 m^2) was representative of the surrounding forest. We estimate that these five parks hold 6.62×10^5 coast live oaks.

Table 1—Coast live oak summary data for the five East Bay parks

Park	Total park area, ha	Area in oak-bay, ha	Percent in oak-bay	N of plot trees by park	Total N of trees
Tilden, 2013	838	176	21	1850	7.89×10^4
Huckleberry, 2013	94	62	66	391	2.48×10^4
Redwood, 2011	726	306	42	1702	1.55×10^5
Anthony Chabot, 2011	1238	490	40	2101	2.48×10^5
Wildcat Canyon, 2011	988	310	31	2135	1.55×10^5
Sum	**3884**	**1344**	**35**[a]	**8179**	$\mathbf{6.62 \times 10^5}$

[a]Average percent of all parks in the oak-bay vegetation type.

Coast live oak mean DBH (standard error) varied from 25.09 (0.31) cm in Anthony Chabot Park to 33.56 (0.82) cm in Huckleberry Preserve (table 2). Stem densities per plot were lower in Huckleberry Preserve and Tilden Park, but varied little among the other parks.

Table 2—Coast live oak plot data for five East Bay parks

Park	N of plots	Stems/ plot	Mean DBH (se)	Mean basal area, m^2/ha
Tilden, 2013	131	14.1	26.56 (.39)	2.45 (.07)
Huckleberry, 2013	31	12.6	33.56 (.82)	3.47 (.16)
Redwood, 2011	107	15.9	28.99 (.29)	2.45 (.05)
Anthony Chabot, 2011	132	15.9	25.09 (.31)	2.1 (.05)
Wildcat Canyon, 2011	136	15.7	30.21 (.41)	3.12 (.08)

Percent living symptomatic coast live oaks (trees with only bleeding and those with bleeding and beetle tunneling activity, with or without *A. thouarsianum* fruiting bodies) ranged from 6 percent for Chabot Park in 2011 to 17 percent for Huckleberry Preserve in 2013 (table 3). Mortality attributed to *P. ramorum* ranged from 2 percent for Tilden Park (2013) to 8 percent for Redwood Park (2011). Total numbers of symptomatic and dead coast live oaks per park were calculated from the estimated percentages of trees in these categories in the 2011 and 2013 field evaluations. For the five parks, we calculated totals of 6.5×10^4 symptomatic and 2.7×10^3 dead coast live oaks (table 3).

Table 3—Percentages of symptomatic and dead coast live oaks for five parks

Park	Percent infected	Percent dead	Total infected	Total dead
Tilden, 2013	9	2	7.1×10^3	1.58×10^3
Huckleberry, 2013	17	3	4.22×10^3	7.44×10^2
Redwood, 2011	11	8	1.71×10^4	1.24×10^4
Anthony Chabot, 2011	6	3	1.49×10^4	7.44×10^3
Wildcat Canyon, 2011	14	4	2.17×10^4	6.2×10^3

Reanalysis of the plots in Tilden Park and Huckleberry Preserve in 2013 provided estimated infection rates of 2.1 percent per year and 3 percent per year, respectively. Based on these rates, new coast live oak infections of 1400 and 594 per year are expected in Tilden Park and Huckleberry Preserve, respectively (table 4). Assuming an arbitrary but probably low infection rate of 2 percent per year, 9,900 new infections per year would be expected in coast live oaks across the five parks.

Table 4—Projected annual new *P. ramorum* infections by park

Park	Infection rate[a]	Estimated starting population[b]	Annual new infections
Tilden	2.1	7.02×10^4	1.4×10^3
Huckleberry	3.0	1.98×10^4	5.94×10^2
Redwood	2.0	1.26×10^5	2.52×10^3
Anthony Chabot	2.0	2.26×10^5	4.52×10^3
Wildcat Canyon	2.0	1.27×10^5	2.54×10^3

[a]Rates for Tilden and Huckleberry were derived from re-evaluation of plots. For the other three parks, a conservative estimate below that for Tilden Park was assumed.
[b]Calculated by removing estimates for infected and dead coast live oaks from the starting populations (2011 or 2013, depending on park).

Disease incidence maps were produced to guide management decisions by documenting areas within each park with infected and dead coast live oaks. Within individual parks, disease levels can differ considerably. In southern Tilden Park, 25.7 percent of the coast live oaks were symptomatic in 2013, as opposed to 7.6 percent in the northern section. In Wildcat Canyon Park, contiguous with northern Tilden Park, 18.3 percent of coast live oaks were symptomatic in 2011. Because SOD infections in coast live oaks occur in characterizable stages, maps can identify areas where the disease has recently become established as well as areas with larger numbers of coast live oaks with late stage disease that pose elevated risks to the public from structural failure. Within individual parks, disease levels differ considerably. Stage-structured maps, based on disease stages, include a temporal component and can be used to identify areas that are expected to show increases in late stage diseased trees.

Two logistic regression models that were constructed using coast live oak-specific data and environmental variables for Anthony Chabot Park differed slightly in selection of statistically significant predictors of risk factors. Model I identified two significant predictor variables, coast live oak DBH and CTI, a topographic moisture index. In Model II, significant predictors were coast live oak DBH, SAR (slope area ratio, a different derived moisture index), and tasseled cap greenness (O'Neill 2014). The derived index CTI assigns low values to steep slopes and small catchments and high values to large watersheds and valley bottoms with gentle slopes. Slope area ratio also weighs the contribution of water flow from adjacent areas as a function of slope. Both the moisture indices identified drier ridges and upslope areas as having elevated SOD risk, which is consistent with the habitats in which coast live oaks are found. Holding DBH constant in the model, increasing CTI decreased the likelihood that a coast live oak will exhibit SOD symptoms. This relationship suggests that soil moisture influences infection of coast live oaks.

Both models predicted that an increase of 10 cm DBH increases the probability that a coast live oak will be symptomatic by approximately 20 percent. For example, a coast live oak with 50 cm DBH in a site with greenness and moisture indices in the average range was predicted to have 15 percent probability and a coast live oak with 80 cm DBH was predicted to have 25 percent probability of becoming symptomatic. Where risk was increased, as determined by SAR and greenness values, an 80 cm coast live oak was predicted to have 70 percent probability of infection.

Contrary to expectations, neither model found that a variable composed of the summed basal areas of the known foliar hosts bay laurel and Pacific madrone, plus California hazel (*C. cornuta*) was a significant predictor of disease incidence.

Preliminary results of analyses of the other four parks led to some differences in the variables that were identified as significant predictors of infection. In contrast to the model results for Anthony Chabot Park, foliar host basal area was significant for three of the other four parks. The tasseled-cap greenness vegetation index, which was consistently significant, establishes a connection between symptomatic coast live oak and areas with decreased levels of green biomass. Closeness to streams was a significant predictor that a coast live oak will be symptomatic, holding other variables constant. These findings also support the conclusion that disease dispersal and hydrologic dynamics are somehow related.

Conclusions

The network of permanent georeferenced plots in the five principal parks in the East Bay Hills provides the opportunity to follow the course of the *P. ramorum* epidemic in forests where the host of greatest management interest, coast live oak, is a dominant species. Management of parklands for multiple uses, including recreation, maintenance of healthy wildlife populations, and watershed protection is a complex challenge. Accurate information is always prerequisite for informed planning. The collection of data by disease stage makes it possible to follow the progression of the disease through time and to detect new areas of increasing disease. For example, SOD incidence in oak-bay stands above the Tilden Nature Area in the northern part of the park increased from 3.1 percent to 4.9 percent over 4 years to 2013. Across the northern section of Tilden Park overall, symptomatic coast live oaks increased from 4.7 percent in 2009 to 7.6 percent.

Projections of coast live oak infection presented in table 4 include all size classes, including the smallest trees, which are known to have very low infection levels. In addition, the possible role of resistance was not considered in these estimates. At present, the extent and durability of resistance to *P. ramorum* are not known, but may affect the long-term impacts of the disease in forests (McPherson and others 2014). Studies to evaluate the extent of resistance in coast live oaks in these parks are planned for 2015 (McPherson and others, Biomarkers identify coast live oaks that are resistant to the invasive pathogen *Phytophthora ramorum,* these proceedings).

The logistic regression model quantifies the relationship between coast live oak stem diameter and probability of *P. ramorum* infection, consistent with findings in other studies (McPherson and others 2005, 2010). The association of bay laurel with elevated risk of infection of coast live oaks has been reported by Kelly and

Meentemeyer (2002), Swiecki and Bernhardt (2002), and McPherson and others (2010). Further, the role of this tree as a source of inoculum is well established (Davidson and others 2002). The lack of a relationship between basal area of bay laurel and two other foliar hosts and coast live oak infection in Anthony Chabot Park may reflect the specific properties of the stands in this particular park. A similar lack of positive association between foliar host basal area and symptomatic coast live oaks was also found in the Redwood Park model, but in models for Wildcat Canyon and Tilden Parks and Huckleberry Preserve the associations was significant. It is worth noting that the presence or lack of a relationship in a model must be understood in light of the recognition that models are abstractions and are only meaningful when interpreted in the context of the system under analysis.

The presence of *P. ramorum* in these parklands is now a fact that land managers will need to address. In areas with little or no detected disease, the pathogen will certainly continue to infect and kill coast live oaks in the near future. Faced with the need for adaptive management of these resources, the mapping project provides the foundation for development of models to identify the factors with the greatest probability of affecting the trajectory of the disease. The production of disease incidence and severity maps is thus fundamental to all that follows.

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