How can we save our native trees?
Drought and Invasive Beetle impacts on Wildland Trees and Shrublands in the Santa Monica Mountains

Final Report for Los Angeles County Contract CP-03-44

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December 2017
Revised January 2018

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EXECUTIVE SUMMARY

Since 2014, hundreds of native trees (alders, oaks, sycamores, willows) in the Santa Monica Mountains have died, mostly due to the drought, but many are also victims of the invasive shot hole borer/Fusarium disease (ISHB/FD) and a new pathogen carried by the western oak bark beetle (WOBB) (Eskalen et al. 2013). Concerned about the ecological implications of extensive native tree loss, the Resource Conservation District of the Santa Monica Mountains (RCDSMM) initiated a citizen science volunteer based study of drought impacts in 2015, tagging over 350 trees in 41 randomly selected 25 meter square plots in critical park areas near the urban wildland interface throughout the western Santa Monica Mountains National Recreation Area (SMMNRA). This effort was augmented in 2017 by the deployment of 46 beetle traps in sensitive riparian areas and upland interface sites to monitor the direction, and rate of spread of invasive beetles, and document tree responses. Results show that extensive drought impacts occurred in 2015, followed by increased tree mortality associated with invasive pathogens in 2016-17. This data provided on-the-ground information for a NASA DEVELOP Project, which used remote sensing tools to assess the landscape level impacts over this same period. Although invasive beetles were detected at 32% of trap locations, distribution was patchy and drought appeared to be a more important stressor. Over 9,000 coast live oaks and 114,000 riparian trees (CA sycamore, alder, willows) died during the study period, resulting in ecosystem service losses estimated in excess of $22 million per year. To date, infected tree removal is the only recommended way to reduce impacts from amplifying host trees. The RCDSMM is working with regional and local parkland managers and other concerned stakeholders to develop a more appropriate and realistic management strategy for wildland trees.

Significant Findings

- Drought was a more significant problem than mortality from invasive beetles as of 2017.
- Drought conditions persist throughout the Santa Monica Mountains despite the rains of 2017.
- Of the 110,183 acres alive in 2013 (not including annual grasslands) in the SMMNRA, only 77,840 live acres remained alive in 2016. Trees and shrubs died in over 32,343 acres in just that time frame.
- Over 9,000 coast live oak and 114,000 riparian trees died resulting in ecosystem service value losses of over $22 million/year. The potential loss of the remaining oaks and riparian trees is conservatively estimated at over $105 million per year. These estimates do not account for pollution removal, temperature moderation, habitat value, aesthetic value, real estate values or replacement and removal costs.
- Infestation of invasive beetles is currently patchy and associated with human activities: contaminated mulch and green waste facilities are likely sources.
- ISHB are attracted to irrigated trees so increased monitoring will be especially needed if the drought ends.
- During the 2017 trap season, 15 traps (32%) detected presence of ISHB and/or WOBB. Plot data on tree condition revealed that in 2015, no invasive beetles were observed on trees, and only 29 (22%) trees inspected had borer holes of any kind. However, by 2017, over 150 (42%) trees showed evidence of borers, both native and invasive.

- Trees heavily infested with ISHB remained alive during the 1 year study period but those infested by WOBB declined and died. Effects of infestation often take time to evolve and cause decline.
- The Los Angeles County Agricultural Commission deployed GSOB traps throughout the SMMNRA during summer 2017, and to date no GSOB has been detected. The US Forest Service also deployed traps for emerald ash borer. Results of that effort have not yet been obtained.
- Continued monitoring of the 353 tagged trees in 41 study plots will provide valuable information on rate of infestation spread and tree condition responses over time.

Management Recommendations

1. Continued participation in the ongoing coordinated local and regional effort to develop an Early Detection – Rapid Response Plan is critical.
2. Coordinated permitting to facilitate swift removal of amplifying or dying trees is needed.
3. Planting more trees is critical. We need to develop priorities on where to focus efforts to replace aging stands, and develop a comprehensive plan to ensure a mixed age stand for the future.
4. Need to gather acorns and seeds from trees that are already in xeric, drought stressed locations whenever possible to broaden the range of these more drought and temperature adapted individuals.
5. ISHB and WOBB are here, but their observed distribution is thus far patchy. This suggests that some focused efforts on containment and removal of amplifying trees might buy some time.
6. Drought impacts to trees in riparian plot areas in particular did not show recovery with the rains of 2017. Targeted planting in those sensitive locations should be considered.
7. Need more eyes on the ground over time. Visual survey project and management using iNaturalist platform should be developed.
8. Continued long term monitoring of tree plots and additional trapping seasons can help keep track of the spread and tree mortality changes.

ACKNOWLEDGEMENTS

This project was possible thanks to funding from the Southern California Research Learning Center, Los Angeles County District 3 Supervisor Sheila Kuehl, and the Los Angeles County Fish and Game Commission. Dr. Richard Stouthamer and Veronica Fernandez provided important assistance with identification and Dr. Akif Eskalen helped with fungi.

Dr. E. Natasha Stavros from Jet Propulsion Laboratory, California Institute of Technology provided guidance for using NASA airborne data and advising the subsequent scientific analyses with this data.

We also thank our DETECTION DETECTIVES: the Topanga Canyon and Malibu Creek Docents, Danielle Alvarez, Julie Clark de Blasio, Brianna Demirci, Joanna Fogarty, Wendi Gladstone, Marissa Kuizenga, John Luker, Mark Mendelsohn, DeLayni Millar, Garrett Nichols, Kerrie Petersen, Gabino Rezendis, John Simon, Teena Takata, Nina Trusso, West Valley United Methodist Church, the Vincents, Dennis Washburn, and Amy Yuelapwan. Citizen Science volunteers contributed over 2000 hours to this project.

Special thanks to WSP member Brianna Demirci for her assistance with the temperature data, and to Denise Kamradt, NPS for her excellent maps. Dr. Marti Witter, NPS and Kim Correlle, CalFire provided guidance and review of the wildfire risk efforts that was much appreciated.

This study benefitted from extensive input from our Technical Advisory Committee, which included:

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Introduction

Invasive pests and diseases are one of the important factors threatening both agricultural and natural resources in Ventura and Los Angeles Counties in a changing climate. The Invasive Shot Hole Borer/*Fusarium* Dieback (ISHB/FD) is a non-native ambrosia beetle/fungi complex that has invaded southern California and is currently threatening tens of thousands of native, residential, and agricultural trees. This invasive species complex is quickly reaching epidemic proportions, destroying entire riparian areas (Borland 2016), and resulting in widespread environmental, economic, and aesthetic implications for the region (Swain et al. 2017). Additionally, the native western oak bark beetle (WOBB) has also been observed to kill oaks with a newly identified fungal associate (Short et al. 2017), and gold spotted oak borers (GSOB) have been found in nearby Green Valley and Santa Clarita (Kevin Turner, pers. communication).

This study provides data on the effects, distribution, and abundance of these pests and their impacts on sensitive riparian areas within the Santa Monica Mountains National Recreation Area (SMMNRA). This data is critical for on-going park management in the face of these invasive pests.

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data was used to assess vegetation drought condition changes from spring 2013-2016. This remote sensing technique documented the extent of the problem, and provided baseline conditions for different woodland and shrubland vegetation types in relation to fuel moisture levels, soils, and other potential abiotic stressors. The landscape level analysis, combined with both invasive beetle trap data and details from small research plots provides local jurisdictions, park agencies, and property owners direction on ways to map the spread of impacts, evaluate the potential ecosystem service impacts, develop risk assessment strategies for addressing wildfire risk, identify and prioritize potential management response strategies to make best use of limited resources. This effort could also set the stage for modeling microclimate distribution shifts of oak woodlands and shrublands to projected conditions associated with climate change.

The specific research questions addressed included:

1) Is there any relationship between drought condition, extreme temperature days (greater than 35^{o}C (95^{o}F)), precipitation, and tree condition?
2) How do tree conditions respond to changes in drought patterns between 2013-2017, based on AVIRIS remote sensing imagery?
3) Is there any correlation between tree condition and density, location, understory composition and competition?
4) What is the current extent of the infestation of ISHB and WOBB in riparian areas near sensitive aquatic species? Based on the regional detection mapping are they expanding into sensitive riparian areas from urban or agricultural systems or vice versa?
5) How fast are these pests spreading?
6) Are they killing riparian trees and if so, how fast?
7) What are the ecosystem service values associated with our coast live oak woodlands?
8) Has drought related tree mortality increased wildfire risk? If so, how might that be mitigated?
9) What management strategies could be used to reduce loss of woodlands and chaparral?

Study Area

The study area included all of the Santa Monica Mountains National Recreation Area (SMMNRA) and a northern buffer zone that connects ecologically sensitive wildlife corridors. The boundary of the SMMNRA encompasses approximately 153,075 acres extending from the Pacific Ocean near Point Mugu on the west, along the border of the Simi Hills to the north, east into Griffith Park and the Hollywood Hills, and south to the coastline along the Santa Monica Bay (Figure 1). Within the SMMNRA are numerous cities, with portions of both Los Angeles and Ventura Counties. Private property and public parklands are interwoven into a complex urban-wildland mosaic that supports almost 400 vegetation associations. The dominant native vegetation is chaparral and sage scrub types. The more limited but ecologically important types, include 15 coast live oak woodland associations, and numerous riparian species complexes. Non-native grasslands are also extensive and have displaced both native grasslands and shrublands.

The SMMNRA contains over 34 miles of coastal creek corridors that are critical habitat for federally endangered aquatic species such as southern steelhead trout (*Oncorhynchus mykiss*) and CA red-legged frogs (*Rana draytonii*). Figure 1 illustrates the boundary of the ecological zone, which extends beyond the actual national recreation boundary to include important adjacent linkage areas. Seven ecological zones have been identified that illustrate the dominant ecological characteristics created by extreme differences in topography (elevations range from 0 m at the coast to 949 m at Sandstone Peak) and extent of marine influences.

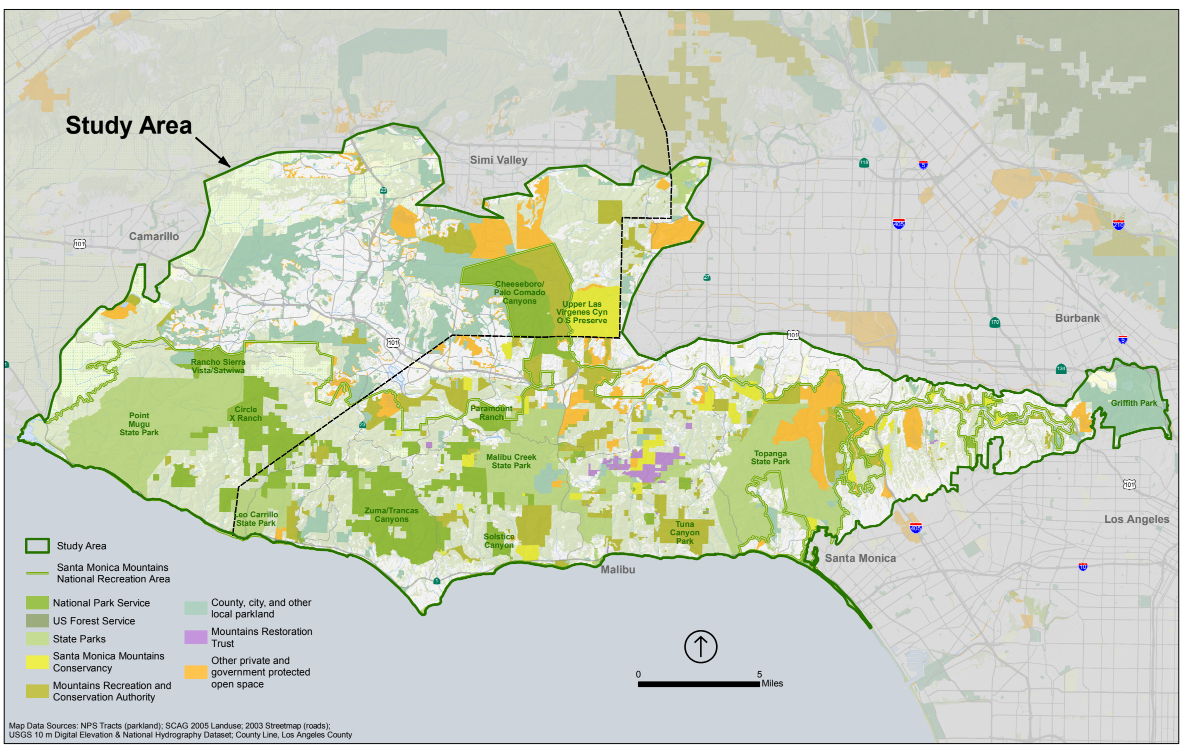

Figure 1. Santa Monica Mountains National Recreation Area and Eco Zones (Courtesy of Denise Kamradt, NPS)

Methods

Tree Condition, Demographics, and Mortality:
Using ArcGIS, a numbered 25 meter square grid was overlaid on selected wildland park areas within the SMMNRA. A random number generator was used to select plots within representational sections of each sensitive riparian portion of the watershed and upland park areas. Reconnaissance visits were made to confirm access and sufficient tree density (greater than three trees per plot). Within each 25 m x 25 m plot, every native tree with diameter at breast height (DBH) over six inches was tagged, measured and health/vigor condition assessed. Smaller diameter trees were noted as understory. Presence of any evidence of insect or disease damage was also noted. GPS coordinates for the center and each corner of the plot were collected. A photo point was also established. In fall 2015, 14 plots were established at Trippett Ranch in Topanga State Park. Ten additional plots were established in Malibu Creek State Park in winter 2016, and in spring 2017, 17 more plots located throughout the entire western region of the SMMNR resulted in a total of 41 plots containing 353 tagged trees. Tree condition and the presence of invasive beetles were assessed in fall 2015, 2016, and 2017. Data on the slope, aspect, understory vegetation, and soils were also collected when each plot was established.

Drought, Temperature and Precipitation:
Local air temperature and precipitation was examined from three locations within the Santa Monica Mountains: Pierce College, Woodland Hills (34.18194444,-118.5744444); Las Flores Rd, Malibu Hills GHCND:USR0000CMAL (34.0583,-118.6333); and at Leo Carrillo State Beach GHCND:USR0000CLEO (34.0456,-118.9358). Drought conditions were provided by the U.S. Drought Monitor (http://droughtmonitor.unl.edu/ CurrentMap/StateDroughtMonitor.aspx ? CA). This data was analyzed to examine the distribution and abundance of extreme temperature days exceeding 95°F (35°C) at representative locations within the study area.

Additionally, climate variables including daily precipitation, minimum and maximum temperature, and minimum vapor pressure deficit (VPD) for 2012-2017 were accessed from the Parameter elevation Regression on Independent Slopes Model (PRISM) climate group's data portal. All precipitation data is reported according to water year (Oct 1 of one year- September 30 next year) according to USGS (2016) standard. PRISM data is provided in 4 x4 km pixels, which were then extracted for each climate variable and a table prepared for each vegetation type, and PRISM climate variable for each year. This permitted analysis of each climate variable plotted against the percent vegetation type alive, which was then fitted to a trendline with the highest r^2 value to examine relationships between specific variables and die off patterns. Details on the processing the climate variable data and its integration into the analysis are provided in Appendix A.

Remote Sensing Data Acquisition and Processing
A suite of data sets (Table 1) were acquired and processed to develop the Relative Fraction of Alive vegetation cover (RFAL), which was then used to allow an integrated analysis of die off over time for different vegetation types including: annual grassland, coastal sage scrub (including summer drought deciduous and summer active), chaparral (including *Ceanothus megacarpus, C. spinosus* and *Malosma laurina*), riparian (which included, and oak woodlands

(both *Quercus agrifolia* and *Q. lobata*). These tools are listed in Table 1 and complete details on the acquisition and processing of data is provided in Appendix A.

Table 1. Remote Sensing Tools utilized in analysis

Data	Source
Airborne Visible Infrared Imaging Spectrometer (AVIRIS L2)	Collected surface reflectance data from a series of flightlines in spring 2013-2016 (15.6 m resolution)
Digital Elevation Model (DEM)	Shuttle Radar Topography Mission (SRTM) from USGS Earth Explorer
National Agriculture Imagery Program (NAIP)	Orthoimagery used to visually confirm land cover types (1 m resolution)
Light Detection and Ranging (liDAR) for western Los Angeles County	Los Angeles Region Imagery Consortium (LAIAC), Internal Services Department. January 2016 data (1 m resolution)

Several processing steps were required to develop a species map of the study area based on the vegetation data provided by the National Park Service (NPS) that was correlated to the spectral bands provided by AVIRIS. Relative fraction of alive vegetation (RFAL) was determined for each 15.6 m^2 pixel according to percent cover by substrate, non-photosynthetic vegetation (i.e. dead), and green vegetation. The RFAL reflects the percent of green vegetation divided by a total of green vegetation plus non-photosynthetic vegetation.

These values were then validated using the 2016/17 observed condition of the 25 m^2 field plots. These data were averaged to find the RFAL that corresponded with a field plot condition of 3.2 (55% dead), which was identified as the threshold for dieback. Trees in this condition are declining and not expected to recover.

Topographic effects on distribution of dieback, such as elevation, slope, and aspect were derived from the DEM using ArcMap, but to zoom in beyond the 30 m resolution provided by that tool, a Triangular Irregular Network (TIN) was developed to show greater details of surface morphology, including ridgelines and streams. Then the TIN was used to examine the relationships between these effects and dieback extent over time.

Although we were not able to complete development of a wildfire risk model using this data, LiDAR paired with the DEM provided information used to calculate a Canopy Height Model (CHM), and canopy density for a limited geographic subset of the study area in Trippett Ranch, part of Topanga State Park. Fire danger was calculated for this small area based on multiplying the canopy density by one minus RFA (relative fraction dead). The details of this proof of concept methodology are found in Appendix A and discussed further in the Wildfire Risk section.

<u>Detection Detectives- Invasive Beetle Trapping</u>

Thirty-three riparian tree traps and 13 additional citizen science volunteer traps were set at selected plots throughout the SMMNRA to monitor for presence of ISHB and WOBB between March – September 2017. The 25 m^2 plots were randomly selected using ArcGIS software to meet access, tree density, and proximity to sensitive aquatic resources criteria. Using the GPS center points, all trees with diameter at breast height (DBH) over six inches within each plot were individually tagged, measured, and condition noted.

Homemade bottle traps consisting of two connected plastic bottles with soapy water in the lower bottle acting as collection basin, were hung outside the driplines of trees within the plots (Figure 2). Querciverol lures (an ambrosia beetle aggregating hormone made by Synergy Semiochemicals Corp.) were placed in the upper portion of the traps and changed every six weeks. Samples were collected and analyzed weekly by RCDSMM biologists, NPS staff, CDPR staff, and volunteers. Samples from each trap/event were kept separate during screening and then sorted with potential ISHB and WOBB individual per each trap/date stored in 95% ethanol in a labeled bottle. Any other organisms collected in the sample were collected in a separate bottle and also labeled by trap id/date. Potential ISHB or WOBB were sent to Dr. Richard Stouthamer's Lab at UC Riverside for visual and genetic confirmation. All other specimens collected were stored in ethanol and archived for future examination.

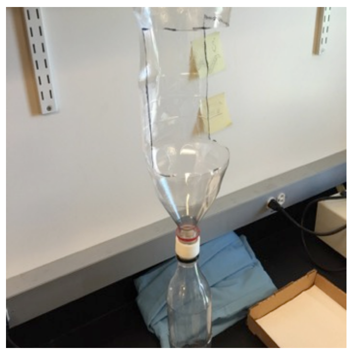

Figure 2. Homemade bottle traps (Photo and design courtesy of Dr. Richard Stouthamer)

Ecosystem Service Analysis:
We used the online i-Tree Ecosystem Analysis tool to calculate annual carbon storage, sequestration, avoided stormwater run-off, and replacement value (iTree ECO Online Calculator 2017). Data on 315 individual trees by species and diameter was entered into i-Tree. The system rejected 38 trees with diameters greater than the upper limit of 100 inches, so those trees were not included in the valuation exercise. I-Tree calculates the amount of carbon storage and gross carbon sequestration by ton/year and uses a price of $129.73/ton as the value in November 2017. Using the closest weather station in the system (Santa Monica) for 2015, precipitation was calculated as 7.5 inches, and the avoided runoff value/year was calculated based on a value of $\$0.067/ft^3$. The structural value of the trees is based on the local cost of having to replace a tree with a similar tree within a landscape setting. As this tool is primarily geared for evaluating conditions in urban forests, we recognize that the values generated are best viewed as providing an order of magnitude value for our urban/wildland interface situation. Wildland trees are not considered to have as high a landscape value, but since the tool does not differentiate, the structural values calculated are on the very high end. This tool does not presently include the ecosystem service values associated with temperature moderation, pollution removal, aesthetics, real estate, or habitat values.

Once we calculated the values per individual coast live oak (*Q. agrifolia*) or riparian tree (CA sycamore, alders, willows), we then scaled this up based on the estimated number of coast live oaks that are potentially found in the SMMNRA. Using the vegetation alliance acreages provided by NPS (AIS et al. 2007), we conservatively estimated that there are approximately 2,700 acres of pure coast live oak woodlands, but a total of 11,000 acres if all coast live oak alliances are included. This is almost double the number of acres estimated for the Santa Monica Mountains region by the Los Angeles County Oak Woodlands Conservation Management Plan (2011), which was hampered by data limitations associated with the base maps prepared by the USFS PSW Vegetation Mapping Program. The NPS data is based on ground surveys and captures a wider variety of coast live oak alliances with other species. The NASA DEVELOP team used their species map and the RFAL map as the basis of their analysis, and identified approximately 2,163 acres of coast live oak woodland, which is slightly different from the NPS data upon which it was based due to inconsistency in mapping scales. For the purpose of this analysis, we used the NASA DEVELOP data to calculate the ecosystem service values, as this represents an extremely conservative estimate.

Our tree plot data determined that there was an average of 8.6 oaks per plot, and roughly 6.5 plots/acre. This resulted in a conservative estimate of 55.6 oaks per acre, totaling at least 151,363 oaks in pure stands, with as many as 600,000 individual trees found in mixed species stands throughout the SMMNRA. The density of oaks varies in each vegetation alliance, so we used the lowest average number based on our plots to under, rather than overestimate the potential number of oak trees in the 11,000 acres throughout the SMMNRA.

The NASA DEVELOP team also evaluated the extent of riparian vegetation, which primarily borders creek channels and is dominated in our plots by CA sycamore, white alder, and various willows. Between 2013-2016, a total of 13,772 acres of riparian vegetation were observed, with a lower density estimate of 35 individuals/acre, based on the plot data. The acreage identified by remote sensing is higher than the pure stands mapped by NPS, which totals 4,226 acres of CA sycamore, white alder and willows. This discrepancy is probably due to definition and boundaries selected by NASA DEVELOP to include the more complex vegetation matrix found along riparian corridors. This vegetation association experienced a serious 32% loss of trees during the study period. Because i-Tree calculates values based on specific individual tree data, and assumes a tree condition rating of good (87% green), we have also rounded down the values generated online to more conservatively represent the values of the existing oak and riparian woodlands.

The extent of chaparral and coastal sage scrub were also noted, but no ecosystem service valuation procedure is in place at this time to evaluate their contributions. Chaparral communities are the dominant vegetation type throughout the SMMNRA. They experienced a 17% die off, while the more rare coastal sage scrub communities experienced a 38% die off, mirroring the extent of riparian die-off. Clearly the largest impact of the drought was in these more mesic areas.

Wildfire Risk Assessment

A major concern in the SMMNRA is the potential risk of increased wildfire, and whether the drought induced die-off generating acres of standing dead trees and shrublands would affect fire behavior. The main use for NASA DEVELOP data products would be to use those data in fire behavior models where we could use the observed increase in non-photosynthetic vegetation (dead) to see how changes in fuel loading and could affect rate of spread and flame lengths (intensity).

Due to time constraints and large file sizes, this effort was limited to a proof of concept effort focused on a subset area of Trippett Ranch in Topanga State Park. A digital elevation model (DEM) referenced to a vertical datum and a digital surface model (DSM) were derived using light detection and ranging (LiDAR) data from January 2016. Additionally, canopy density was computed. Finally, fire danger was computed by multiplying canopy density by the relative fraction of dead vegetation. Technical details on how this information was generated are found in Appendix A. The results of this proof of concept effort suggest that there is some promise for utilizing this tool to augment traditional fire models to examine wildfire risks, but more work is needed.

Results

Tree Demographics, Condition, and Mortality:

A total of 353 trees were tagged in 41 plots throughout the SMMNRA (Figure 3). The majority of trees were coast live oaks, with CA sycamores, arroyo willow, valley oaks, white alder, elderberry, and laurel sumac also observed (Table 2). Only a few valley oaks were observed.

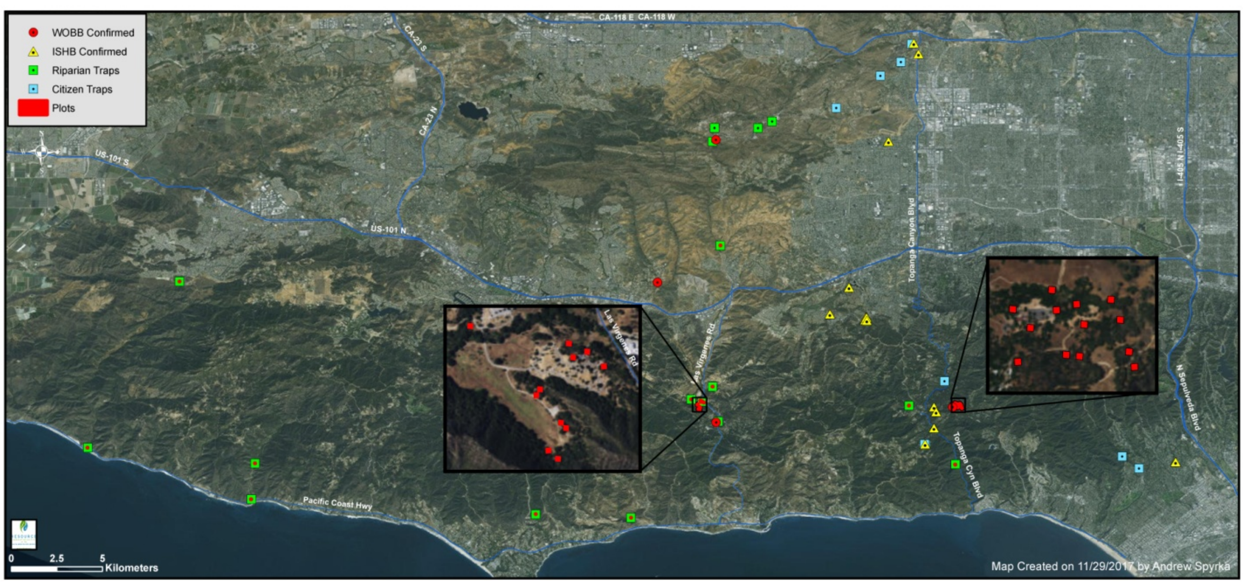

Figure 3. Locations of all tree plots and beetle traps in the SMMNRA

Table 2 Summarizes the number of individuals of each species, the average number of trunks, range and average diameter at breast height. Additional details on other tree metrics are included in Appendix B.

Table 2. Demographic Summary of Tagged Trees, SMMNRA 2017

Species Name	Common Name	Number of Individual Trees	Avg. Number of Trunks	Avg. DBH (inches)	Range of DBH (inches)
*Albizia julibrissin**	Mimosa silk tree	3	1	22	16-27
Alnus rhombifolia	White alder	6	1.8	13.34	5.3-18.4
Malosma laurina	Laural sumac	1	3	10.24	NA
*Myoporum laetum**	Myoporum	1	3	15.16	NA
Platanus racemosa	CA sycamore	15	1.5	23.4	6.5-77.17
Quercus agrifolia	Coast live oak	299	1.6	26.27	4.6-228
Quercus lobata	Valley oak	5	1.2	8.8	5-18
Salix lasiolepis	Arroyo willow	22	2	17.68	5.9-55.5
Sambucus mexicana	Elderberry	1	1	17.72	NA
TOTAL		353			

* non-native species

Of the 299 coast live oaks in the plots, the majority were mature to senescing trees, with fewer younger trees observed than in any of the larger size classes (Figure 4). This pattern of fewer young trees reflects a limited number of past recruitment pulses, and suggests that coast live oak woodlands within the SMMNRA are aging without significant new recruitment by younger replacement trees. The younger trees appeared to be healthier, with fewer borer holes and higher condition ratings than larger, mature trees.

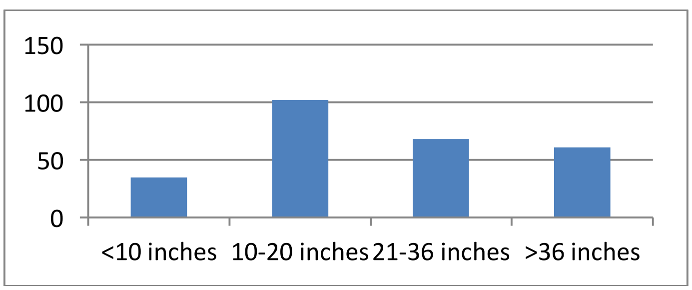

Figure 4. Distribution of trunk sizes for coast live oak

Changes in tree condition over time are only available from the 14 plots at Trippett Ranch and 10 plots at Malibu Creek State Park, where previously condition data was obtained in 2015 and 2016. The majority of plots were in good to fair condition, as were the majority of the individual trees (Tables 3-4). The trees at both Trippett Ranch and Malibu Creek (Table 5) show a steady decline as the number of trees in the lower condition classes increased, with limited signs of recovery following the increased rains in 2017. This slight increase or stabilization from 2016-2017 reflects the new shoots produced in spring 2017 following the rains. Overall, we determined that trees with condition rating over 3.2 were not likely to recover.

The relatively high numbers of tree deaths per year is notable. Typically coast live oaks live for between 100-200 years, and yearly mortality rates have been calculated at about 2-10/ acre (Tietje 1993). The loss of so many trees in a five year period is reflective of extreme drought impacts.

Table 3. Summary of tree plot condition Fall 2017.
Tree condition was rated as 1(excellent) = 75-100% green leaves, 2 (good) = 51-74% green leaves, 3 (fair) = 25-50% green leaves, 4 (poor) = less than 25% green leaves, 5 = dead.

Avg. Tree Condition	**Number of Plots/condition**	**Percent of Plots/condition**
1-2	8	19
2-3	16	40
3-4	13	32
4-5	4	9
Total	**41**	100

Table 4. Summary of individual tree condition Fall 2017.
Tree condition was rated as 1(excellent) = 75-100% green leaves, 2 (good) = 51-74% green leaves, 3 (fair) = 25-50% green leaves, 4 (poor) = less than 25% green leaves, 5 = dead.

Tree Condition	**Number of Trees/condition**	**Percentage of Trees/condition**
1	38	11
2	107	30
3	121	34
4	32	9
5	55	16
Total	**353**	100

Table 5. Summary of Tree Condition changes in plots 2015-2017
Note that the number of trees changes each year due to removal of dead trees and adding plots in 2017.

Trippet Ranch	**2015 (n=101)**	**2016 (n=136)**	**2017 (n=123)**
Tree Condition			
1 Excellent	47 (46%)	29 (21%)	4 (0.03%)
2 Good	23 (22%)	45 (33%)	39 (32%)
3 Fair	14 (14%)	39 (29%)	63 (51%)
4 Poor	9 (0.09%)	9 (0.06%)	14 (11 %)
5 Dead	8 (0.08%)	14 (10%)	8 (0.06%)

Malibu Creek		**2016 (n=84)**	**2017 (n=133)**
Tree Condition			
1 Excellent		13 (15%)	20 (15%)
2 Good		25 (30%)	47 (35%)
3 Fair		35 (42%)	35 (26%)
4 Poor		6 (0.07%)	11 (0.08%)
5 Dead		5 (0.06%)	20 (15%)

Tree mortality increased in Malibu Creek State Park plots, but does not appear to increase in the Trippett Ranch plots due to the difficulty of locating all tree tags. We suspect that the missing trees are those which had fallen and lost tags, or were removed. If these 13 missing trees are assumed dead and included in the analysis, then the number of dead trees increases in Trippett as well (21 dead, 15%). Additional information on mortality based on the remote sensing data analysis is provided below.

Further analysis of other data collected indicated that trees with less canopy, had more live understory vegetation, but there was no significant correlation in the tree plots between tree condition and other variables such as tree height, or density of trees/plot slope steepness. There was a slight, but not significant relationship between tree condition and aspect where the trees on south facing slopes showed more decline than those on other aspects (n=358, p-value 0.05446, R^2 0.007743).

Drought, Precipitation and Temperature

The SMMNRA was subject to a multi-year drought that ranged in severity from “abnormally dry” in fall 2012, increasing to “exceptional drought” for 2015- January 2017, and returning to abnormally dry-moderate drought conditions by Fall 2017 (US Drought Monitor 2017) (Figure 5). Rainfall amounts were minimal during the study period (Figures 6-7) but highest in 2017. Overall the amount of dieback of oaks most positively correlates to precipitation (Figure 8). Data for 2017 is incomplete at the time of the report but does reflect the 2016-2017 water year fairly accurately.

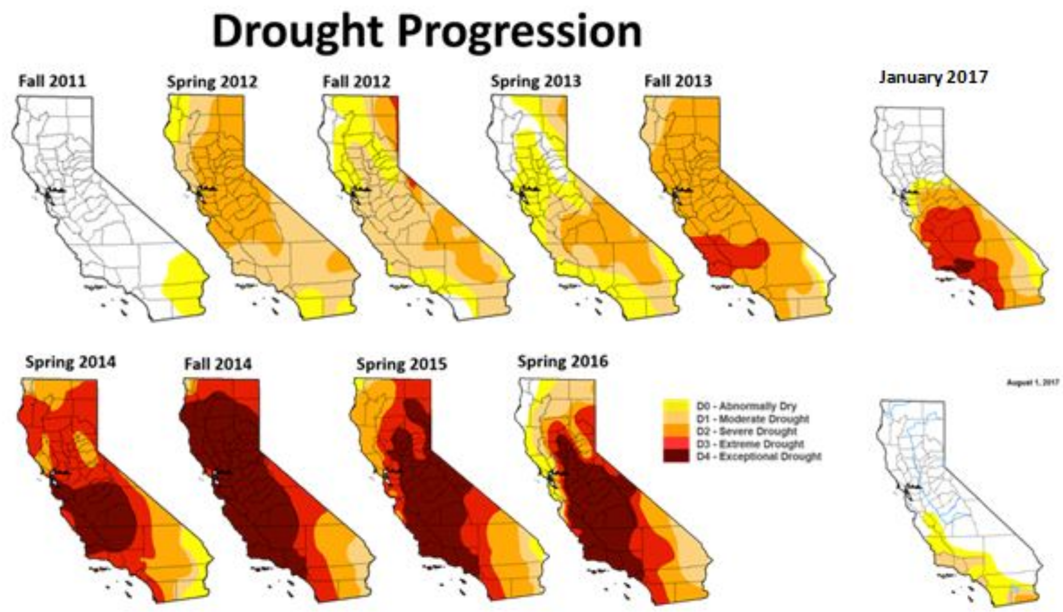

Figure 5. Progression of drought (Courtesy of the U.S. Drought Monitor site)

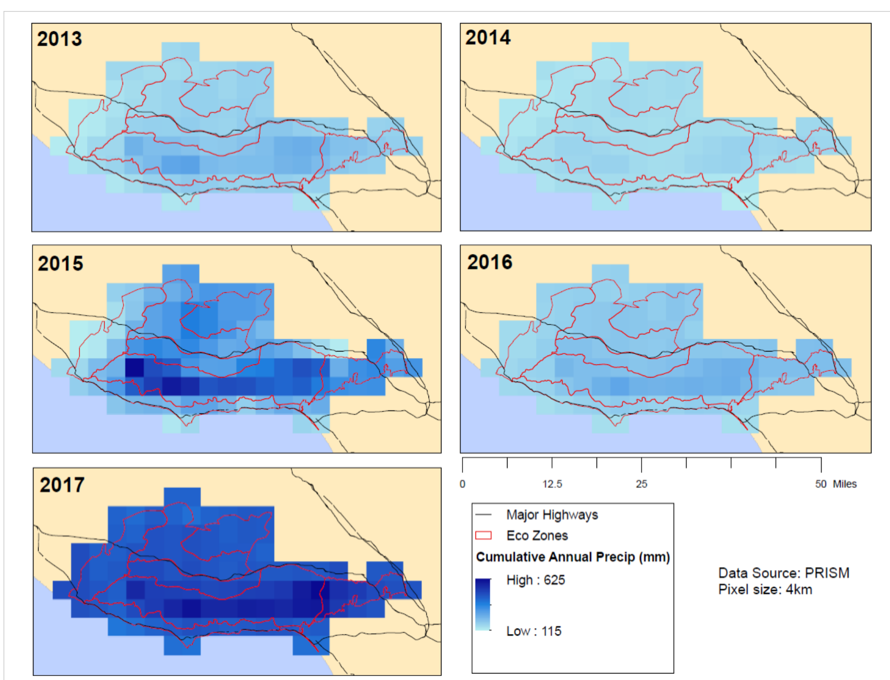

Figure 6. Cumulative Annual Precipitation PRISM data 2013-2017 in the SMMNRA (Courtesy of the NASA DEVELOP team)

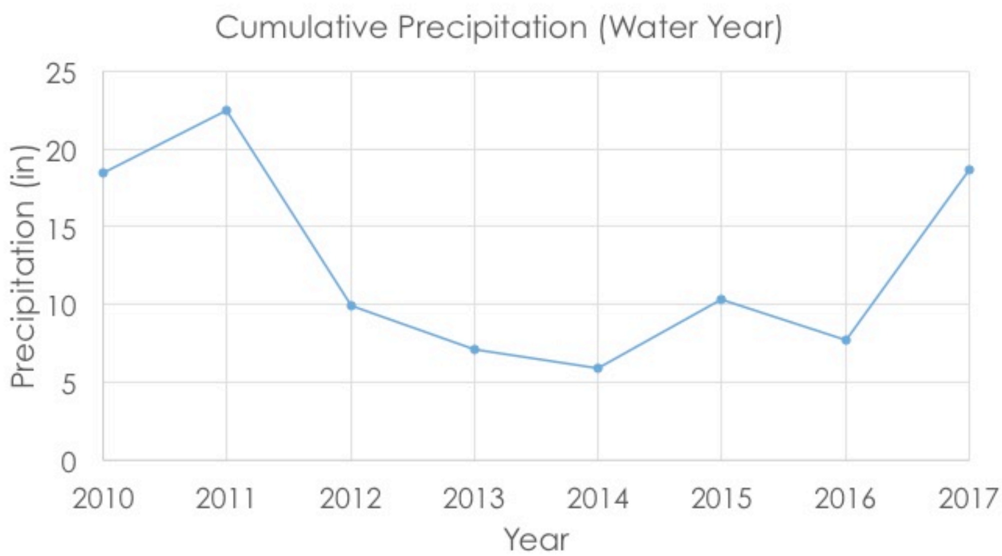

Figure 7. Cumulative Annual Precipitation 2013-2017 in the SMMNRA (Courtesy of the NASA DEVELOP team)

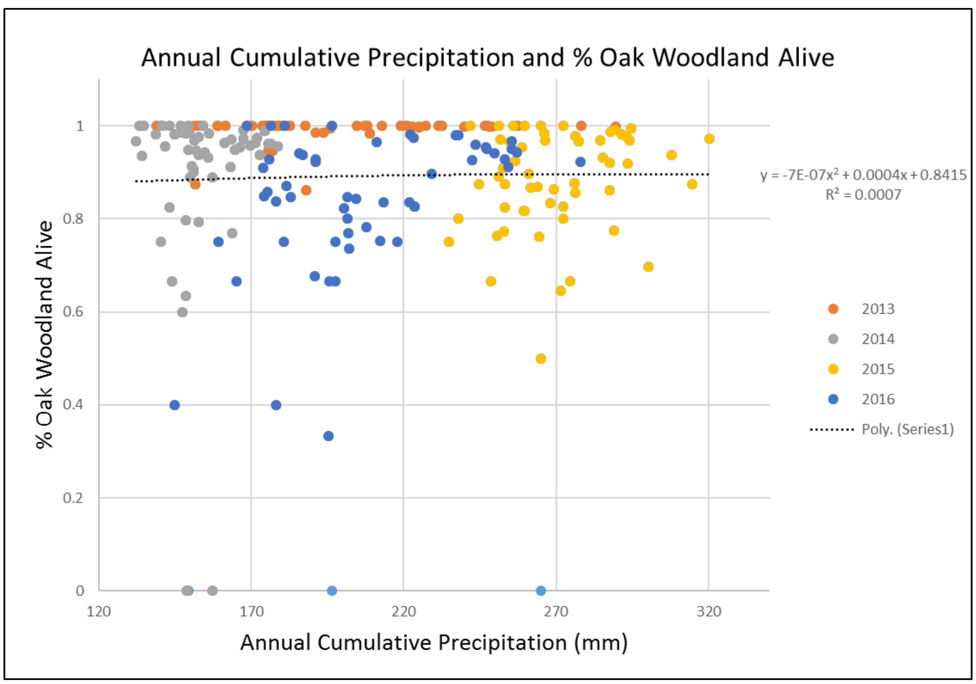

Figure 8. Correlation between Precipitation and percentage of oak woodlands alive 2013-2016 water years (Courtesy of the NASA DEVELOP team)

The annual mean temperature (Figure 9) was warmest in 2014 and 2015, cooling slightly in 2016. Data for 2017 only includes up to October 2017.

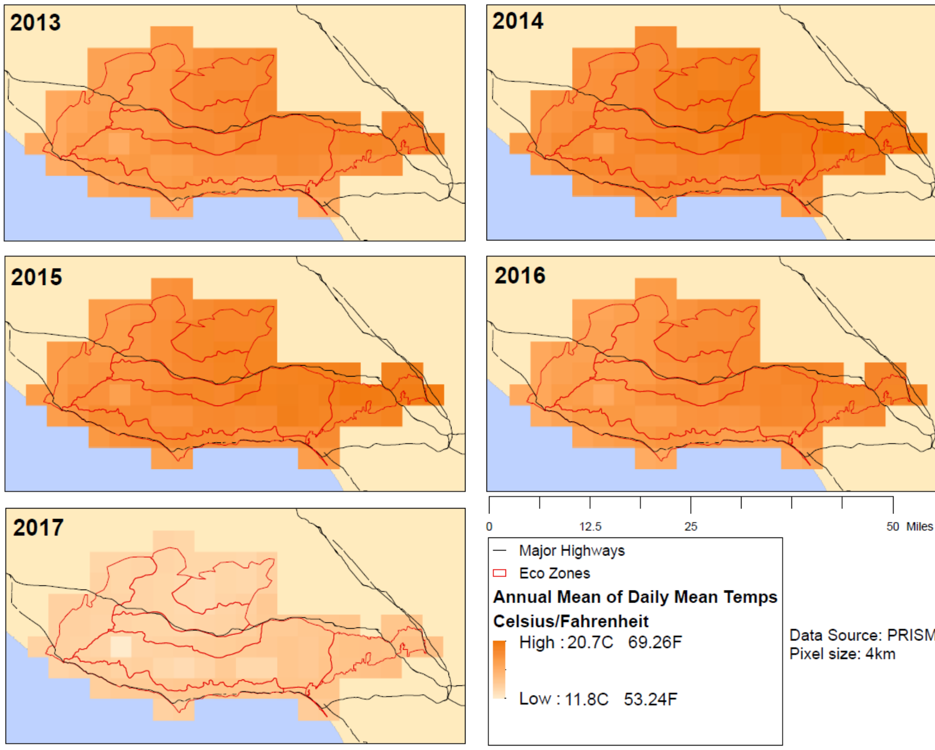

Figure 9. Cumulative Annual Mean Temperature (PRISM average of daily mean temperatures) 2013-2017. (Courtesy of the NASA DEVELOP team)

The number of days over 35°C (95°F) and the concentration of the hottest days in the north eastern section of the SMMNRA is notable (Figure 10), although it did not significantly correlate with the percent of oak woodlands alive (Figure 11). One hypothesis is that while the trees and chaparral vegetation in the SMMNRA have evolved in the typical Mediterranean climate pattern of hot, dry summers and cool, wet winters; numbers of extreme heat days and the expansion of time when these days occur (from April through November) may be causing additional synergistic stress in combination with the drought, particularly for coast live oaks and ceanothus. The relationship between extreme heat days and tree condition needs further study.

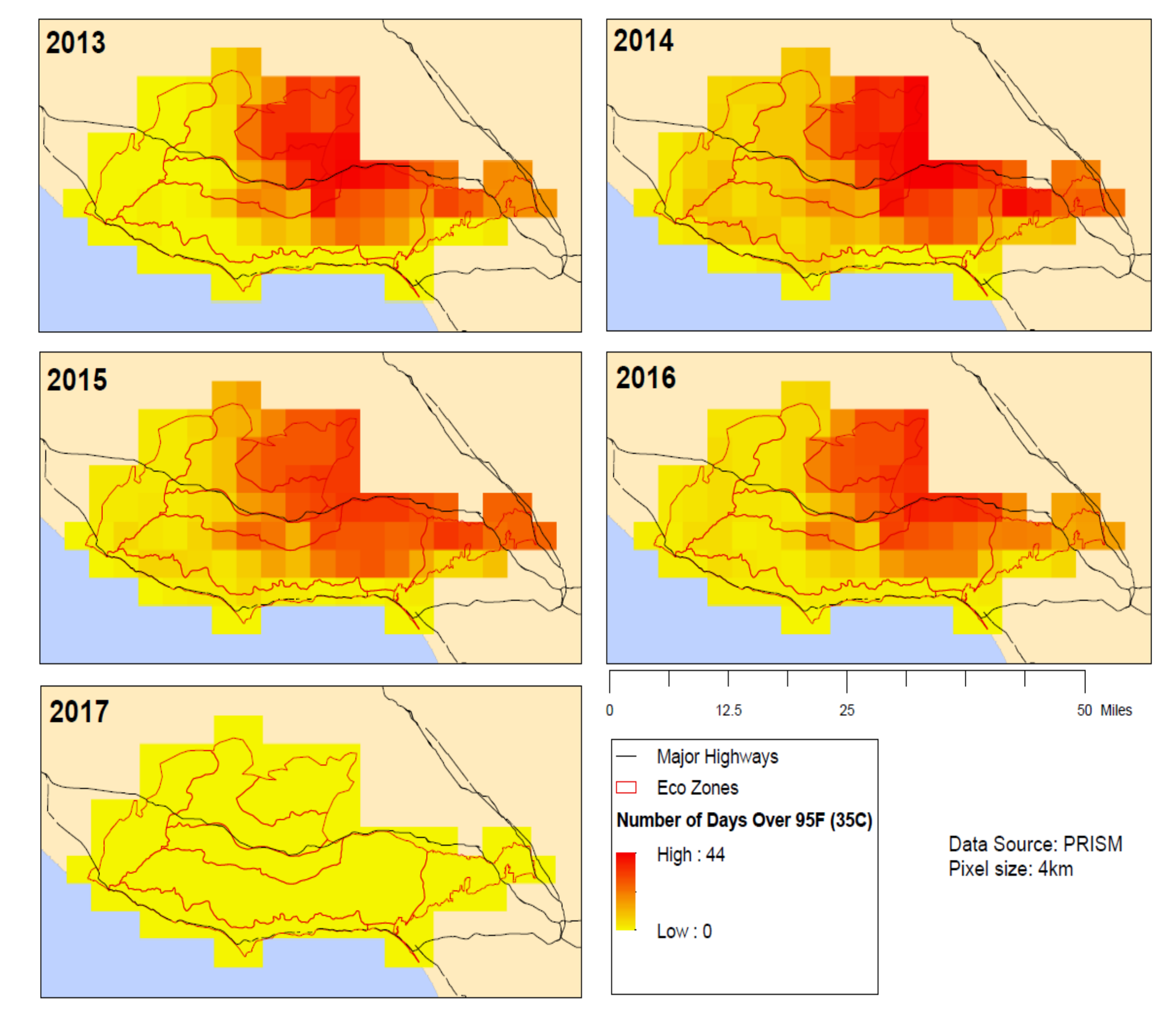

Figure 10. PRISM data showing range of number of extreme temperature days >95°C (35°C). (Courtesy of the NASA DEVELOP team)

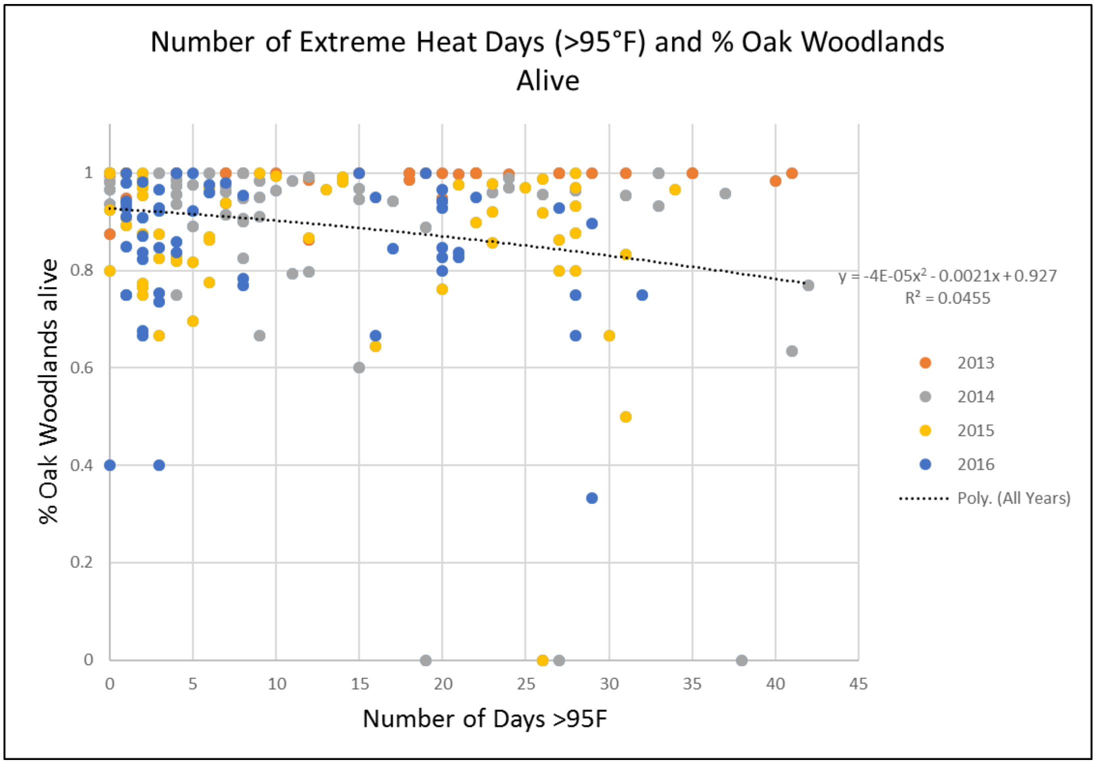

Figure 11. Number of Days over 95^{o}F (35^{o}C) and percentage of oak woodlands alive 2013-2017 (Courtesy of the NASA DEVELOP team)

The PRSIM data is based on 4 km spatial resolution. When extreme temperature data is looked at closely for representative locations in the central part of the study area, some interesting patterns are observed. Pierce College Station in Woodland Hills consistently experienced high numbers of extreme temperature days, as shown in Figure 12. Our initial hypothesis was that the number and temporal distribution of extreme temperature days increased during the drought period, but the long term data suggests that the number of extreme temperature days is widely variable, and while the Woodland Hills location showed an increase over time, the total number of days in the more coastal location of Malibu Hills (Las Flores Rd.), showed a decreased number of extreme temperature days during the study period (Figure 13). Clearly the relationship between extreme temperature days, drought patterns and tree response needs more study.

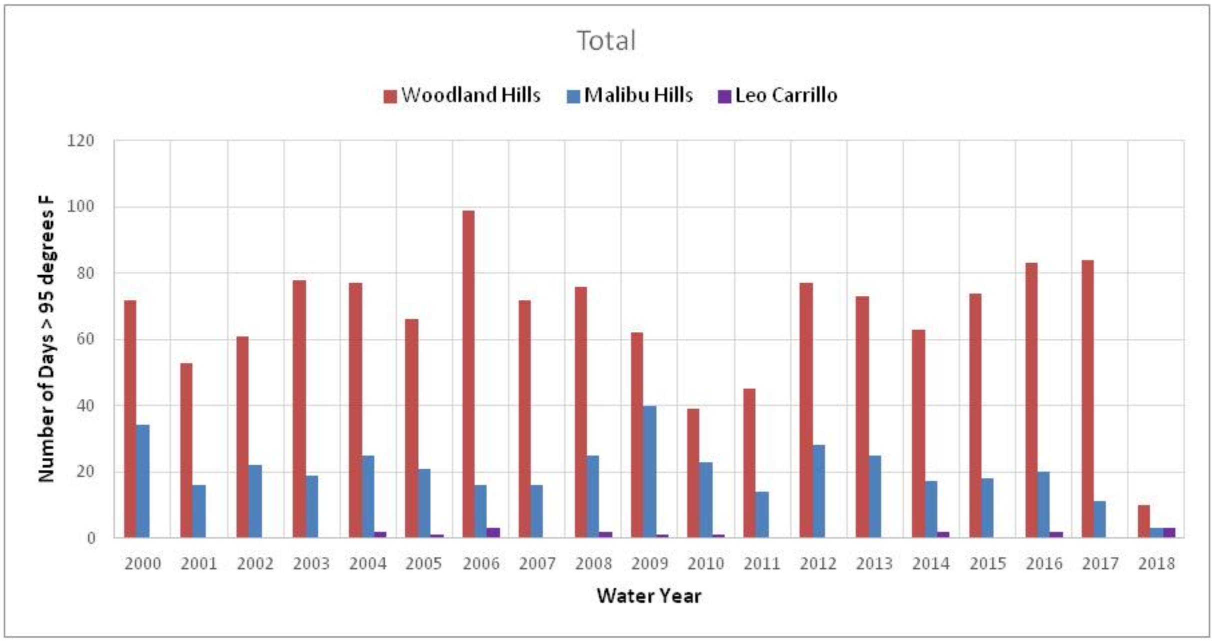

Figure 12. Summary of extreme heat days in representative locations in the SMMNRA. Data courtesy of the National Centers for Environmental Information (Formerly National Climatic Data Center), NOAA NOTE: 2018 WY data only includes October 2017.

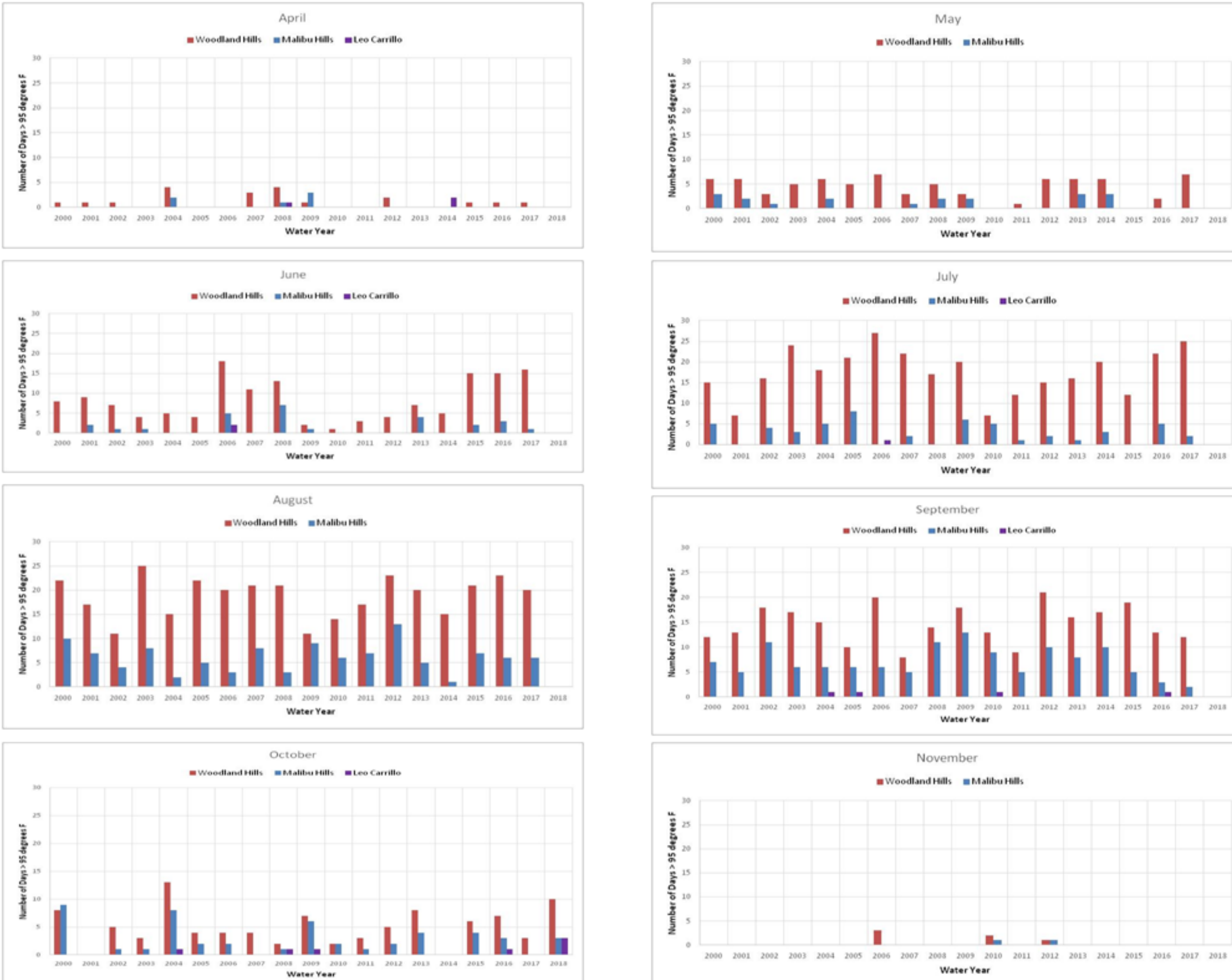

Figure 13. Monthly distribution of extreme temperature days in the study area. Data courtesy of the National Centers for Environmental Information (Formerly National Climatic Data Center), NOAA

Remote Sensing Results

One of the more challenging problems of this study was to develop the correct spectral library of species classifications using the Multiple Endmember Spectral Mixture Analysis (MESMA) on the AVIRIS images. Using Viper Tools (Roberts et al. 2017) to streamline the process of classifying an image by unmixing endmembers, we were able to develop pure representations of a spectral class associated with a specific vegetation type and condition. MESMA was used to create a spectral library that created training data to classify AVIRIS images. Classifications for substrate, water and the most common vegetation types in the SMMNRA, are of particular concern for examining fuel load changes over time that could be incorporated into wildfire models. The species composition of each class is detailed in Table 6 and the resulting vegetation mapping using these species classes is shown in Figure 14. These classifications were verified by comparing the MESMA generated data with the NPS vegetation layers. Additional details describing the technical elements of this effort are found in Appendix A.

Table 6. Species compositions for MESMA classifications

Classification	**Species included**
Annual Grass	All ruderal and native grass species
Ceoanothus megacarpus	Dominant chaparral species of concern
Ceanothus spinosus	Dominant chaparral species of concern
Chaparral - common	*Adenostoma fasciculatum, Cercocarpus betuloides, Quercus berberidifolia*
Coastal sage scrub- drought deciduous	*Artemisia spp., Eriogonum fasciculatum, Salvia spp*
Coastal sage scrub- summer active	*Eriogonum cinereum*
Laurel sumac	*Malosma laurina*
Coast live oak woodland	Pure stands of *Quercus agrifolia*
Riparian woodland	*Alnus rhombifolia, Juglans californica, Platanus racemosa, Salix spp*

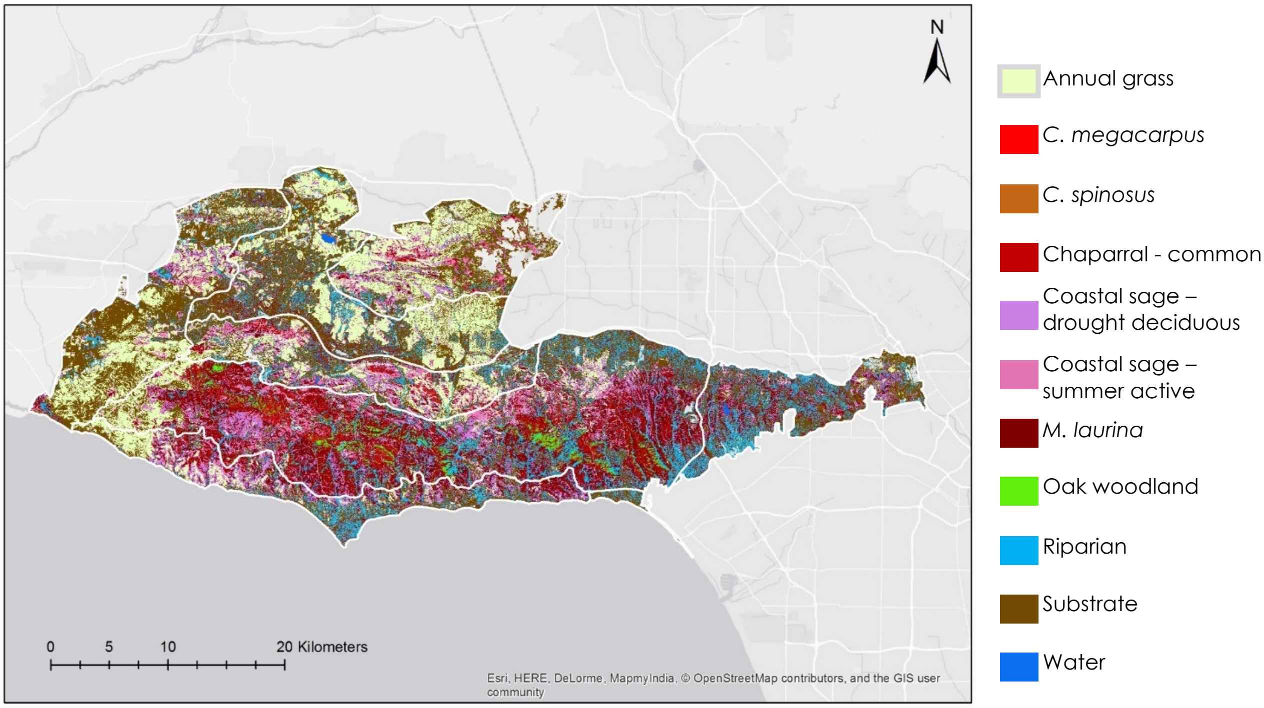

Figure 14. Species classification over the Santa Monica Mountains using Multiple Endmember Spectral Mixture Analysis (MESMA) on AVIRIS imagery. (Courtesy of the NASA DEVELOP team)

Fraction of Alive Cover

The relative fraction of alive vegetation (RFAL) was calculated for each 15.6 m pixel and correlated with actual field plot conditions (Appendix A provides technical details). The RFAL threshold value was found to be 0.5431, with an R^2 value of 0.0251 (Figure 15). The low R^2 value can be attributed to the low sample size of plots (n=22) and to the difference in data collection times. The AVIRIS imagery was taken in June, while the field plot data was recorded from September to October. It is noteworthy that oak trees are dying within months, meaning that the field condition recorded could be much worse than the RFAL alive values obtained. In addition, when the team created the plot to better understand the condition metric, the field condition observed tended to be an overestimate of the field fraction alive (Figure 15).

As illustrated in Figure 15, the distribution of dead vegetation tracks with the number of days of precipitation, and the number of extreme temperature days >95^{o}F (35^{o}C). Both annual precipitation and temperature are based on PRISM pixels of 4 km. The fraction of dead pixels of this same size is shown, but does not track as well by pixel due to the varied fractions of alive vs. dead of each vegetation type, which were mapped at a 15.6 m pixel size.

In terms of acreage, of the 110,183 aces of vegetation alive in 2013 (not including annual grasslands) only 77,840 live acres remained in 2016. Trees and shrubs died in over 32,343 acres in just that time frame.

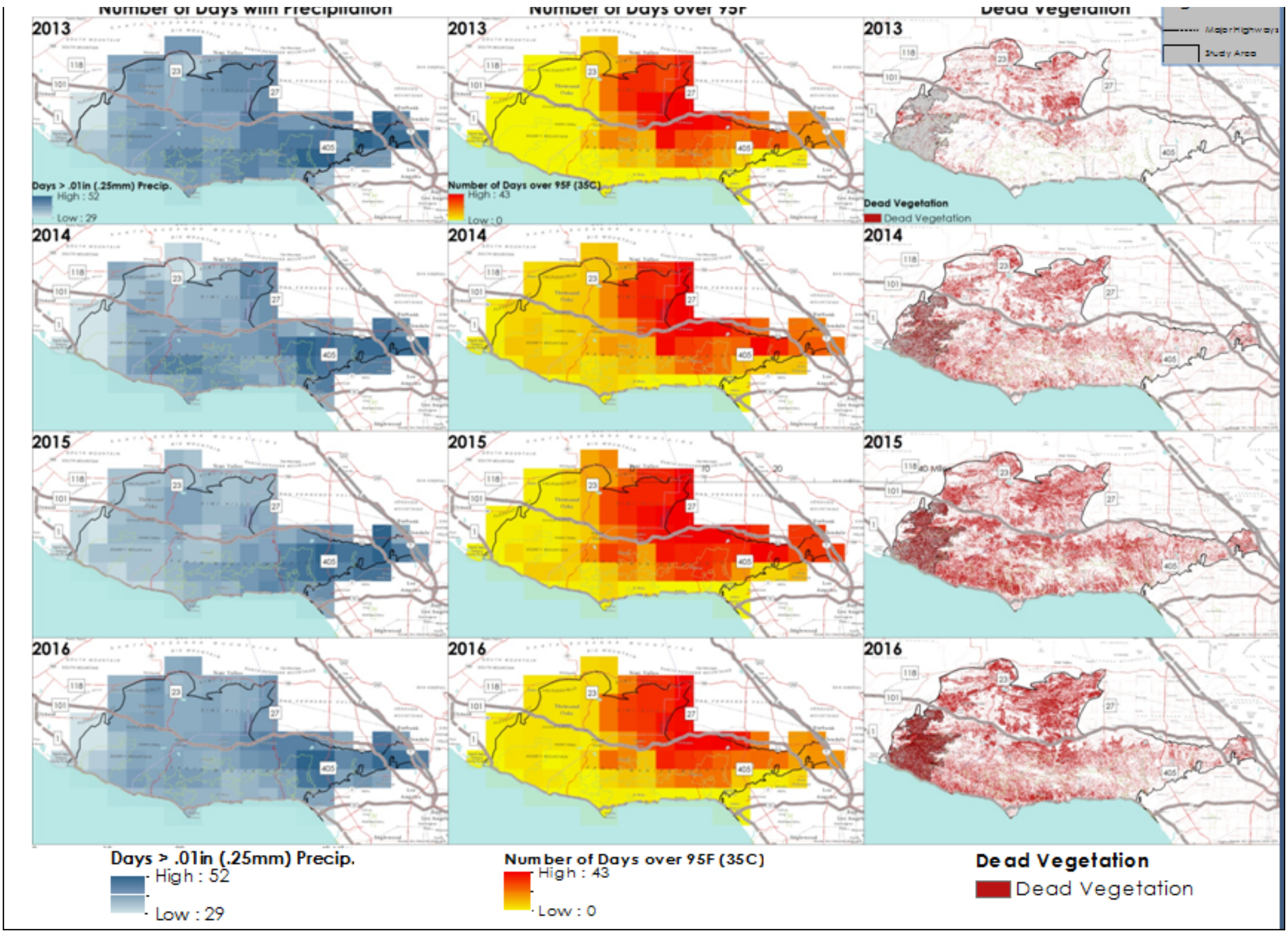

Figure 15. Summary of changes in annual precipitation, extreme temperature days 95°F (35°C) and percentage of oak woodlands alive 2013-2017
(Courtesy of the NASA DEVELOP team)

Due to lack of time, it was not possible to refine this analysis further, but Table 7 summarizes the changes in alive vs. dead vegetation by acre between 2013-2016. The increased acreage of dead oak woodlands, riparian areas, and chaparral highlight the impact of the drought over time. It was not possible to process the AVIRIS flightlines for 2017 to determine if there was any discernable recovery following the rains in winter 2017, but that would be an interesting follow up. It is important to note that the AVIRIS flights occurred in spring, so this loss represents an extremely conservative estimate of true die-back, which would be expected to increase during the fall.

Table 7. Summary of alive and dead acres of oak woodlands and riparian woodlands in the SMMNRA 2013-2016 (based on RFAL calculated by NASA DEVELOP team)

Vegetation Type	Acres alive 2013	No. trees alive 2013	Acres dead 2013-2016	No. Trees Lost 2013-2016
Annual grass	26634		16391	
C. megacarpus	3445		726	
C. spinosa	1839		141	
Chaparral	16754		2931	
Coastal sage scrub - drought decidous	27044		10851	
Coastal sage scrub- summer active	12795		4408	
M. laurina	35091		9865	
Oak woodland	2700	151,200	163	9,128
Riparian woodland	10514	367,990	3258	114,030
TOTAL acres	**110183**		**32343**	

<u>Topographic Effects</u>

A few significant relationships were observed between slope, aspect, and tree condition. Trees on the south facing slopes or steeper slopes (greater than 10 degrees) were of lower condition rating than those found in other locations. This is consistent with the analysis based on tree plot and field condition observations. Additionally, the RFAL for oaks also decreased to the east, and the fraction of dead oaks increased from 2013-2016 (Figure 16). Analysis of the relationship of chaparral dieback and aspect did not show as strong an effect (Figure 17). It was interesting to see that *Ceanothus megacarpus*, which goes drought deciduous, also did not show a strong correlation with aspect.

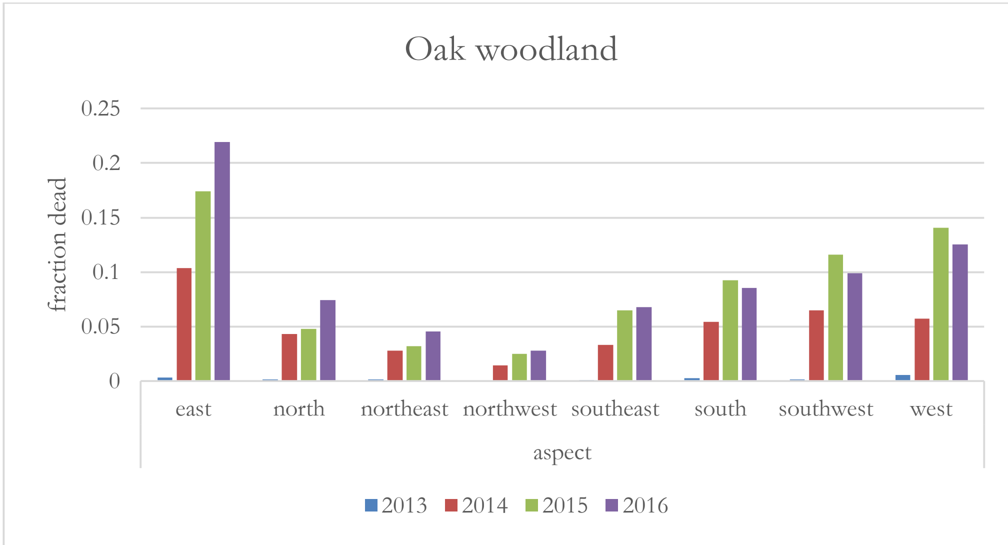

Figure 16. Fraction of dead oak woodland pixels shown by aspect and year. (Courtesy of the NASA DEVELOP Team)

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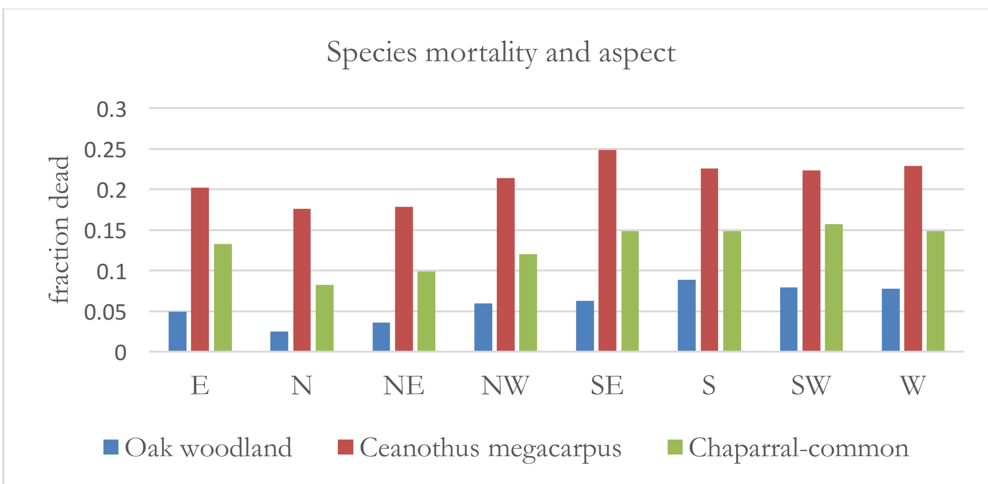

Figure 17. Fraction of dead pixels shown by aspect and year. **(Courtesy of the NASA DEVELOP Team)**

<u>Detection Detectives- Invasive Beetle Trapping</u>

In addition to the 33 sensitive riparian traps, volunteers set and monitored an additional 13 traps. Traps were located throughout the SMMNRA as listed in Table 8, many, but not all, associated with 25 m^2 plot data and tagged trees.

Table 8. Locations and numbers of Riparian Traps

Creek/Watershed Location	Number of Traps
Arroyo Sequit Creek	2
Big Sycamore Creek	1
Cheeseboro Creek	1
Las Virgenes Creek (Upper Open Space Preserve)	1
Los Angeles River (Calabasas sites)	7
Los Angeles River (Santa Susanna Field Lab)	5
Malibu Creek	5
Paramount Ranch	1
Rancho Sierra Vista Satwiwa	1
Ramirez Creek	1
Solstice Creek	1
Topanga Creek	7
TOTAL Number of Traps	**46**

During the 27 week long sampling period, over 850 individual trap samples were collected. Potential target species (ISHB and WOBB) were found in 225 samples sent to UC Riverside for confirmation. Only 52 of these came back with confirmed ISHB, WOBB or both (Figure 18). A total of 15 traps had multiple positive detections, 32% of all locations.

Numerous other ambrosia species were present but not identified beyond family. Therefore we do not know if the alder die off at the Topanga Bridge site was actually due to the fruit tree pin hole borer (*Xyleborinus saxesenii*) or not, although that is suspected. No GSOB were found in the SMMNRA at this time. Volunteers and partners contributed over 2000 hours to this effort by setting, maintaining and monitoring traps.

Figure 18. Confirmed locations of ISHB and WOBB in the SMMNRA 2017.

One interesting result is the patchy nature of the infestations, as illustrated in the map showing the patterns in the Calabasas area (Figure 19). All of the traps set at Headwaters Corner near the intersection of Old Topanga Canyon Road and Mulholland Highway detected both ISHB and WOBB, as did most of the other trap locations within the city of Calabasas. Reconnaissance visits to check the trees found that CA sycamores, coast live oaks and willows were all showing signs of infestation, however no plots were set or trees tagged in these trap locations. For many sites, potential infection via contaminated mulch was suspected, but not confirmed.

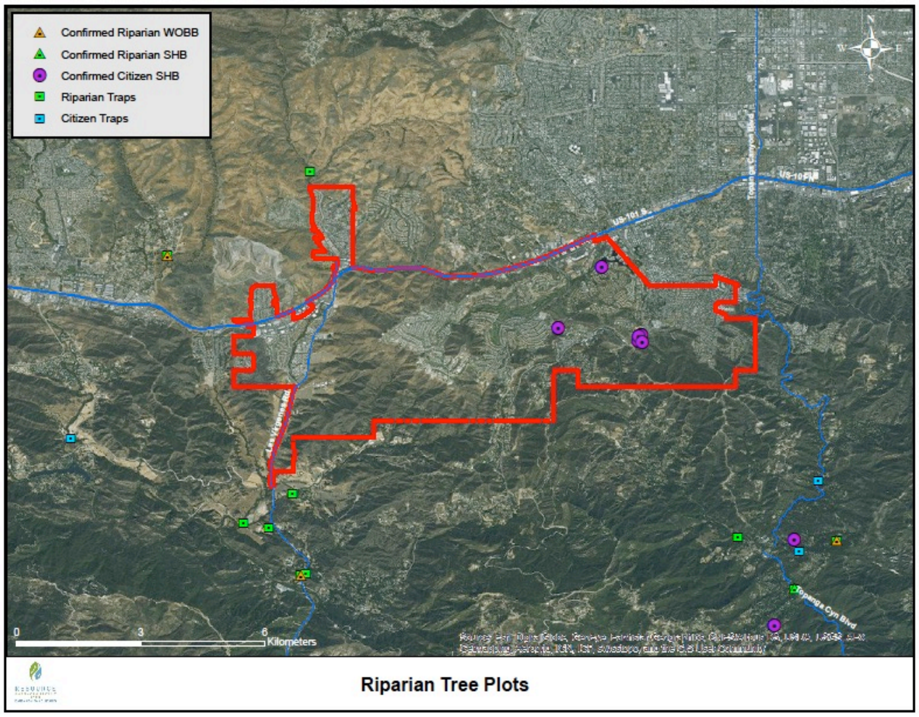

Figure 19. Detail of Trap locations in Calabasas showing concentration of confirmed ISHB and WOBB 2017.

Table 9. Summary of Confirmed ISHB and WOBB in the SMMNRA 2017

Invasive Shot Hole Borers	**Western Oak Bark Beetle**
Calabasas:	SSFL Southern Buffer Rd, Chatsworth
Mountains Restoration Trust	Cheeseboro Park
Calipatria Ave	Las Virgenes Open Space Preserve
Park Serena Ave	Malibu Creek State Park
Chatsworth: all sites	Nicholas Flats, Leo Carillo State Park
Santa Suzanna Field Lab	Trippett Ranch, Topanga State Park
Santa Suzanna State Historic Park	Tapia State Park
Various private properties	Old Topanga Canyon Rd., Topanga
Topanga:	Greenleaf Rd, Topanga
Peterson Trap Entrada Rd	Medley Lane, Topanga
RCD office, Topanga Canyon Blvd.	Robinson Rd., Topanga
Behind Topanga Market Center	Entrada and Waveview Rds, Topanga
Medley Lane	

At the start of the study in 2015, no non-native beetles were detected in any of the trees, although WOBB was suspected to be present. This changed during the study as ISHB and WOBB were eventually detected in several sycamore and oak trees in 2016-2017. A total of 156 (41%) of 353 trees had evidence of borers in 2017, as compared to 29 trees (22%) of the 113 tagged in 2013. Presence of any borer hole observed on a coast live oak was significantly correlated to tree decline and mortality (p-value=0.0018, r^2 =0.2082).

Fungi Detections

Although not a direct focus of the study, the presence of borer holes was noted during trapping and tree tagging, and wood samples collected in several cases for assessment by the Eskalen Lab, UC Riverside.

Results of those investigations found the canker pathogen *Diplodia corticola*, a type of Botryosphaeria species, on dying coast live oaks at Tapia (section of Malibu Creek State Park). This highly aggressive pathogen is more frequently observed in association with gold spotted oak borer, but at this location the vector species was not GSOB, but another unidentified boring beetle. WOBB was detected at this site, but is not thought to be associated with these fungi (Lynch et al. 2013).

Other dying coast live oaks in Topanga were infected with *Geosmithia langdonii*, another dry fungi species that is associated with WOBB, and the trees were adjacent to traps that also detected WOBB.

Most puzzling was the detection of *Neopestalotiopsis sp*. on a dying coast live oak that was located near a trap that detected ISHB and not WOBB. This opportunistic secondary canker pathogen is most often found causing problems for grape vines and is not thought to be associated with either ISHB or WOBB (Dr. Akif Eskalen, per. Communication).

Ecosystem Service Impacts

Using a conservative estimate of 600,000 coast live oaks in the SMMNRA as our basis, i-Tree calculated the ecosystem services values provided by these trees (Table 10). On average, each individual tree was worth $299, and the coast live oak trees throughout the SMMNRA are worth over $179.4 million per year. If the structural value calculations were included, the individual tree value increases to $29,919 and the total value for the oak woodlands throughout the mountains to over $179 billion. If we consider the structural value to be a proxy that includes additional ecosystem service values such as temperature moderation, pollution removal, aesthetics, real estate and habitat values, we are still potentially underestimating the overall ecosystem service values provided just by the coast live oaks.

Table 10. Values for ecosystem services of Coast Live Oaks in the SMMNRA based on i-Tree November 2017.

Ecosystem Service	1 Coast Live Oak	151,200 Coast Live Oaks	600,000 Coast Live Oaks
Carbon Storage (ton)	2	604800	1,200,000
Carbon Storage ($129.73/ton)	$294	$44,452,800	$176,400,000
Gross Carbon Sequestration (ton)	0.03	4,536	18,000
Gross Carbon Sequestration ($129.73/ton)	$4	$604,800	$2,400,000
Avoided Stormwater Runoff (ft^3/yr)	11	1,663,200	6,600,000
Avoided Stormwater Runoff ($0.067/ ft^3)	$1	$151,200	$600,000
TOTAL VALUE/Year	**$299**	**$45,208,800**	**$179,400,000**
TOTAL VALUE 100 Years	**$29,900**	**$4.5 billion**	**$1.79 billion**

The riparian woodlands experienced the most tree loss between 2013-2016. Using a conservative estimate of $164/tree annual ecosystem service value, the loss observed totaled over $18. 7 million per year.

Table 11. Comparison of ecosystem service values for the number of alive trees in 2013, compared to the value of trees lost between 2013-2014.

	Acres alive	# trees alive	Ecosystem service value/yr	Acres trees lost	# trees lost 2013-2016	Ecosystem service value/yr
Oak woodland	2,700	151,200	$45,208,800	163	9,128	$2.729 million
Riaprian trees	10,514	367,990	$60,350,360	3,258	114,030	$18.7 million

Further investigation of the potential for directed planting to not only restore habitat, but to also maximize potential carbon storage and sequestration is recommended. Planting should utilize seeds (acorns) and cuttings (for riparian species) collected from trees that are surviving the drought. It is thought that selection from more xeric locations could assist in managing the woodlands in light of projected climate changes.

Wildfire Risk Assessment

A canopy height model was developed using the DEM and DSM for a single dataset in Trippett Ranch, Topanga State Park is shown in Figure 20. Tree height was verified using the tree plot data from that location and the model corresponded well to on-the-ground conditions.

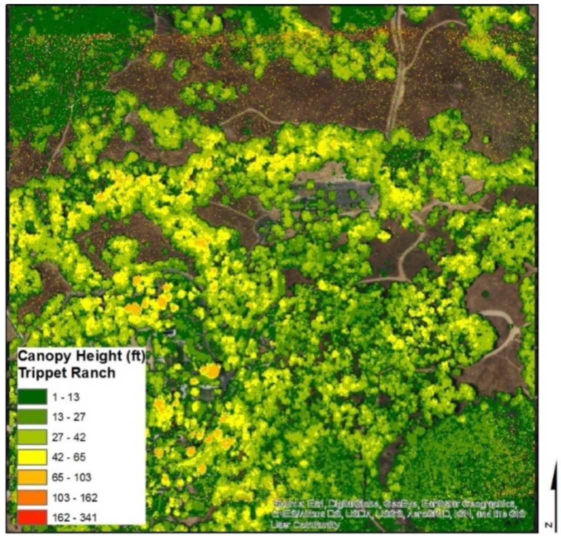

Figure 20. Canopy Height Model sample showing tree height in Trippett Ranch, Topanga State Park January 2016.

The Fire Danger probability map (Figure 21) for the sample site at Trippett Ranch was developed by multiplying canopy density with the relative fraction of dead vegetation. The pixels tend to line up with areas of lower height grasses and shrubs under 1 foot, with taller oak woodlands having less fire danger potential. This result is consistent with other fire risk model results that treat oaks as lower fire risk than flashy annual grass fuels. Further work is needed to determine if the assumptions that relative fraction of dead threshold values accurately portray fire danger. These kinds of maps could be useful in directing management and fuel reduction to areas of highest risk along the urban/wildland boundary.

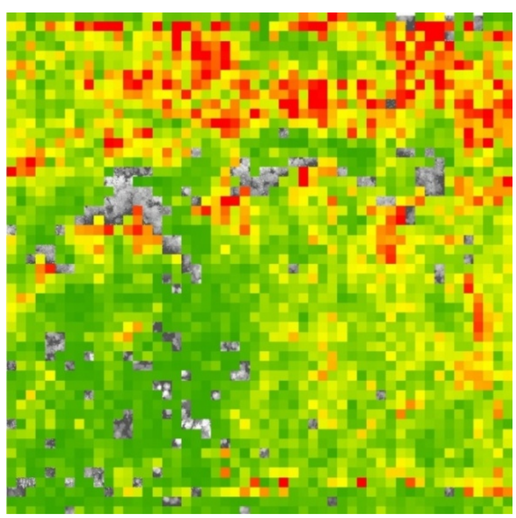

Figure 21. Fire Danger probability map for sample site at Trippett Ranch.

Discussion

This interdisciplinary effort utilized a variety of spatial scales and temporal changes to examine the impacts of the 2013-2016 (and continuing) drought, extreme temperature days (greater than 95°F (35°C)), invasive beetles, and abiotic factors such as slope and aspect on native tree and shrubland condition in the Santa Monica Mountains National Recreation Area. This area is a mix of large wildland parks surrounded by urban development, and fragmented by freeways and major roads. Despite this fragmentation, the Santa Monica Mountains are identified as a biodiversity hotspot, containing many types of habitats with associated flora and fauna (Rundel and Tiszler 2007). From the ocean to the ridges, across the western end of the San Fernando Valley to the Santa Susanna and Simi Hills, the SMMNRA is home to over 200,000 people (US Census Bureau 2017), and numerous rare, threatened and endangered species (Rundel and Tiszler 2007).

Developing a baseline understanding of the extent of drought die-back is essential in order to identify appropriate responses. In terms of acreage within the SMMNRA, of the 110,183 aces alive in 2013 (not including annual grasslands) only 77,840 live acres remained in 2016. Over 9,000 coat live oak and 114, 000 riparian trees and shrubs died in over 32,343 acres in just that time frame. Tree mortality studies of the Sierra Nevada and other US Forest Service parks suggest that over 70 million trees have died due to the impacts of bark beetles and drought. McPherson et al. (2017) estimated that over 173 million trees in urban forests throughout California are at risk for impacts from the ISHB. The scale of this dieback is extraordinary, and the potential for as yet unidentified impacts to the complex ecosystems currently supported by these forests is staggering.

<u>How extensive are the drought impacts in the Santa Monica Mountains?</u>
Between 2013-2016, over 9,000 coast live oak and 114,000 riparian trees died. Typical tree mortality ranges between 2-3 tree/acre annually (Tietje 1993), so this event represents an enormous increase in dead trees in a short time frame. The baseline cohort of over 350 tagged trees, mostly in sensitive riparian corridors, set the stage for long term monitoring.

It appears that drought is the main stressor causing dieback of native trees and shrublands, although the synergistic effect of extreme temperature days occurring during spring months in addition to late summer and fall may also be contributing factor. Our hypothesis that the temporal distribution of extreme temperature days over more months, and more extreme temperature days during the drought was not supported by the data, when looking at specific locations in the SMMNRA. However, the landscape level patterns of native tree and shrubland mortality within the PRISM bands of more extreme heat days and lower rainfall suggest there is more to this story (Figure 15). Further examination of these inter-related variables is needed to better understand how projected increases in extreme temperature days, and lower rainfall overall as a result of climate changes, could be anticipated to impact native vegetation in the future.

Although drought typically produces heterogeneous spatial and temporal impacts (Carnicer et al. 2011), this study found that the worst die off occurred in more mesic areas supporting coastal sage scrub and riparian corridors. This is of great concern, as these riparian corridors are critical habitat for endangered southern steelhead trout and red-legged frogs. Riparian trees provide shade that moderates creek water temperatures and prevents extensive algal blooms that deplete dissolved oxygen levels. The roots of willows, alders and sycamores stabilize the creek banks, preventing erosion and bank failures. Leaf litter falls into the creek where it is transformed into detritus that supports a diverse community of benthic macro-invertebrates, which are the basis of the food web. The cascading effects of tree loss are associated with trophic level collapse that can be severe and long lasting (Anderegg et al. 2012). For example, we have observed a shift from a mayfly (*Baetid sp.*) dominated benthic macroinvertebrate community to a chironomid (midges) dominated community (Montgomery et al. 2015). It is not clear if this is the new normal, or if the biodiversity will shift again if rains return and creek flow is restored. Steelhead prefer mayflies, and it is not clear if the midges provide the same food accessibility or nutritional value.

<u>What are the potential impacts and extent of the current distribution of ISHB and WOBB?</u>
To date, the distribution of ISHB and WOBB in the SMMNRA are patchy, but where established have resulted in severely declining tree health over a short time frame. During the 2017 trap season, 15 traps (32%) detected presence of ISHB and/or WOBB. Plot data on tree condition revealed that in 2015, no invasive beetles were observed on trees, and only 29 (22%) trees inspected had borer holes of any kind. However, by 2017, over 150 (42%) trees showed evidence of borers, both native and invasive.

The Los Angeles County Agricultural Commission deployed GSOB traps throughout the SMMNRA during summer 2017, and to date no GSOB has been detected. The US Forest Service also deployed traps for emerald ash borer. Results of that effort have not yet been obtained.

Tree mortality from ISHB has been slow, with some reproductive host trees detected in 2015 still surviving and supporting further amplification of ISHB individuals. The infestation of ISHB in Calabasas is a real concern, as these areas are adjacent to significant wildland park resources. Discussions with the city manager are on-going to provide them with up to date resources on rapid response.

Documentation of ISHB at traps near green waste facilities is also an effort that requires additional work. Coordination with the Agricultural Commission, and both city and county agencies will be needed to confirm these facilities as sources, and work with owners and tree trimming companies to reduce spread from infected mulch. Most tree trimming companies do not have the equipment needed to chip infested tree material to less than 1 inch as recommended. Green waste facility equipment varies and also may not be able to sufficiently reduce potential spread. The National Resources/Urban Forestry SHB Coalition is working on these important issues.

The presence of ISHB and WOBB in several sites throughout Topanga is also of great concern. In the case of WOBB, increased coast live oak mortality has reached over 20 acres in upper Topanga State Park. Portions of Topanga Creek have been infested with ISHB, and recently fruit tree pinhole borers (*X. saxesenii*) appear to be associated with severe alder die off in the creek. Public education and outreach to prevent further spread due to improper tree removal, firewood movement, and contaminated tree trimming tools is on-going. Coast live oaks, CA sycamores, willows and alders have all been impacted, resulting in the removal to date of over 25 trees on private property alone.

Confirmation of WOBB and associated canker pathogens at Tapia Park (part of Malibu Creek State Park) resulted in the removal 39 dead oaks. An additional 25 oaks were removed in the Malibu State Park campground areas due to high potential for failure. Boland (2016) reported on the massive loss of willows in the Tijuana River within a year following infestation by the ISHB, and hundreds of sycamores have died and been removed throughout parks in Orange County (McPhearson et al. 2017).

What are the cost of ecosystem service losses?

The rapid loss of tree canopy translates not only into direct and indirect impacts on sensitive riparian corridors, but also significant loss of ecosystem services provided by these trees. Carbon storage and stormwater runoff are the only two parameters evaluated by this study using the online tool i-Tree. Annual loss of these functions is estimated to be over $22 million for the oak and riparian trees that died during the drought. The potential loss of the remaining oaks and riparian trees is conservatively estimated at over $105 million per year. These estimates do not account for pollution removal, temperature moderation, habitat value, aesthetic value, real estate values or replacement and removal costs. Clearly the economic impacts from tree loss are significant.

Has drought related tree mortality increased wildfire risk?

Due to time limitations, it was not possible to answer this question, but the data developed by the NASA DEVELOP team is being shared with Los Angeles County, NPS, and CalFire. Use of this data in both standard and the novel LiDAR based modeling developed by the NASA DEVELOP team is anticipated for the future. Standing dead trees may or may not increase wildfire, depending on a variety of other factors that play into the modeling scenarios.

What management strategies could be used to reduce loss of native woodlands and chaparral?

The loss of approximately 29% of our woodlands and shrublands between 2013-2016 translated into significant economic losses for our community, as shown in this study. Preventing further loss will be partly dependent on rainfall patterns, with limited opportunity for active intervention.

To date, the only control method available to stop the spread of these beetles is removal of infected trees to prevent further spread. This requires a coordinated system for verifying and permitting prompt removal. Slightly infested high value landscape trees may benefit from some treatments, but they are costly, have limited control capability (although they can buy time), and are not appropriate for a wildland setting (Jones et al. 2017). The felled material from infested trees requires special treatment, either by transfer to a landfill site, chipping to under 1 inch diameter, or solarizing, which is time consuming and difficult to manage successfully.

The cost of removing all of the infested trees at one property in Calabasas is estimated at over $25,000. Containing the infestation for as long as possible is currently recommended by the regional shot hole borer coalition (Natural Resources/Urban Forestry SHB Coalition 2017), but the funds to accomplish this management strategy are just not available. The RCDSMM is working with SMMNRA to identify trees that pose significant risks to sensitive riparian and wildland resources. Limited grant funding ($60,000) to accomplish targeted removal on public lands are all that is currently available to address this need. Assistance for private property owners whose property is adjacent to wildlands is desperately needed.

The majority of oak and riparian woodlands in the SMMNRA are aging mature stands with minimal and very spotty natural recruitment success. Replacement planting using native tree species in urban/wildland interface areas is also recommended, even though they will continue to be at risk for infestation by beetles. The ISHB tends to favor healthy moist trees that are larger diameter trunk sizes (Swain et al. 2017). It takes 5-10 years for seedlings to reach the size preferred by the beetles, buying time for the potential development of other containment strategies. Because ISHB attacks such a wide number of species, both native and landscape, the best way to preserve native biodiversity and ecosystem service values is to support recruitment of younger native tree species. The costs of irrigation to get even the drought tolerant native trees established needs to be factored into the effort, as it is not clear when the drought conditions will end.

While only limited funds are available for monitoring, the value of citizen scientist volunteers should be recognized. Funding support for training, data management, and analysis are sorely needed. The RCDSMM, in collaboration with UC Cooperative Extension, Ventura, CA will be seeking grant funds to develop an iNaturalist project using visual surveys to help track changes over time. Funding to continue the trapping and tree plot monitoring will also be solicited.

MANAGEMENT RECOMMENDATIONS

1. Continued participation in the ongoing coordinated local and regional effort to develop an Early Detection – Rapid Response Plan is critical.
2. Coordinated permitting to facilitate swift removal of amplifying or dying trees is needed.
3. Planting more trees is critical. We need to develop priorities on where to focus efforts to replace aging stands, and develop a comprehensive plan to ensure a mixed age stand for the future.
4. Need to gather acorns and seeds from trees that are already in xeric, drought stressed locations whenever possible to broaden the range of these more drought and temperature adapted individuals.
5. ISHB and WOBB are here, but their observed distribution is thus far patchy. This suggests that some focused efforts on containment and removal of amplifying trees might buy some time.
6. Drought impacts to trees in riparian plot areas in particular did not show recovery with the rains of 2017. Targeted planting in those sensitive locations should be considered.
7. Need more eyes on the ground over time. Visual survey project and management using iNaturalist platform should be developed.
8. Continued long term monitoring of tree plots and additional trapping seasons can help keep track of the spread and tree mortality changes.

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