Bay Area Drought Impacts
Forest Service Agreement Number: 22-JV-11272131-002
Project Title: Bay Area Drought Impacts and Douglas-Fir Structure on the San Francisco Peninsula
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Reporting Time Period: 7/31/2022 to 12/31/2022
Agreement Start Date – End Date: 2/2/2022 to 9/5/2022

Final Report

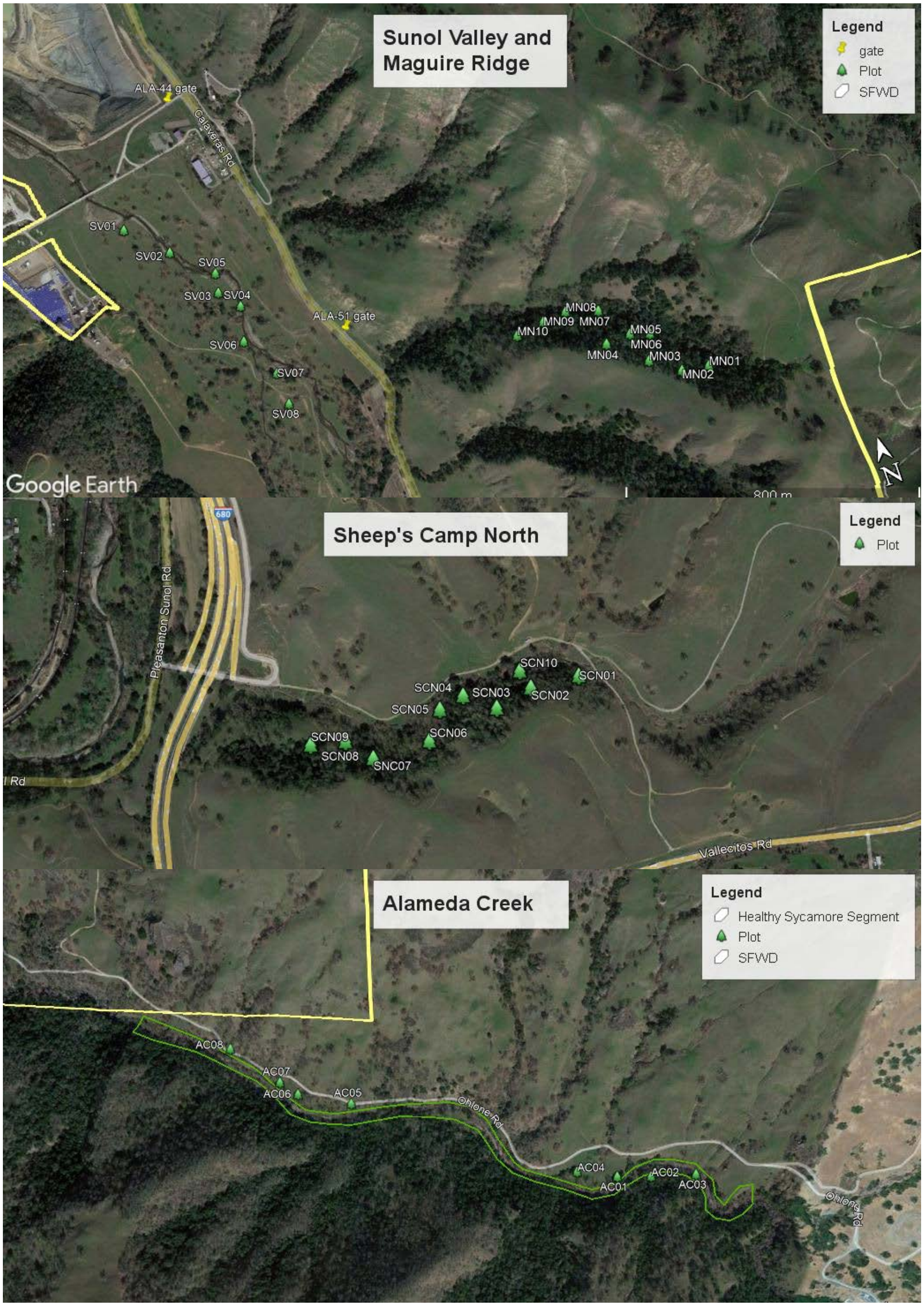
Summary. Widespread and synchronous decline in tree and plant health throughout the Bay Area aligns with extreme to exceptional drought conditions resulting from historically low precipitation totals and climate change-driven increases in spring and summer temperatures. This tree decline is contributing to increasing fuels amidst the unprecedented fire seasons witnessed in recent years, while land managers, cities, counties, water districts and others are working to reduce fuel loads and develop vegetation management strategies to adapt to drought, new climate extremes and other changes in climate.

Objectives. Unprecedented Bay Area tree decline calls for research to determine the mechanisms by which climatic drought impacts trees and shrubs of different sizes and species, as well as the consequences of drought, such as shifts in fuels profiles, increased tree mortality rates, depressed tree regeneration, and weed invasion. We will establish a network of plots to serve as a baseline and provide opportunities for monitoring changes in future years, as well as to investigate the underlying hydrological drivers of tree water stress and mortality. Extreme drought conditions and temperature stress is widespread throughout CA including the Bay Area, where tree mortality could lead to dramatic changes in plant community composition that could have cascading consequences for the hydrology of Bay Area watersheds, as well as wildfire risk. In addition, we will evaluate the physiological status of oaks and sycamores in the East Bay by analyzing leaf samples and determining water-use efficiency ($\delta^{13}C$) between species and between locations to assess baseline drought adaptation strategies.

Methods. A total of 36 plots were established in the East Bay on SFPUC lands. Twenty plots were established in oak woodlands; 10 plots were located at Sheep Camp and 10 at Maguire Ridge-North. Sixteen plots were established in sycamore riparian woodlands 8 plots were located at Alameda Creek and 8 in Sunol Valley (see Figure 1). All data (plot, tree, regeneration data, and some images) were entered into iForm Builder (see attached datafiles) (https://www.iformbuilder.com/features-2/beyond-forms/).

Plot sampling. At each study site, 8-10 plots (500 m^2, i.e., 25.2 m diameter) were established with their location based on species composition, oak woodlands and sycamore riparian. Once stands were located at a site, a random starting point was chosen for the first plot in each respective woodland. Additional plots were 100 m from the previous plot and were placed by randomly selecting a compass bearing of 0, 90, 180 or 270, or contouring from the initial location, so long as the bearing kept us within the oak and/or sycamore woodland. Locations of all plots were recorded and given a GPS location. Within each plot, woody plant species were identified and diameter at breast height (d.b.h.) was taken for all individual stems ≥ 1.0 cm d.b.h. and 1.37 m tall. All tree positions (azimuths and distance) from the plot center were recorded and mapped. Plant status was noted (live or dead) and each tree was designated a crown position (understorey, intermediate, codominant, dominant or emergent) as well as crown condition (rated 1–10 as follows: (1) ≤10% dead, dying, damaged, or infected; (2) 11–20% dead, dying, damaged, or infected; (3) 21–30% dead, dying, damaged, or infected, etc.). Year of death was estimated for snags, downed logs, and stumps based on bark, twig, and needle retention. The slope and aspect of each plot and visible signs of past fire (i.e., basal fire scars) were also recorded, as well as litter depth (in cm), land-use history (e.g., hl= historical logging, gr=grazing, fs=fire suppression, rt=recent thinning, pf=prescribed fire, wf=wildland fire; n=none), percent rock cover, and forb and shrub cover.

Figure 1. Drought plot network at Sunol Valley, Maguire Ridge, Sheep Camp, and Alameda Creek.



Seedlings and saplings <1.37 m tall were evaluated within each plot in a 5 m^2 circular subplot from the center tree. Seedlings were placed into 2 seedling size classes: 1=seedlings <50 cm (20 in) height; seedling class 2= seedlings >50cm (20 in) height. When seedlings were present whorl counts were taken (number of branch whorls is a proxy for age) - only for live regeneration.

Pathogen and insect sampling. Signs and symptoms of pathogens and insects were recorded as well as abiotic agents of mortality (e.g., drought), where possible. Pathogen and insect presence were noted for live and dead trees. Initial list of pests and other damaging agents are as follows: 1=Armillaria, 2= Ambrosia beetle, 3=Anthracnose, 4=Biscognauxia spp., 5=Bot Canker, 6=Flatheaded appletree borer, 7=Gold Spotted Oak Borer, 8=Horned Moth, 9=Hypoxylon, 10=Mediterranean Oak Borer, 11=Metallic wood boring beetle, 12=Mistletoe, 13=SOD, 14=Twig Borer/Girdler, 15=Western Oak Bark beetle, 16=Western Sycamore borer, 17=Chlorosis, 18=Cuscuta salina, 19=Drought stress, 20=Ozone, 21=Mechanical damage, 22=Poison Oak choking, 23=Rot (Brown), 24=Rot (Canker), 25=Rot (Heart), 26 =Rot (White), 27=Sun Scorch, 28=Willow borer, 29=Woodpecker.

Water-use efficiency sampling. Two to 3 leaves of oak and/or sycamore were harvested from each sample tree in the field, labeled, and placed into a coin envelope containing 3 packets of desiccant to start the dry down process. In the lab all samples were placed in the drying oven at 45°C for 72 hours to further dry down leaf samples. Once dry, leaves were placed into a mortar with liquid nitrogen and coarsely ground. Leaf tissue was then transferred into 20-ml glass vials and oven-dried at 60°C for 96-hours. Two to 3 mg of ground and dried needle tissue from each sample tree was placed into an individual well of a 96-well microplate for analysis. Samples were analyzed for $\delta^{13}C$ at the Stable Isotope Facility at UC Davis (http://stableisotopefacility.ucdavis.edu/). Data are presented as carbon isotope ratios for $\delta^{13}C$ (‰).

Table 1. Abiotic and biotic disturbance agents at Alameda Creek, Maguire Ridge, Sheep Camp, and Sunol Valley.

	Abiotic				Biotic										
Species/Site	Fire scar	Drought	Windthrow	Wilting	Anthracnose	Rots	Canker pathogens	Beetles	Gall	Leaf herbivory	Mistletoe	Poison oak choking	Woodpecker	Total number of agents	Total Live Trees
Aesculus californica															
Sunol Valley	0	0	0	13	0	38	38	0	0	0	0	0	0	90	18
Sheep Camp	0	0	0	0	0	18	11	4	0	4	0	0	0	39	5
Platanus racemosa															
Alameda Creek	9	34	0	9	21	32	98	2	0	20	0	0	18	235	36
Sunol Valley	9	2	0	32	55	36	126	19	0	2	0	0	26	297	34
Quercus agrifolia															
Alameda Creek	0	5	0	0	34	10	0	30	5	0	0	0	0	84	13
Sunol Valley	0	0	0	0	64	0	64	128	0	0	0	0	0	256	1
Maguire North	3	8	0	0	37	62	46	93	0	3	0	1	13	264	64
Sheep Camp	8	0	2	0	17	52	27	35	0	0	0	0	10	142	31
Quercus douglasii															
Alameda Creek	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Maguire North	0	32	0	0	0	43	21	43	21	21	0	0	0	181	6
Sheep Camp	0	0	0	0	0	36	2	4	23	0	2	0	6	77	30
Quercus kelloggii															
Maguire North	0	32	0	0	0	64	32	128	0	0	0	0	0	256	2
Quercus lobata															
Alameda Creek	0	13	0	13	0	64	26	0	26	0	0	26	0	166	5
Sunol Valley	0	0	0	0	0	64	64	0	0	0	0	0	0	128	1
Maguire North	0	39	0	0	15	54	25	25	54	69	0	0	5	290	13
Sheep Camp	8	0	3	0	2	52	23	17	37	23	0	5	12	184	41
Umbellularia californica															
Alameda Creek	0	0	0	0	18	0	0	9	0	0	0	0	0	27	7
Sunol Valley	0	0	0	0	64	0	64	0	0	0	0	0	0	192	1

Figure 2. Abiotic and biotic disturbance agents at Alameda Creek, Maguire Ridge, Sheep Camp, and Sunol Valley.

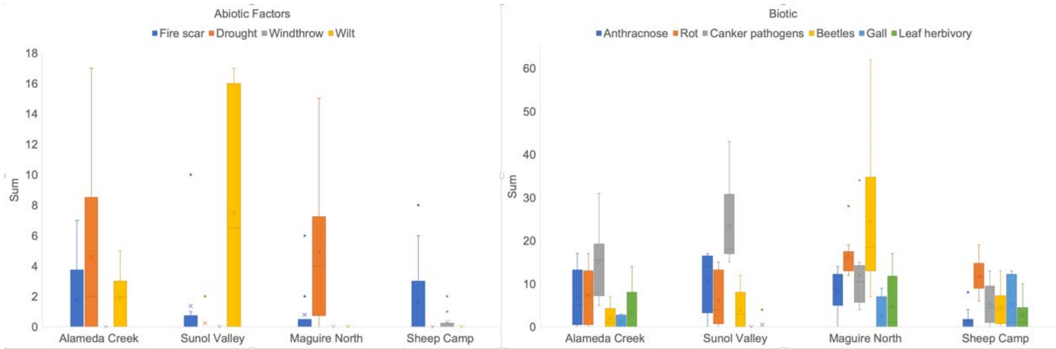


Table 2. Forest health metrics for 2 oak and 2 sycamore riparian woodlands in the east Bay – SFPUC lands.

Location	Forest Type	Mortality (%)	Quercus Mortality (%)	PLRA Mortality (%)	Crown Condition	Site $\delta^{13}C$ (‰) – WUE
Maguire Ridge – North	Oak Woodland	11	11		4	-28.05
Sheep Camp – North	Oak Woodland	13	17		3	-27.24
Alameda Creek	Sycamore Riparian	7		7	4	-28.98
Sunol Valley	Sycamore Riparian	23		32	3	-30.20

Results. A total of 363 trees were mapped and evaluated. Sycamore-riparian woodlands, Sunol Valley and Alameda creek were the 2 sites with observable drought stress, specifically Sunol Valley, and less so in the two oak woodland sites, however Maguire Ridge showed signs of drought stress more so than at Sheep Camp (see Figure 2). Abiotic disturbance agents included drought, fire scars, wilt, and windthrow (Table 1, Figure 2). There were numerous pests that were ubiquitous at all 4 sites ranging from Anthracnose, rot pathogens (root and stem), canker pathogens, beetles, gall insects, leaf herbivores, mistletoe, and woodpecker damage (see Table 1, Figure 2). Maguire Ridge and Sunol Valley had the highest numbers, respectively, of biotic and abiotic disturbance agents followed by Alameda Creek and Sheep Camp (Figure 2). The highest mortality was found at Sunol Valley (23%) followed by Sheep Camp (13%), Maguire Ridge (11%) and Alameda Creek (7%) (Table 2). Sunol Valley had high sycamore mortality (32%) compared to Alameda Creek (7%) and oak mortality was slightly higher at Sheep Camp (13%) compared to Maguire Ridge (11%) (Table 2). Crown condition ratings (overall crown health) ranged between 3 and 4 out of a rating of 10 (10 being essentially dead) for all 4 study locations (Table 2).

Biological, environmental, and land-use characteristics of the 4 study locations are shown in Table 3. The sycamore riparian woodlands varied in sycamore density and basal area with high basal area (45.6 versus 16.6) and high densities (130 versus 98) in the Sunol Valley compared to Alameda Creek and low sycamore regeneration compared to Alameda Creek (14 versus 113) (Table 3). The two oak woodlands were similar in basal area and stand densities. Both sites were on steep north, northeast facing slopes. Characteristic to both sites was the lack of any oak regeneration, both locations had high forb cover (90.1-97.5), with the majority of the species being invasive, conditions that can suppress oak recruitment (see Table 3). Notable were the 2 to 3 black oaks found at Maguire Ridge (Table 3).

Intrinsic water-use efficiency (iWUE) as measured by analyzing the carbon stable isotope, $\delta^{13}C$, in leaves of sycamore and oak species showed differences between species and sites (Table 2). The less negative the value of $\delta^{13}C$ the more water-use efficient the individual(s) are and the more negative $\delta^{13}C$, the less water-use efficient the individual(s). In Table 2, oak species in the oak woodlands are more water-use efficient than sycamore in sycamore riparian, with oak species at Sheep camp being the most water-use efficient (-27.24) and sycamore at Sunol Valley the least water-use efficient (30.20) (Table 2).

Table 3. Environmental, biological and land-use characteristics for 36 stands in sycamore riparian and oak woodlands in the East Bay, on SFPUC lands.

	Locations			
	Alameda Creek	Maguire Ridge	Sheep Camp	Sunol Valley
Elev (m)	212.4	244.2	114.3	84.8
Slope (%)	8.9	50.8	47.4	4.4
Aspect (deg)	179.0	55.1	260.4	271.1
Litter Depth (cm)	3.3	5.9	2.6	2.1
% rock	21.6	0.2	0.9	2.1
% forb	53.5	90.1	97.5	90.9
% shrub	7.9	2.0	0.8	1.6
Dom Shrub Sp.	ARCA, TODI	TODI, RHCA, MAFA	TODI, XYBI, HEWH	TODI
Land Use	gr	gr	gr, wf	gr
Class 1 Seedlings (total) (no.)	113	1	0	14
Class 2 Seedlings (total) (no.)	7	0	0	0
Basal Area (PLRA) (m^2 ha^{-1})	16.6	0.0	0.0	45.6
Basal Area (QUAG) (m^2 ha^{-1})	9.7	23.9	10.6	3.1
Basal Area (QUDO) (m^2 ha^{-1})	0.0	1.4	9.0	0.0
Basal Area (QULO) (m^2 ha^{-1})	1.9	4.4	14.9	0.3
Basal Area (QUKE) (m^2 ha^{-1})	0.0	0.5	0.0	0.0
Density (PLRA) (inds. ha^{-1})	98	0	0	130
Density (QUAG) (inds. ha^{-1})	38	142	68	3
Density (QUDO) (inds. ha^{-1})	3	12	64	0
Density (QULO) (inds. ha^{-1})	13	32	106	3
Density (QUKE) (inds. ha^{-1})	0	4	0	0
mean d.b.h. (PLRA) (cm)	42.7	0.0	0.0	58.3
mean d.b.h. (QUAG) (cm)	41.6	43.6	47.5	126.2
mean d.b.h. (QUDO) (cm)	3.2	37.4	41.6	0.0
mean d.b.h. (QULO) (cm)	33.9	38.6	42.0	40.1

Notes: land-use: gr=graizng, wf=wildland fire; class 1=seedlings <50 cm (20 in) ht, class 2= seedlings >50cm (20 in) ht; Tree species codes: AECA=*Aesculus californica* – California buckeye; PLRA=*Platanus racemosa* – Western sycamore; QUAG=*Quercus agrifolia* – California live oak, QUDO=*Quercus douglasii* – blue oak, QULO=*Quercus lobata* – valley oak, QUKE=*Quercus kelloggii* – California black oak. Shrub species codes: ARCA=*Artemisia californica* – California sagebrush; RHCA=*Rhamnus californica* – California coffeeberry, MAFA=*Marah fabaceus* – California manroot; TODI=*Toxicodendron diversilobum* – poison oak; XYBI=*Xylococcus bicolor* – Mission manzanita; HEWH=*Hesperoyucca whipplei* – Chaparral yucca.

When comparing sycamore across the 2 sites, sycamore trees at Alameda Creek were more water-use efficient than trees at Sunol Valley (Figure 3). There was a broader range in iWUE for blue oak at both Maguire Ridge and Sheep camp but blue oaks at Sheep camp appear more water-use efficient then blue oaks at Maguire Ridge (Figure 2). Coast live oak and Valley oak had similar iWUE but for both species the range in iWUE was broader at Sheep Camp then Maguire Ridge (Figure 3). Overall, *Quercus* species were more water-use efficient at Sheep Camp compared to Maguire Ridge (Figure 3, bottom).

Conclusions. Sycamore riparian study sites showed the effects of drought more so than the 2 oak woodland sites. Specifically, Sunol Valley, not only in forest health metrics but also the species iWUE values, being less water-use efficient than sycamore at Alameda Creek. Historically there have been significant hydrological disturbances to Sunol Valley limiting water availability and uptake. Future drought studies in the East Bay will benefit greatly by linking ecohydrological studies and monitoring (e.g., leaf water potential, sap flow, seasonal stomatal conductance, subsurface hydrological monitoring, soil moisture, etc.) to vegetation dynamics and forest health at all 4 study areas and other locations on SFPUC lands to better understand the linkages in forest health, drought responses, and vegetation dynamics with critical hydrological studies, monitoring, and measurements.

Figure 3. Intrinsic water-use efficiency (iWUE) as measured by analyzing the carbon stable isotope, δ13C, for sycamore, Coast live oak, Blue Oak, and Valley oak at Alameda Creek, Sunol Valley, Maguire Ridge and Sheep Camp.