Los Angeles County Native Tree Priority Planting Plan

Final Report for Los Angeles County Contract #SPF03-03

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VISION STATEMENT

Beginning in 2019, proactive management will limit climate associated losses of woodland communities and promote conditions to preserve, protect, and enhance suitable sites for native tree species. In 2100, oak and riparian woodlands will continue to grow throughout the SMMNRA in suitable microclimate refugia. These woodlands will support self-sustaining processes including structure, function, recruitment, growth, and threat resistance.

MISSION STATEMENT

Native trees and woodlands of the SMMNRA are a limited and highly valued landscape component. They provide habitat and linkages for other plant and animal species; they provide fundamental ecosystem services; and they provide aesthetic and recreational enjoyment. The SMMNRA Native Tree Priority Planting Plan articulates strategies to maintain biodiversity and resiliency of local trees and woodlands that provide critical habitat and linkage connectivity as climate change creates significant stressors to their long-term survival. Future species assemblages may not be the same as the current suite of biodiversity but should be sustainable into the future. Restoring habitat connectivity, even if composed of translocated native species, will be key. Human intervention, regrettably, will be needed to sustain native tree persistence in the SMMNRA.

PLAN OBJECTIVES

- Create maps that identify sites of high, moderate and low vulnerability to climate change that will provide the basis for designating management units for native tree species.
- Identify existing geographic locations where woodland assemblages are anticipated to persist under future climate change conditions to enhance carbon storage and ecosystem services benefits.
- Restore degraded habitats in suitable sites to increase reproductive productivity, diversity and carbon capture to mitigate climate change impacts: select species tolerant of anticipated climate; promote diverse age classes and species mixes; create a variety of successional stages.
- Identify refugia less affected by climate change than other areas and provide a parcel map layer for priority land acquisition to land management agencies and organizations.
- Develop a prioritized planting program of collaborative projects between public and private landowners throughout the SMMNRA.
- Protect and enhance existing native oak and riparian woodland to restore mixed age class demography supporting future reproduction, promote ecosystem functions and provide self-sustaining populations in response to threats including fire, flood, extreme temperatures, and invasive pests.
- Identify potential sites and species to test for assisted migration opportunities; if deemed appropriate, facilitate planting incorporating California natives that may not currently exist within the plan area.
- Identify, protect, and where needed, enhance critical connectivity areas.
- Identify seed selection criteria based on genomes thriving on edges of species’ ranges or those with the highest tolerance for expected conditions.

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1. WHY DO WE NEED THIS PLAN?

Land ownership in the Santa Monica Mountains National Recreation Area (SMMNRA) is a complex mosaic of private and public lands (Figure 1). However, our native oak and riparian woodlands provide ecosystem services and benefits that cross these jurisdictional boundaries and function as an integrated whole. Threats from drought, wildfire, climate change, and invasive species are similarly distributed across the entire landscape. Tree species that currently occupy the Santa Monica Mountains have a proven ability to survive cyclic climate changes (ie., Pacific Decadal Oscillation) and weather (ie., Madden-Julian Oscillation, Atmospheric Rivers), as well as the cycle of annual summer drought that defines Mediterranean climates. From this perspective, questions of tree species persistence in the SMMNRA can be framed by how much change these trees can tolerate, rather than modeling shifts in ideal conditions.

A variety of local city, county, state and federal agencies regulate management of their woodlands, each having individual rules and regulations for their jurisdictions. To date, there has not been a coordinated effort to consider the anticipated effects of climate change and the recent impacts from the seven-year drought and Woolsey Fire regarding restoring and expanding native oak and riparian woodlands. Given anticipated climate changes for the SMMNRA, it is urgent that we develop a strategic plan to prioritize planting areas where trees could be expected to survive into the next century. This blueprint will help guide a coordinated, inter-jurisdictional approach leveraging required mitigation planting with voluntary restoration.

Often following a wildfire or in response to combating climate change, there is a community response to plant trees in order to “do something”. Many areas of the mountains do not support trees and some areas that do now, may not in the future. It is crucial to avoid indiscriminate tree planting in places where planting is not necessary or successful and to focus restoration efforts in areas where trees can persist into the future. However, there are areas where tree planting can and should be encouraged.

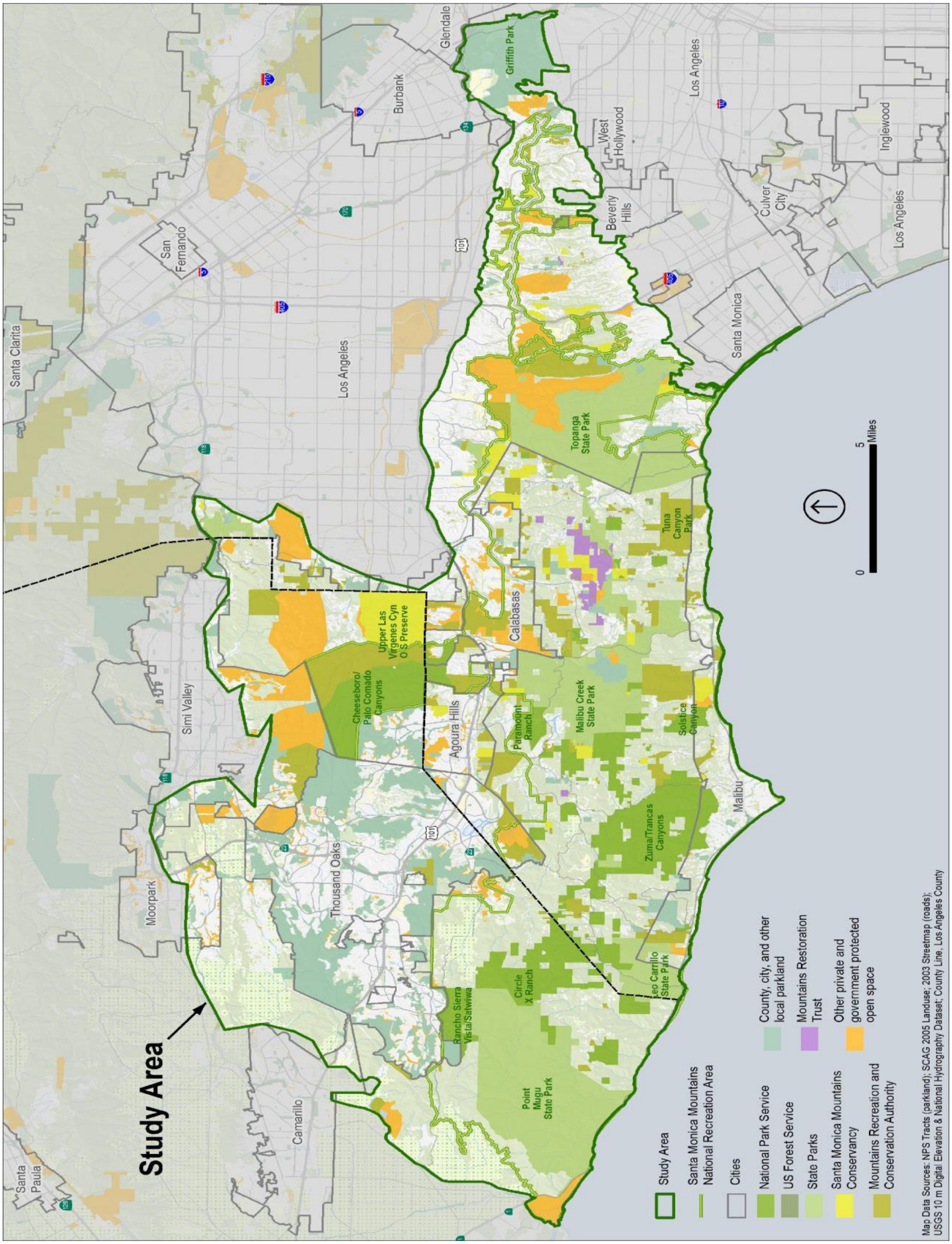
The LA County Our County Sustainability Plan (2019) outlines several steps that the County can take to support ecosystem and human health and resilience. Strategy 2D defines tree canopy cover targets for urban areas but notes that encouraging connectivity with natural areas will increase the success of this effort. Actions 44-45 recommend strengthening tree protections and encouraging development of tree planting and maintenance programs. Goal 5 identifies the need to ensure that our increasingly urban ecosystems thrive into the future. Implementing this planting plan will assist in addressing Strategy 5A (increase ecosystem function, habitat quality, and connectivity, and prevent the loss of native biodiversity in the region) and Strategy 5B (preserve and enhance open space, water ways, and priority ecological areas). Action 71 (increase the number of native trees on public property) and Action 73 which calls for preserving and protecting priority ecological sites and priority species are both supported by the information developed in this planting plan.

Additionally, the County Community Climate Action Plan 2020 (2015) identifies expanding urban forest programs, and promoting land restoration and re-vegetation, as well as preservation of current natural areas. While these actions are not calculated to provide a significant reduction in green house gas production, they could potentially provide additional carbon sequestration and storage, along with temperature moderation, stormwater runoff reduction and reduced air pollution.

Priority planting areas could change as more knowledge about species sensitivities or tolerance of climate change impacts is learned and as unanticipated future disturbances occur. This climate change adaptation planting program is a living document and the online dynamic maps will be the reference source of adaptive changes to the plan.

Native trees are keystone species, supporting thousands of species of insects, amphibians, reptiles, birds and mammals. If we lose the trees, then we lose all of these other species as well. Human activity is an integral part of this network of life; successfully managing for a future that includes native trees will require active management on both private and public lands. The benefits from supporting the growth of native trees in the face of climate change are real. They provide significant economic value, ecosystem services, especially carbon sequestration, and wildlife enhancement. The population in the SMMNRA is expected to continue growing, with over 22 million people anticipated to live in southern California by 2040 (SCAG 2015). The recreational, social, cultural, and health benefits associated with access to natural open spaces, especially in heavily urbanized southern California, are well documented (Bratman et al. 2019, Garnache et al. 2018, Louv 2005).

Long term monitoring by the RCD of coast live oak woodlands in the SMM's show that they are composed of mature to senescing trees, with little natural recruitment. Analysis of the drought-induced mortality between 2012-2016 found that thousands of oaks, and over a hundred thousand riparian trees were lost. A typical level of oak tree mortality ranges between 2-10 trees per acre annually (Tietje 1993) and we found that during the 2012-2018 drought mortality in the SMMNRA increased (Dagit et al. 2017). Further losses from invasive beetles and increased mortality from the Woolsey Fire (particularly in riparian corridors), are another source of tree loss (Figure 2).



Map Data Sources: NPS Tracts (parkland); SCAG 2005 Landuse; 2003 Streetmap (roads); USGS 10 m Digital Elevation & National Hydrography Dataset; County Line, Los Angeles County

Figure 1. Map of SMMNRA showing land ownership and city boundaries.

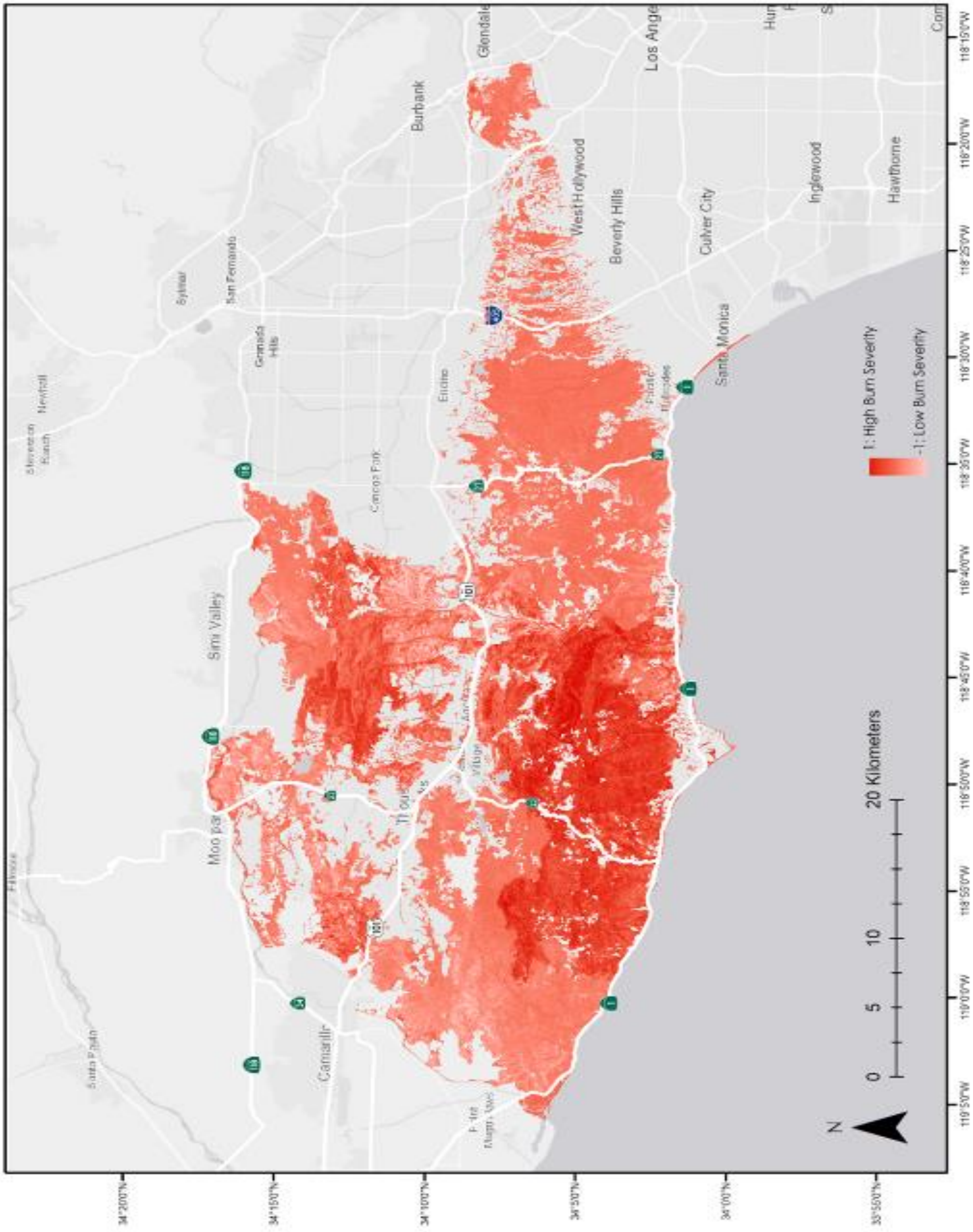


Figure 2. Burn Severity following the Woolsey Fire (excerpted from Appendix D NASA DEVELOP Technical Report).

This plan is designed to direct limited funds efficiently and effectively for long-term, successful establishment of native trees. It recognizes that locations of remaining mature adult trees may not be the best places to replant. Trees that are now mature started out as seedlings in a very different climate regime, with lower temperatures and fewer extreme temperature days. The natural recruitment pattern for coast live oaks is episodic and infrequent, associated with a large acorn production followed by a year of good rainfall allowing seedlings to become established (McCreary 2001). Even when conditions are suitable, acorn distribution is limited to the areas near a mature tree, or spread by scrub jays, which can result in suitable areas being vacant for long periods. Groundwater table changes associated with extended drought, changes in land use and impervious surface cover, and other drainage alterations have also changed dramatically. To grow a forest for the future, we need to identify potentially suitable locations that can sustain trees in the face of predicted shifts.

Overall native oak and riparian tree recruitment has been sparse and documentation of sites with active recruitment is very limited. It is estimated that under natural conditions, seed and sapling dispersal varies from just a few to several hundred meters outside the dripline of mature trees (Hayes and Donnelly 2014, McLaughlin and Zaveleta 2012). By expanding existing stands and developing new stands located in predicted climate suitable areas, we can increase landscape level distribution to bolster resilience and maximize long term persistence given the uncertainties of future disturbances.

This plan provides maps and a conceptual framework to coordinate decisions by landowners on where, when, and what to plant. It is designed to support cooperative efforts to direct limited restoration and mitigation funding into prioritized areas that can support long-term persistence across the Santa Monica Mountains landscape.

2. BACKGROUND ANALYSIS SUMMARY

The criteria used to develop the proposed prioritized planting strategies are more fully described in the Appendices; however they are briefly summarized here.

2.1 Conceptual Framework (Appendix A)

Planning to conserve native trees into an uncertain future needs to be flexible and based on a defensible set of assumptions within a realistic conceptual framework. The principle is to build upon existing stands of trees (Habitat Suitability Model Appendix C), and then to identify locations where temperature and drainage conditions, as well as topography, are anticipated to be suitable in coming years 2070-2099 (Appendix D). Using a decision making guide based on increasing redundancy and buffers to reduce risk to existing oak and riparian woodlands, managing for asynchrony, and using disturbances to promote and develop multi-age stands, we hope to promote connected landscapes that promote dispersal and establishment in suitable areas as conditions change. This framework identified and assessed threats to native tree species and examined potential adaptive strategies that will provide guidance on where to plant, what species to plant, when to plant and outline long term monitoring strategies to evaluate success of the effort.

All models of current species distributions (and secondarily their abilities to respond to threats) are based on information gathered over the last 150 years – less than the upper life expectancy of many tree species in the study, and a window of observation that is <1% of the time that the current climate has been in place. In addition, historical accounts hint that some species distributions have undergone remarkable, anthropogenically induced changes since European colonization of the SMMMRA. Given that models of species distributions and responses to stressors are based on available, recent data, they carry an element of unknowable variations. As discussed, (Adaptive Management; pg 66) uncertainty created by the unknowable can only be addressed by a strongly adaptive management structure, which monitors and corrects model errors.

Finally, climate change may be amplified or confounded by other forces, such as invasive exotic tree pests and pathogens, smog, imported irrigation water, and other recent external threats. The uncertainty introduced by these factors has a knowable component, shown by the predictable wave of damage caused by the limited infestation shot hole borer (*Euwallacea spp*.)/*Fusarium* complex (McPhearson et al. 2017). But this problem is only one trans-boundary process that may cross into the SMMNRA from the constellation of problems emanating from the surrounding urban landscape. Again, these predictable and as yet unknowable problems reinforce the need for a strong adaptive component to any management action that grows out of this plan.

2.2 Species Selection and Guilds (Appendix B)

A variety of resources were used to identify the most abundant native trees found within the SMMNRA (Raven et al. 1989, CalFlora.org), but the maps were developed based on the National Park Service vegetation survey conducted between 2001-2004 (NPS Vegetation Survey 2007), augmented by records from the CalFlora and other herbarium resources. We narrowed down the analysis from the 17 species possible, to focus on those that provided significant habitat and for which information on current distribution was available. Variables such as landscape position, water availability preferences, and general geographic distribution were tabulated. Trees were grouped by similar habitat preferences into two guilds: Upland and Canyon Guild; and Riparian Guild. These guild associations, with walnut and bay laurel modeled individually were used by the NASA DEVELOP team for grouping species during climate modeling assessments. Each species has responded to climate-related stressors in different ways, but some generalities can be applied. First, Riparian (guild) species have a narrower envelope of responses than Upland (guild) species, and hence the distributions of riparian trees are easier to link to stressor variables across the SMMNRA. Upland species (such as *Quercus agrifolia*) have a broader envelop of responses and maintain distributions that are more difficult to directly link to habitat and other environmental variables across the SMMNRA.

2.3 Habitat Suitability Modeling (Appendix C)

The goal of the habitat suitability modeling was to determine where suitable habitat for each native tree species significant to the SMMNRA currently is, so that this information could then be analyzed in conjunction with projected climate layers to determine potential planting areas and current or planned corridors. Landscapes are in a state of constant change, so developing a basis for understanding the existing conditions, even with the range of uncertainty that is unknowable, provides a framework to direct planting efforts. It is anticipated that as additional information is incorporated into this planning process, the details on selecting suitable habitat will evolve.

The dominant native trees in this analysis included *Acer macrophyllum* (big leaf maple), *Acer negundo* (box elder), *Alnus rhombifolia* (white alder), *Juglans californica* (California black walnut), *Platanus racemosa* (California sycamore), *Populus fremontii* (Fremont cottonwood), *Quercus agrifolia* (coast live oak), *Quercus berberidifolia* (scrub oak), *Quercus lobata* (valley oak), *Salix lasiolepsis* (arroyo willow), *Salix laevigata* (red willow), and *Umbellularia californica* (California bay laurel). We focused on these trees because they are significant to the SMMNRA for the habitat (including food, shelter, nesting material) and other ecosystem services they provide. Others were chosen due to their rarity or biogeographical significance (for instance, the SMMNRA is at the southern edge of the valley oak's range).

A vector-based suitability analysis was done in ArcGIS Pro 2.3.0. Layers incorporated into the model included the digital elevation data for LA and Ventura Counties, soils, streams, roads, maximum average temperature and evapotranspiration, as well as the NPS Vegetation Survey (2007) layers. Habitat maps were generated for each species displaying current habitats and potential expansion habitats. The representative concentration pathways (RCP)s for RPC 8.5 (business as usual) were modeled by the NASA DEVELOP team and then superimposed on the current and potential expansion habitat maps.

We examined the location of existing mature trees that have potential to produce seed, are adjacent to important known or suspected wildlife linkages, and that survived the drought and wildfires. Although static maps are contained in this document, dynamic maps that provide additional information are found on the Los Angeles County GIS Data Portal at https://egis3.lacounty.gov/dataportal/2019/12/12/native-tree-restoration-priority-planning-areas/.

2.4 Future Conditions Analysis (Appendix D)

The NASA DEVELOP team built on the data analysis completed and reported in Dagit et al. (2017) to assess the extent of impacts from the Woolsey Fire (2018) and to identify potentially suitable locations for planting based on modeling the representative concentration pathways (RCP) scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) for the Fifth Assessment Report (IPCC 2014, Meinshausen et al. 2011). Monthly values of precipitation rate, minimum near-surface air temperature, and maximum near-surface air temperature from NEX-DCP30 (30-arcsecond grain size) were averaged over four time periods to reflect the life stages of trees: 1950-1979; 1980-2005; 2020-2060; and 2061-2099. MAXENT software was used to build models to help resolve different spatial scales using linear quadratic and "hinge only" features (Raes and ter Steege 2007). The occurrence data was sub-sampled using 60% for training and 40% for testing each of 10 replicate runs. The regularization multiplier was set at 2.5 to reduce overfitting (James 2014).

The targeted time periods were necessary to reflect the different climatic conditions which are optimal for seedling vs. mature trees. The time period 1950-1979 covered the end of a recruitment pulse of many tree species in the SMMNRA (R. Dagit, personal communication, July 8, 2019) through their seedling and sapling life stages. We assumed that the same cohort matured during the 1980-2005 time period. The current distribution of this cohort is assumed to be reflected in the NPS vegetation polygons used to determine species presence. The 2020-2060 time period reflects recruitment and the seedling stage for the cohort to be planted by the RCDSMM and other partners as part of their effort to restore the Santa Monica Mountains. The purpose of using targeted time periods was to project the future distributions of seedlings when they are seedlings and mature trees when they are mature trees. Our results suggest that slope, aspect, and flow accumulation may be better predictors of California Walnut Woodland, California Bay Woodland, Oak Woodland, and Riparian Woodland distributions than precipitation rate, minimum temperature, and maximum temperature.

Our analysis of distributional change of occurrence probability showed that all vegetation guilds expanded rather than contracted, when comparing current to future probabilities. Similarly, the distribution change between the forecasted RCP 4.5 and 8.5 scenarios showed greater expansion than contraction, but only marginally. This expansion across both distributions and into potentially novel climatic conditions, may indicate that these particular vegetation guilds are adapting to the changing climate.

3. ENVIRONMENTAL AND ECOSYSTEM SERVICES BENEFITS

Ecosystem services provided by trees include a wide range of environmental, economic, psychological, and social benefits (Figure 3). The value of the ecosystem services provided by trees can be quantified with tools that measure benefits such as air quality improvements, energy conservation and temperature moderation, stormwater runoff avoided and stored, as well as carbon storage and sequestration.

Using a variety of online tools, the conservative values for water conservation and stormwater runoff retention; air quality benefits; and carbon sequestration and storage benefits are discussed below. It was not possible to develop values for temperature moderation as the majority of trees analyzed in this project were located in public open space parks rather than strategically placed adjacent to structures. Numerous studies have found that having native trees, especially oaks near or on private property can significantly increase the property values (Standiford and Scott 2015). We also were unable to develop a value for the ecological, habitat associated services. Therefore, the ecosystem service values summarized are a very conservative estimate of the actual value of native trees in the SMMNRA.

Figure 3. Ecosystem services matrix (Courtesy of M. Witter).

Less easy to quantify, but just as valuable, are cultural and supporting services such as the view of the oak savanna along Highway 101, the shade and sound of a hike on trails, along creeks, and through riparian woodlands, habitat to support mountain lions, and provide a nesting site for a humming bird. Almost everyone can tell a story about a special tree that they know.

Social benefits are many, varied, and also difficult to quantify, although a body of research suggests that connecting people with nature, cultural history, and sense of place can improve physical health and provide valuable memories and opportunities for recreation, resulting in reduced crime, violence, and stronger communities. Additionally, there is evidence that trees and other natural features also provide mental health benefits. These benefits include but are not limited to a positive effect on cognitive function, memory, student performance, and creativity, as well as a decrease in mental stress (Bratman et al. 2019).

Preserving and expanding our existing native oak and riparian woodlands so intact, fully functioning ecosystems persevere into the future fulfills the mandate of our public lands agencies. According to the National Park Service's 2002 visitor survey and 2014 visitor count, approximately two million visitors spend time recreating in the SMMNRA each year (M. Beck, NPS, personal communication August 2019). A recent nationwide study of the value of NPS protected lands calculated the economic value of the SMMNRA to surrounding communities (Figure 4).

Explore benefits by park

Filter by National Park Service Unit: Santa Monica Mountains NRA

Santa Monica Mountains National Recreation Area

Visits

Total 2018 Park Visits: 867,153

Spending

Total 2018 Visitor Spending: $38,488,000

Jobs

Jobs created by 2018 Visitor Spending: 476

Income

Income from 2018 Visitor Spending: $20,160,000

Spending in 2015: $36,048,000

Figure 4. Economic value of services provided by the Santa Monica Mountains National Recreation Area (https://headwaterseconomics.org/dataviz/national-park-service-units/).

3.1 Water Quality, Storm Water Retention and Erosion Control

The value of the ecosystem services provided by tree species in the SMMNRA was calculated using the i-Tree online tool MyTree for each individual tree species. Values from Topanga, Woodland Hills, Malibu, and Agoura Hills were averaged in order to obtain a value representing the range of conditions that span the SMMNRA. Tree size information was based on the average size of a mature specimen of each species as measured in our tree plots, also distributed across the SMMNRA. The value of these benefits is summarized by tree species in Table 1.

Trees intercept surface water flow and slow rainfall allowing groundwater recharge and reducing the volume of stormwater runoff. Roots and litter also stabilize slopes and reduce erosion potential. Riparian trees with large canopies such as sycamores are effective at decreasing runoff and the cumulative effect of many trees to reduce stormwater runoff and slow overland flow is significant.

Table 1. Summary of Average Annual Stormwater and Runoff Avoided Benefits by Tree Species per tree per year

Species	Dbh (in)	Height (ft)	Stormwater Runofff Avoided (gal)	Rainfall Intercepted (gal)	Runoff Avoided ($)
Acer negundo (box elder)	10	40	58.74	460.34	0.52
Acer macrophyllum (big leaf maple)	10	30	69.9	547.81	0.62
Alnus spp. (alder spp.)	10	30	61.88	484.97	0.55
Platanus racemosa (California sycamore)	15	45	112.66	882.93	1.01
Juglans californica (California walnut)	12	25	84.4	661.52	2.24
Populus spp. (Cottonwoods)	15	50	76.29	597.9	0.68
Quercus agrifolia (coast live oak)	10	35	62.22	487.64	2.87
Quercus lobata (valley oak)	12	50	80.38	629.97	0.72
Salix spp. (willow spp.)	8	30	36.95	289.6	0.33
Umbellularia californica (California bay laurel)	15	35	95.82	750.95	0.86

3.2 Air Quality Benefits

Trees, especially those with large leafy evergreen canopies are effective at removing air pollutants associated with urban environments such as carbon monoxide, ozone, and particulate matter from auto emissions. Coast live oak, California sycamore and bay laurel trees are especially effective air filters as shown in Table 2.

Table 2. Summary of Average Annual Air Quality Benefits by Tree Species per tree per year.

Species	Dbh (in)	Height (ft)	Carbon Monoxide (oz)	Ozone (oz)	Nitrogen Dioxide (oz)	Sulfur Dioxide (oz)	Particulate Matter <2.5 Microns	Annual Benefit ($)
Acer negundo (box elder)	10	40	0.16	6.01	0.68	0.21	<.10	0
Acer macrophyllum (big leaf maple)	10	30	0.19	7.23	0.82	0.25	<.10	0.1
Alnus spp. (alder spp.)	10	30	0.17	5.58	0.63	0.19	<.10	0
Juglans californica (California walnut)	12	25	0.23	11.78	1.34	0.4	0.12	0.1
Platanus racemosa (California sycamore)	15	45	0.31	12.45	1.41	0.43	0.11	0.1
Populus spp. (Cottonwoods)	15	50	0.21	7.54	0.85	0.26	<.10	0
Quercus agrifolia (coast live oak)	10	35	0.17	10.54	1.41	0.34	0.35	0.1
Quercus lobata (valley oak)	12	50	0.22	8.56	0.97	0.3	<.10	0
Salix spp. (willow spp.)	8	30	0.1	3.23	0.36	0.11	<.10	0
Umbellularia californica (California bay laurel)	15	35	0.27	12.24	1.62	0.31	0.39	0.1

3.3 Carbon Sequestration and Storage

One of the major ecosystem service benefits provided by trees is both annual sequestration of carbon absorbed from the atmosphere by photosynthesis each year and long term storage density (the amount of carbon trapped in roots, trunk, branches and leaves per unit area). Tree species vary in their ability to store carbon as shown in Table 3. By combining annual sequestration and storage values we get a sense of annual value per tree. Due to their deep root systems and abilities to tap into reliable subsurface water, coast live oak trees can grow and create canopy in locations where other trees cannot survive. The loss of coast live oak trees often means the complete loss of woodland canopy and above ground carbon sequestration.

Once established many native trees (species listed in Table 17) resprout after injury – even when the entire tree is destroyed because their root systems are left mostly intact. Hence these trees rapidly sequester carbon because they quickly recover above ground biomass.

The amount of carbon/ha stored in trees is substantially higher than in shrub or grassland areas, therefore it is advantageous to recover woodlands that may have been lost due to human activities (e.g. firewood harvesting in the 19th century, past clearing for livestock and crops, drought, wildfires, etc.).

Table 3. Summary of Average Annual Carbon Storage/Sequestration by Tree Species per tree per year.

Species	Dbh (in)	Height (ft)	Sequestered (lbs)	Sequestered ($)	CO2 Stored to Date (lbs)	CO2 Store to Date ($)
Acer negundo (box elder)	10	40	165.65	3.85	1422.93	33.09
Acer macrophyllum (big leaf maple)	10	30	84.53	1.97	1464.03	34.05
Alnus spp. (alder spp.)	10	30	172.49	4.01	1361.64	31.67
Juglans californica (California walnut)	12	25	96.12	2.24	1570.9	36.53
Platanus racemosa (California sycamore)	15	45	192.79	4.48	2551.87	59.35
Populus spp. (Cottonwoods)	15	50	<.10	0	2531.95	58.89
Quercus agrifolia (coast live oak)	10	35	123.26	2.87	1250.96	29.09
Quercus lobata (valley oak)	12	50	338.9	7.88	1730.63	40.25
Salix spp. (willow spp.)	8	30	60.61	1.41	530.84	12.35
Umbellularia californica (California bay laurel)	15	35	54.38	1.26	2738.83	63.7

3.4 Ecosystem Service Value by Species

Table 4 provides an extremely conservative estimate of the total annual value of carbon, air quality and storm water mitigation services provided by an individual tree for each of the native tree species. These values do not take into consideration the aesthetic, ecological, recreational, health, or cultural benefits of trees. Trees also provide temperature moderation benefits depending on their proximity to buildings, roads and other impervious surfaces. Depending on the albedo of the surface and the location of the tree, energy is conserved by shade cooling, evapotranspiration air cooling, and slower wind speeds.

Table 4. Summary of Average Annual Ecosystem Service by Tree Species per tree per year.

Total Ecosystem Service Value:	**2019 ($)**
Acer negundo (box elder)	37
Acer macrophyllum (big leaf maple)	37
Alnus spp. (alder spp.)	36
Juglans californica (California walnut)	40
Platanus racemosa (California sycamore)	66
Populus spp. (Cottonwoods)	60
Quercus agrifolia (coast live oak)	35
Quercus lobata (valley oak)	49
Salix spp. (willow spp.)	15
Umbellularia californica (California bay laurel)	65

Although wildland trees are not usually measured for their individual contribution to ecosystem services, they do in fact provide significant quantifiable economic benefits to the SMMNRA. The conservative value of ecosystem services provided by coast live oaks is estimated at $35/tree/year. Based on the estimated density of 56 oaks/acre, there are at least 600,000 coast live oaks providing approximately $21 million dollars of ecosystem services per year in the SMMNRA. This value does not include additional ecosystem services that were not quantified such as temperature moderation, pollution removal, aesthetics, real estate, and habitat value.

Based on the Dagit et al. (2017) analysis, riparian woodlands experienced more tree loss than other woodland types between 2013-2016 and this was exacerbated by additional loss from the Woolsey Fire (Appendix D). Using a conservative estimate for California sycamores of $66/tree annual ecosystem service value, and an estimate of 35 trees/acre the loss observed totaled over $18.7 million per year.

4. HOW TO USE THIS PLAN

The geographic area analyzed for this plan includes the entire SMMNRA with a slight buffer to the north to include parts of the Simi Hills. Figure 1 shows the boundaries of seven cities, Los Angeles, and Ventura County unincorporated areas, as well as public lands owned by CA Department of Parks and Recreation, Mountains Conservation and Recreation Authority, National Park Service and local land trusts. Table 5 summarizes the ownership by acreage and associated tree ordinances or plans guiding management and mitigation requirements.

Table 5. Matrix of land ownership and planning documents for the SMMNRA.

Jurisdiction	**Number of Acres**	**Guiding Documents**
CA Department of Parks and Recreation	36,186	Leo Carrillo State Park General Plan, Malibu Creek State Park General Plan, Point Mugu State Park General Plan, Topanga State Park General Plan Danielle will look for veg plans
City of Agoura Hills	5,005	General Plan, Tree Protection Ordinance
City of Calabasas	8,781	General Plan, Tree Protection Ordinance
City of Hidden Hills	1,080	General Plan, Tree Protection Ordinance
City of Malibu	12,691	General Plan, Tree Protection Ordinance, Local Coastal Plan
City of Los Angeles	440	General Plan, Tree Protection Ordinance
City of Thousand Oaks	35,411	General Plan, Tree Protection Ordinance
City of Westlake Village	3,524	General Plan, Tree Protection Ordinance
Los Angeles County (unincorporated area)	4,170	General Plan, Tree Protection Ordinance, Local Coastal Plan, Oak Woodlands Conservation Management Plan, Significant Ecological Areas Plan, Santa Monica Mountains North Area Plan
Mountains Recreation and Conservation Authority	17,079	Site specific vegetation restoration plans
Mountains Restoration Trust	1,446	Site specific vegetation restoration plans
National Park Service	23,614	Santa Monica Mountains National Recreation Area General Plan
Ventura County	104	General Plan, Wildlife Corridor Plan, Tree Protection Ordinance, Local Coastal Plan

Many of the guidance documents include similar requirements for replacing trees removed for development, but the size, species, and location of both restoration and mitigation plantings varies by agency and jurisdiction. That said, many policies are similar in requiring replacement or restoration planting be done using seeds from within the same watershed, and in specifying how many replacement seedlings/saplings will be planted. The number of mitigation trees required often is higher if the planting will occur off-site, rather than on the same developed parcel. However, there are many instances when it is not possible to replant on site after development. Requirements also expect that these replacement trees will survive into maturity.

These constraints provide an opportunity for jurisdictions to work collaboratively at a landscape level to direct mitigation planting to areas on adjacent private or public lands.

This plan advocates that voluntary and mitigation driven plantings be coordinated to expand, and in some cases initiate, new tree stands based on anticipated climate projections.

5. WHERE TO PRIORITIZE PLANTING?

Planning to conserve native trees into an uncertain future needs to be flexible and based on a defensible set of assumptions within a realistic conceptual framework. Our assumptions are detailed in Appendix A, but the principle is to build upon existing stands of trees, and then to identify locations where temperature and drainage conditions, as well as topography, are anticipated to be suitable in coming years 2070-2099 (Appendix C and D). Additionally, we reviewed recommendations provided in the California Wildlife Relationships System (Thorne et al. 2016), as well as climate projections specific to southern California (Hall et al. 2012). Because establishment of native tree species is often closely tied to availability of water, we also reviewed the results of the analysis of potential flow changes and associated impacts on stream communities (Taylor et al. 2019).

Sites where mature oaks and riparian trees are present in 2019 may reflect suitable establishment conditions when these trees were recruited over the last 100 years and not necessarily the current conditions. For instance, changes in hydrology and impervious surface cover, as well as drought have constricted current recruitment of valley oak seedlings and saplings to areas closer to more reliable and accessible water sources (Hayes and Donnelly 2014). This pattern is not well studied for other species.

A systems approach to identifying potential planting sites integrates current information on site conditions (microclimate, topography, drainage) and landscape level conditions (extreme temperatures, drought, wildfire). Species selection and density may also need adjustment in fuel modification zones that provide defensible space around existing or proposed structures, especially where private property abuts public open spaces.

With the assistance of the NASA DEVELOP team, we examined where trees are currently alive following the 2012-2018 drought and the recent wildfires, and what physical conditions are associated with their existing distribution pattern (Figures 5 and 6). Physical attributes (slope, aspect, proximity to drainages, soil type) were then augmented with layers of temperature and evapotranspiration. The tolerance ranges used in the models were based on a literature review focused on seedling/sapling establishment parameters for individual species when available. We also modeled habitat suitability by overlaying the 2007 NPS Vegetation layers with physical attributes (slope, aspect, proximity to drainages, soil type) and climate variables (evapotranspiration) within areas occupied by the trees. In addition, we examined layers of temperature and evapotranspiration separately. Due to the limitations of the available data, it was not possible to identify potential micro-refugia. The existing and potential distribution maps for each species are found in Appendix C.

With the assistance of the NASA DEVELOP team, these existing and potential suitability maps were then analyzed through the lens of predicted climate change models. The maps included in this planting plan include the climate model overlay showing potential climate conditions anticipated by the emissions Representative Concentration Pathway (RPC) 8.5 business as usual model parameters (IPCC 2014). They also examined the patterns using the reduced emissions trajectory of RPC 4.5, which was the target used in the Paris Accord. Details on this process are found in Appendix D.

The maps generated below are a compromise between most accurately predicting habitat and including all possible locations where the trees might occur within the SMMNRA. There could be additional areas outside the ranges created by the model (Appendix C) that could also be suitable and there could also be areas identified as potentially suitable in the future for some reason unknown at this time. Based on the limitations, there is higher confidence in the projected suitable habitat for the riparian guild species due their limited habitat constraints and less confidence for upland species.

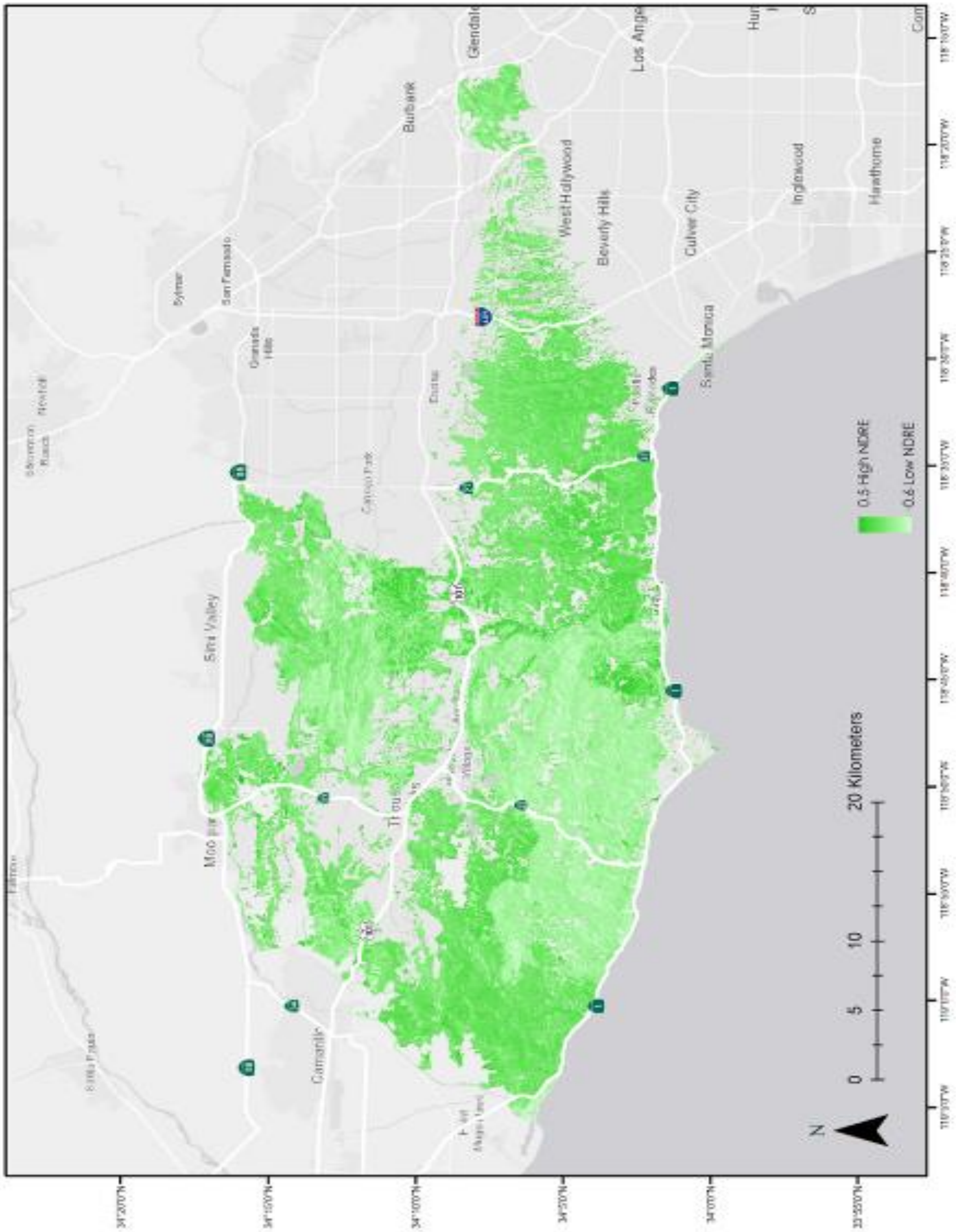


Figure 5. Composited NDRE Index image over the Santa Monica Mountains displaying vegetation health following the Woolsey Fire (from RapidEye, 2019). Lighter colors represent non-photosynthetic vegetation and darker green colors indicate thriving vegetation in June 2019 (Excerpted from Appendix D NASA DEVELOP Technical Report).

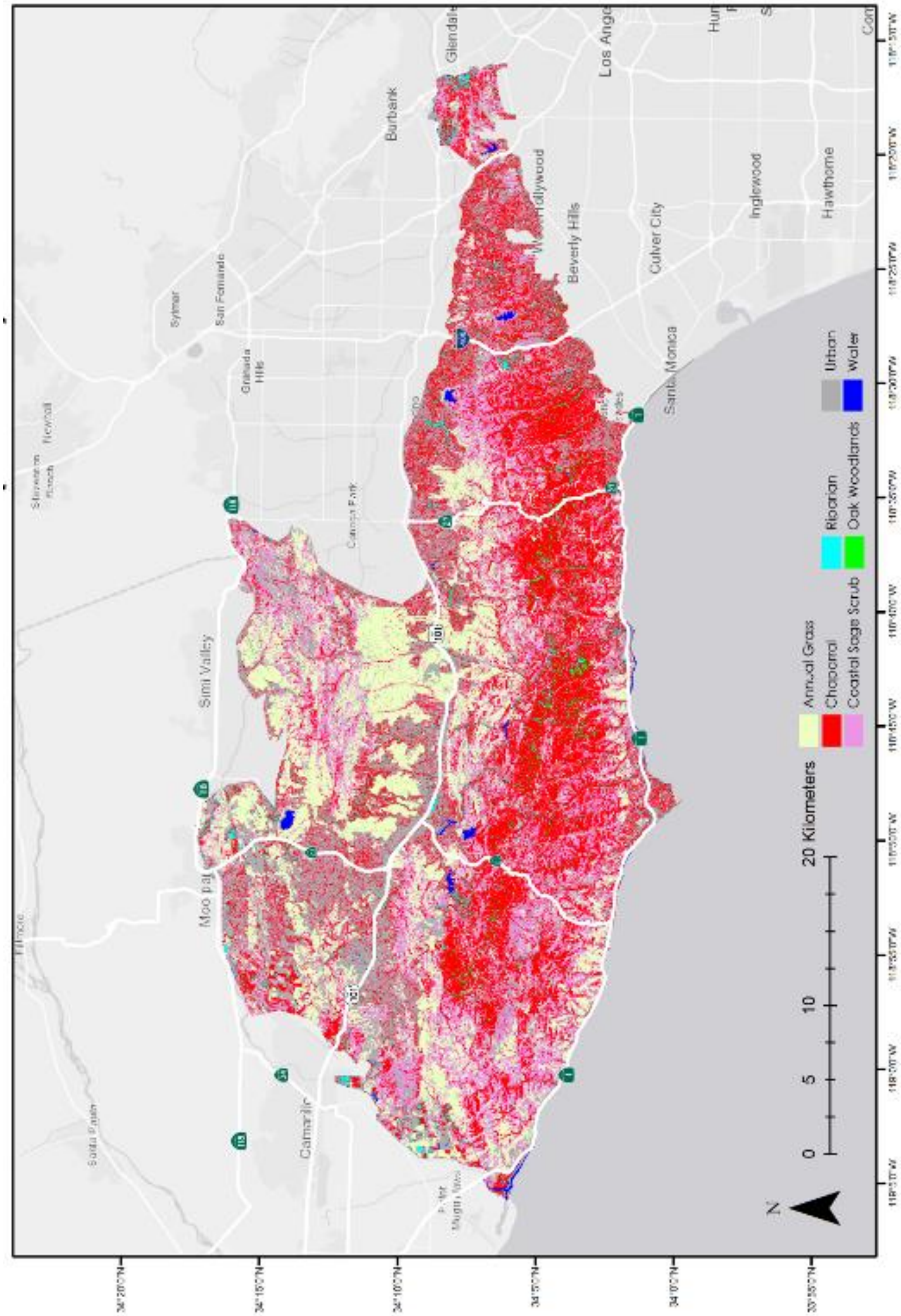


Figure 6. Species distribution based on AVIRIS MESMA Classification of imagery acquired 06/25/2018 (excerpted from Appendix D NASA DEVELOP Technical Report).

5.1 Decision Analysis Guiding Site Selection

The decision-making framework uses site variability in resilience and exposure to define management actions (Magness et al. 2011). Refugia can be created or maintained in high resilience and low exposure areas. Ecosystem maintenance is the appropriate management decision under low resilience and low exposure conditions. Ecosystem maintenance can include maintaining current conditions by managing stressors such as invasive species, fragmentation, or restoring the site. These sites may transition into other states due to low resilience, and could become stepping stones for shifts to new states. High resilience and high exposure sites are likely to develop natural adaptation processes. Low resilience and high exposure sites are candidates for facilitated transitions. Developing consistent costs associated with both restoration and mitigation planting projects among all providers will also be necessary.

5.2 General Concepts Developed in the Decision Model

Suitability models are used to develop potential sites to plan for transitions and assist species migrations along expected climate gradients. Decisions will need to be made on whether to plant species or genotypes with higher tolerance to future conditions, or a new suite of species. This might include evaluation of elevation as a proxy for genetic similarity rather than within watershed proximity to help guide seed selection. Potential barriers to dispersal for target species and options for improving connectivity need to be identified. Sites that are more buffered against climate change and disturbance can be identified to serve as refugia. Seed banks should be created to re-establish extirpated populations.

General guidelines for decision-making are to:

- Increase redundancy and buffers to spread risk;
- Manage for asynchrony and use establishment phase to reset succession (i.e. disturbances can be triggers for planting new species);
- Use disturbances and diebacks due to drought, beetles, or fire to promote diverse age classes, species mixes and genetic diversity;
- Prioritized planting in areas impacted by invasive plant species to convert back to natives;
- Promote connected landscapes to facilitate dispersal and migration.

With these general concepts in mind, the following decision tree is proposed to guide selection and management? of priority planting sites based on maps of projected future habitat suitability:

1. **Habitat that will remain suitable:**
    - Create resistance to change:
        - Reduce anthropogenic stressors (erosion, invasive plants, fire effects, invasive beetles)
    - Promote resilience to change
        - Determine most sensitive life stages;
        - Intensive management during establishment phase
        - Promote diverse age classes, genetic diversity and seed mixes
        - Manage sites to decrease fire impacts (ladder fuels, buffer around sites)

2. **Habitat that will be less suitable (wholly or in part) in the future:**
   - Create resistance to change by focusing on:
     - Reduce anthropogenic stressors (erosion, invasive plants, fire effects, invasive beetles)
     - Plant with high tolerance propagules
     - Prioritize larger sites and sites in close proximity to facilitate dispersal and create stepping stones to future suitable sites
     - Prioritize sites least likely to be impacted by fire

- **Habitat that currently is not suitable may become more suitable in the future:**
  - Prioritize sites:
    - that have been impacted by disturbance (ex: fire, pests, drought)
    - that have been identified in other models as no longer suitable to the existing vegetation type
    - based on connectivity
    - identify sites that are more buffered against disturbance

  - Treatments mimic, assist, or enable ongoing adaptive processes:
    - Seed dispersal and migration
    - Changes in species dominance and community composition
    - Changing disturbance regimes.
    - Encourage gradual adaptation and transition; mimic succession

For all these potential conditions it is critical to articulate clear goals at the start of each project and for each location. Developing restoration designs with specific hypotheses in mind and with trigger points that will initiate management decisions/actions will be critical to evaluate the success of the project. Examples of potential goals include maintaining ecosystem integrity, achieving restoration cover goals, preserving ecosystem services, and protecting wildlife.

Additionally, thoughtful monitoring plans will be needed that are designed to:
- Detect changes in baseline conditions
- Facilitate timely adaptation actions
- Gauge effectiveness of management actions

6. PLANTING MAPS

The following static maps are representations of analyses described more fully in Habitat Suitability Modeling and Existing Conditions (Appendix C) and NASA DEVELOP Technical Study (Appendix D). The online versions of these maps will be hosted by Los Angeles County GIS Data Portal with initial support from RCDSMM at https://egis3.lacounty.gov/dataportal/2019/12/12/native-tree-restoration-priority-planning-areas/.

These maps are dynamic and have the option of adding additional overlays to show property boundaries, County designations for habitat protection categories (H1, SEA, etc.), designate a buffer for potential fuel modification impacts, wildlife linkage corridors, and other layers. The static maps included in this document provide the broad overview illustrating current distribution and potential areas having similar characteristics where no trees are currently observed, overlaid with the business as usual RPC 8.5 emissions model predictions.

While the main focus of this planting plan is to identify priority parcels on public lands, many private parcels also have suitable conditions to assist in restoring future woodlands. The online versions of the maps have sufficient detail for a property owner to determine if their land is suitable for planting for the future. The overarching goal is to encourage functional vegetation associations/communities driven by existing and predicted climatic limitations.

6.1 Limitations of the Planting Maps

The tree distribution data was collected from 2001-2004, and therefore does not reflect the impacts of the drought and various fires that have occurred since that time. The data was subjected to lengthy QA/QC resulting in the GIS layers provided as the basis of this analysis in 2007.

The NPS Vegetation Survey (2007) data that provided the tree species distribution only displayed the dominant trees in the polygon area, although there were multiple species that were actually present after reviewing the ground-truthed results. This suggests that the polygons do not accurately represent where all locations of each tree species may be growing or established. This may introduce error to the results because species may be present but not dominant, or so interspersed in a more dominant vegetation assemblage that it is not noted. Results of limited ground truthing suggest that this could be why many of the willow species were mapped in limited areas, when in fact they are more widespread in the landscape but not dominant.

Additionally, we had scale sizes for various data layers ranging from 10 meters to 250 meters, which may not provide the most detailed information and can mask potential micro-refugia locations. For example, the temperature data was based on 250 m grid cells, but the species polygons were more specific. When integrating these layers, it was very possible to miss areas where temperature ranges were suitable or not.

It was not possible to obtain groundwater or water table level data that could be helpful in developing a more sophisticated model for upland species distribution away from mapped drainages. We used levels of evapotranspiration and integrated that with slope and aspect as a surrogate to examine potential suitable sites where perched water tables might be available.

It was also not feasible to include the role of fog in supporting recruitment and survival of trees in the coastal zone.

Most of our tree species had polygon data, but box elder, big leaf maple, and Fremont cottonwood only had point data because there are so few of them in the study area. Since there are so few of them, it was difficult to accurately represent what conditions these trees preferred within the SMMNRA. Each point represented one tree.

The static maps provided in this document are meant for initial examination of potentially suitable planting sites. Online maps have the ability to add layers such as the topography, slope, fire perimeter, burn severity data, city and property boundaries, jurisdictional designations of habitat such as Environmentally Sensitive Habitat Areas (ESHA's) and it will also be possible to zoom in more closely to get a better sense of the immediate surrounding conditions.

Due to time constraints, climate models used by the NASA DEVELOP team were based on using guilds of species with similar distribution and growth patterns, rather than for each individual species. This is consistent with other models that were based on the 30-meter resolution vegetation maps developed by the California Department of Forestry and Fire Protection GIS Data 2016 (EcoAdapt 2017, Thorne et al. 2016). These models examined vegetation macro-groups to identify current climate envelopes occupied by that group and then projected the response to future climate changes. Further, we examined the climate flow predictions for southern California (Taylor et al. 2019) and found that most of our predicted areas of suitability were within the same geographic areas identified by that modeling effort. Despite the limitations of our finer scale efforts, our results overall are consistent with the distribution predicted by these more extensive modeling efforts.

6.2 Upland and Canyon Guild Species Analysis:

The native oak species were considered as a single guild including *Quercus agrifolia*, *Quercus berberidifolia*, and *Quercus lobata*. Although they were evaluated individually, both *Juglans californica* and *Umbellularia californica* are found closely associated and within oak dominated assemblages (NPS 2007). Even though there are differences among their habitat preferences, there are overlapping habitat similarities that conform to the CDFW Southern oak woodland habitat categories (EcoAdapt 2017, Thorne et al. 2016). All the oak species are widespread throughout the SMMNRA found in a variety of conditions from warm interior valleys to the coast, on slopes of various aspects down into riparian canyon corridors. In the SMMNRA, oak woodlands and savannah habitat are often interwoven with both chaparral and mesic riparian corridors. Much of the current distribution of oak woodlands is also an artifact of historic grazing, logging for firewood production, and disruption due to development throughout the SMMNRA (Los Angeles County Oak Woodlands Conservation Management Plan 2011). Additional details on the habitat characteristics examined are found in Appendix C.

Raven et al. (1989) also noted the rare presence of *Q. wislizeni* at the Triunfo Lookout, on Saddle Peak and in both Cold Creek and Santa Ynez canyons. Due to its limited occurrence, we were unable to assess the habitat suitability for this species but recommend that further research be focused on the potential for adding this to the species mix for planting in the future.

Current distribution is predominantly comprised of mature adult trees, with few locations with more mixed age stands (Dagit et al. 2017). Oaks recruit in pulses when good rains that facilitate germination and establishment follow a high acorn production year. Trees reach reproductive maturity in 10-20 years, and adults can live for more than 100 years. Davis et al. (2016) found that locations where seedling establishment occurred were on a microscale level that was difficult to model. The current distribution of seedlings has not been adequately mapped and should be the subject of future research.

Subsurface hydrology has not been modeled for the SMMNRA and there is no feasible way to examine subsurface water availability on higher slope areas where water may be perched and accessible to roots, although we know that such locations exist. Our habitat suitability modeling approach focused on drainages with a 25-meter buffer as the best available data on presence of surface and high-water table areas. By comparing the areas with trees that survived the drought to those areas where trees died, we tried to get a better sense of limiting factors, but that effort was not as productive as hoped, and instead we relied upon the broader scale landscape level analysis detailed in Appendix D.

Evaluation of vulnerability by EcoAdapt (2017) found that overall, oak woodlands have low-moderate sensitivity to anticipated climate changes as they currently persist in a wide range of temperature and soil moisture conditions, and due to their widespread distribution have low-moderate exposure to future climate stressors. Threats identified for oak woodlands include sensitivity to reduction in precipitation and soil moisture, exposure to wildfire, introduced pests and diseases, and changes associated with land conversion and development. The adaptive capacity of these oak species is considered moderate, but due to the extensive habitat alteration and fragmentation already experienced by these woodland communities it is recognized that active management will be needed to support future woodlands (EcoAdapt 2017).

Oaks are recognized for their resilience to wildfires and many contributions to biodiversity, as well as important ecosystem services as noted above. The LA County Oak Protection Ordinance and Coastal Implementation Plan, as well as ordinances in most cities within the SMMNRA require mitigation for the removal of oaks at typically 10 replacement trees for every tree removed. There are also requirements for replacement planting if there is more than 30% encroachment into the tree protection zone. Often it is not possible for private property owners to plant the required trees on the site where trees were removed, although that is preferred. Coordinating mitigation planting on public lands to help restore connectivity and create multi-age stands is an opportunity.

Calscape (https://calscape.org/) provides a wealth of information on distribution and planting details for each of these species including suggested companion plants and uses by wildlife. Local experts Tom Hayduk (Nursery Manager and Seed Collector, CDPR) and Jack Smith (TreePeople Nursery Manager) provided additional notes on locally appropriate methods of propagation.

6.2.1 Quercus agrifolia (Coast Live Oak)

Coast live oaks are the iconic southern California oak species with their evergreen canopy, varied architecture and widespread distribution. They are associated with locations having fine-loamy and loamy soils but are also found on a wide variety of soil types. They show no preference for slope or aspect although they need access to groundwater, which is more frequently accessible on north facing slopes. Although coast live oaks are extremely drought tolerant with roots that can extend deep to tap into groundwater reservoirs, the recent drought (2012-2018) resulted in extensive mortality. Their tolerance for average maximum temperatures ranged from 17-25° C and evapotranspiration ranged from 217-342 mm.

Acorn production is variable both by year and by individual tree (Koenig et al. 2013). Acorns mature in one year and are a main food for many species, including humans historically (Pavlik et al. 1991). Their seedlings take time to become established, with extensive root development occurring prior to above ground growth. Without supplemental water and maintenance of a weed free zone, seedling recruitment is low in natural settings. Browsing damage is common and both above and below ground protections enhance survival. Seedlings planted in association with other native plants that provide shade in the early years fare better (R. Dagit, personal communication, September 2019).

Propagation Notes:
Acorns are usually ripe in the fall between September and October depending on weather conditions. The most viable acorns are those gathered directly from the tree by twisting them gently from their cap, or by hitting them with a soft broom and gathering what falls on a tarp below. Each acorn needs to be inspected carefully to make sure there is no infestation or disease. They should be smooth and show no signs of holes or bumps. The next step is to drop them into a bucket of water. Discard any acorns that float to the top. Soak in mild bleach solution, keeping sinkers and removing floaters. Carefully dry those that sink to the bottom and store in a refrigerator until ready to plant within a few months (McCreary 2001).

Let acorns dry and sow the same day or place into cold stratification in refrigerator, using ziploc bags, mixing acorns with propagation soil and tag with botanic name, collection date and location. Check bag every few weeks and sow when acorns start to germinate in bag in deep liners (2”x7”), 50 to a tray. Sow acorns with pointed end in soil and blunt cup end above soil level. Most important is to keep freshly sown acorns safe from hungry and persistent rodents, primarily ground squirrels, using hardware-cloth cages.

Transplant healthy saplings to treepots in spring and plant into oak woodland habitat the following fall. Alternately, direct sowing of acorns into habitat has great value by skipping the year required for the nursery propagation cycle while giving the oak an advantage of a more natural taproot developed w/o pruning. Protection from squirrels with caging is necessary to prevent feeding the grateful bushy tails.

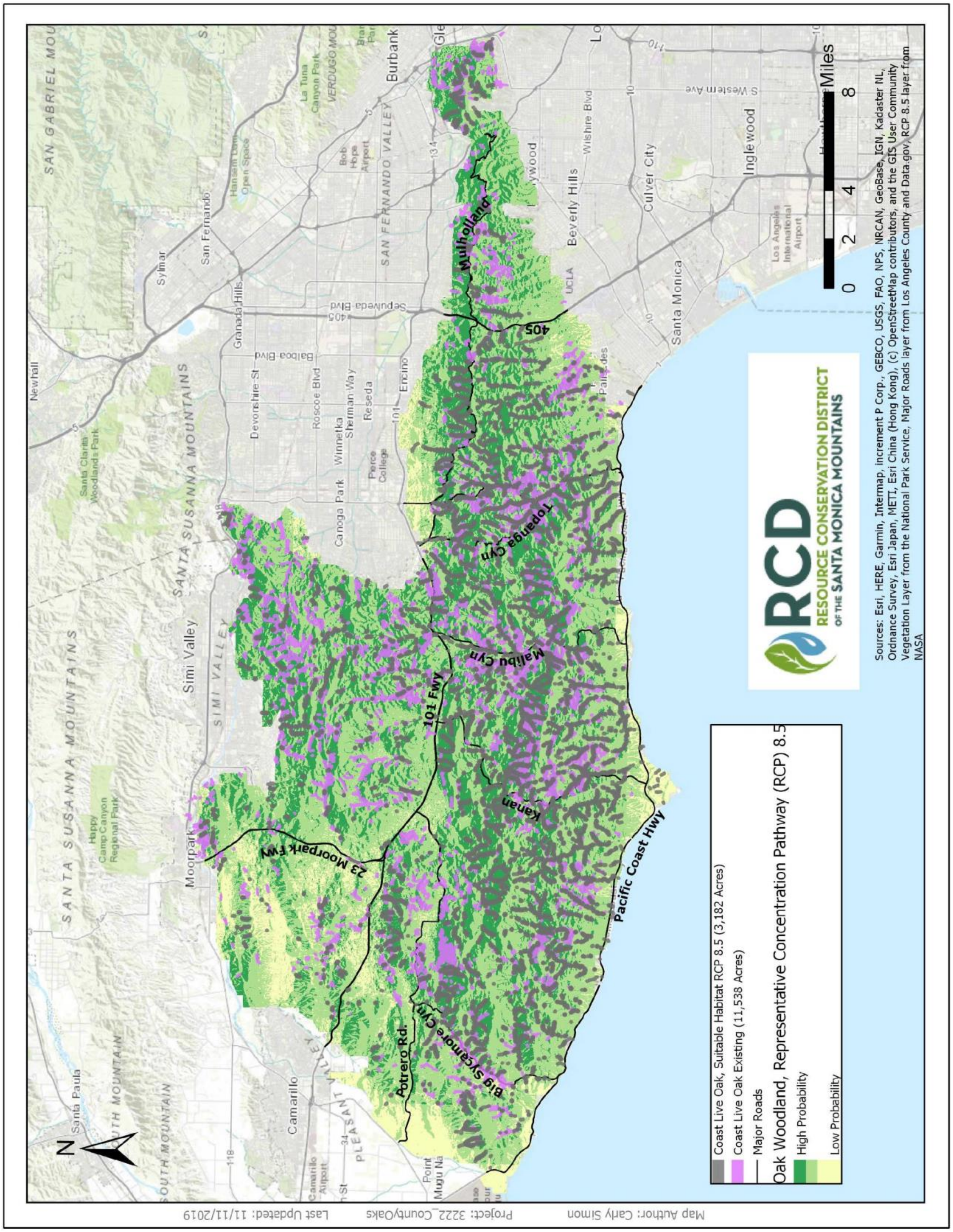
Coast live oaks are especially effective at slowing spread of wildfires and are able to recover from almost complete burning (Dagit 2002, Plumb et al. 1981). Although they are extremely resilient, fire return intervals greater than 10-30 years are associated with lower recovery of mature adults, greater impacts on saplings, and mixed results for seedling establishment (Steinberg 2002).

Based on the NPS mapping data (2007) coast live oaks were found on over 11,000 acres throughout the SMMNRA, but further analysis suggests that drought and wildfire impacts have reduced that by loss of over 9,000 trees (Dagit et al. 2017). Coast live oaks are a keystone species supporting several thousand other plant and animal species (Pavlik et al. 1991). They provide important habitat along wildlife corridor linkages as well as in riparian zones. Impacts from fragmentation due to urban development, some agriculture, and fuel modification can all be addressed with the priority planting plan.

As shown in Figure 7, coast live oaks are abundant at present and future climate projections suggest that they will be able to continue to occur widely throughout the SMMNRA. Based on the existing distribution and the combined overlay of potentially suitable locations as well as predicted areas suitable given climate predictions, we recommend prioritizing planting of coast live oaks on public lands as noted in Table 6. Selection of actual planting locations will benefit from additional examination of the map online, to get more details of each location. Since coast live oaks also can be used as firebreaks, consideration on planting locations that can also serve to reduce impacts of development along the wildland interface is recommended.

Table 6. Priority Planting Recommendations for Quercus agrifolia (Coast Live Oak) on public lands (2019).

Location	**Landowner**	**Notes**
Cheseboro Park	NPS	Replace trees lost to wildfire and develop multi aged stand
Las Virgenes Open Space Preserve	MRCA	Replace trees lost to wildfire and develop multi aged stand
Malibu Creek State Park, Bulldog Motorway	CDPR	Replace trees lost to wildfire and develop multi aged stand
Malibu Creek State Park, Group Campsite	CDPR	Replace trees lost to wildfire and develop multi aged stand
Malibu Creek State Park, Reagan Ranch	CDPR	Replace trees lost to wildfire and develop multi aged stand
Malibu Creek State Park, Tapia	CDPR	Replace trees lost to wildfire and develop multi aged stand
Topanga State Park, Rodeo Grounds	CDPR	Revegetation following restoration
Topanga State Park, Trippett Ranch	CDPR	Replace trees lost to drought and beetles
Headwaters Corner	City of Calabasas	Replace trees lost to wildfire
Dry Creek Canyon Park	Varied	Replace trees lost to wildfire
All CDPR, MRCA and NPS lands with suitable habitat	CDPR, MRCA and NPS	Expand woodlands wherever appropriate based on analysis of site conditions.
Griffith Park	City of Los Angeles	Replace trees lost to wildfires and invasive beetles, especially on north facing slopes



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community. Vegetation Layer from the National Park Service, Major Roads layer from Los Angeles County and Data.gov, RCP 8.5 layer from NASA

Figure 7. PRIORITY PLANTING SITES - Quercus agrifolia (Coast Live Oak).

6.2.2 Quercus berberidifolia (California Scrub Oak)

Scrub oaks have widespread distribution and are a key species in various woodland and chaparral vegetation assemblages but are more common at the higher elevation bands (NPS 2007). They are taxonomically complex and hybridize readily in the SMMNRA, although *Q. berberidifolia* is the most common and widespread upland oak species (Roberts 1995). They are often the dominant species within the various chaparral community types in association with chamise and ceanothus, as well as in the understory of coast live oak dominated stands. They are associated with locations having fine-loamy and loamy soils. They are often found on moderate to steep slopes up to 45^o and prefer north and eastern aspects Although shrub oaks are extremely drought tolerant with roots that can extend deep to tap into groundwater reservoirs, the recent drought (2012-2018) resulted in extensive mortality. Their tolerance for average maximum temperatures ranged from 18-25°C and evapotranspiration ranged from 228-324 mm.

Acorns mature in one year and often scrub oak acorns are more abundant during years when both coast live oak and valley oak acorns are less abundant (RCDSMM, unpublished data). Their seedlings take time to become established, with extensive root development occurring prior to above ground growth. Without supplemental water and maintenance of a weed free zone, seedling recruitment is low in natural settings. Browsing damage is common and both above and below ground protections enhance survival. Seedlings planted in association with other native plants that provide shade in the early years fare better (Keeley 1992).

Propagation Notes:

Scrub oaks produce acorns every year and they are usually ripe in the fall between September and October depending on weather conditions. The most viable acorns are those gathered directly from the tree by twisting them gently from their cap, or by hitting them with a soft broom and gathering what falls on a tarp below. Each acorn needs to be inspected carefully to make sure there is no infestation or disease. They should be smooth and show no signs of holes or bumps. The next step is to drop them into a bucket of water. Discard any acorns that float to the top. Soak in mild bleach solution, keeping sinkers and removing floaters. Carefully dry those that sink to the bottom and store in a refrigerator until ready to plant within a few months (McCreary 2001).

Let the acorns dry and sow the same day or place into cold stratification in refrigerator, using ziploc bags, mixing acorns with propagation soil and tag with botanic name, collection date and location. Check bag every few weeks and sow when acorns start to germinate in bag in deep liners (2”x7”), 50 to a tray.

Sow acorns with pointed end in soil and blunt cup end above soil level. Most important to keep freshly sown acorns safe from hungry and persistent rodents, and primarily ground squirrels, using hardware-cloth cages. Transplant healthy saplings to treepots in spring and plant into oak woodland habitat the following fall. Alternately, direct sowing of acorns into habitat has great value by skipping the year required for the nursery propagation cycle while giving the oak an advantage of a more natural taproot developed without pruning. Protection from squirrels with caging is necessary to prevent feeding the grateful bushy tails.

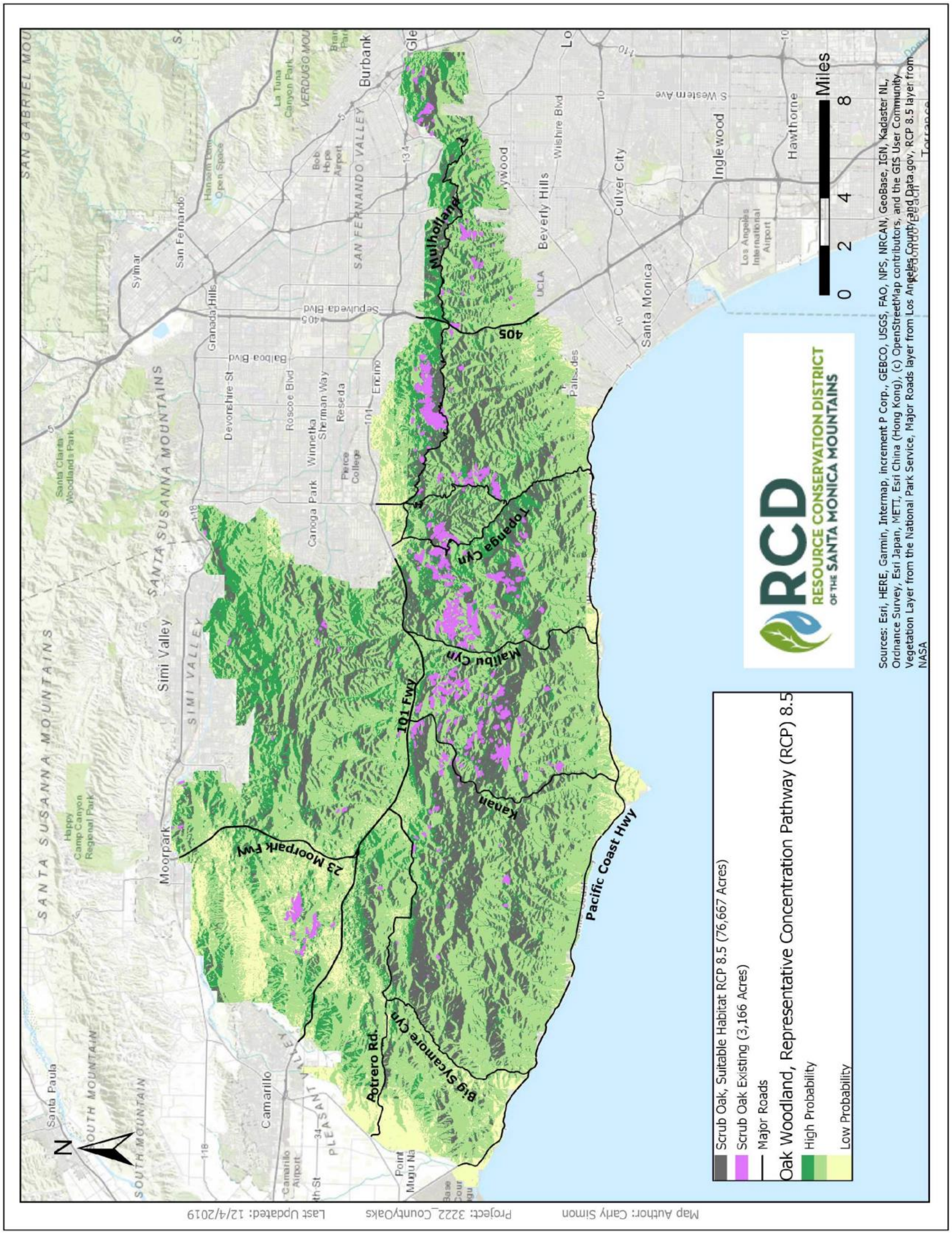
Scrub oaks have relatively thin bark, are easily charred and often top killed in a fire. They generate basal sprouts (Minnich et al. 1995). Fire return intervals less than 30 years are associated with lower recovery of mature adults, greater impacts on saplings and mixed results for seedling establishment (Fryer 2012). Scrub oak is often classified as a postfire obligate sprouter and can develop greater resistance to fire impacts following multiple resprouts over time (Keeley 1992, 2006).

Based on the NPS mapping data (2007) scrub oaks were found on over 3,166 acres throughout the SMMNRA. Scrub oaks support numerous other plant and animal species (Pavlik et al. 1991). They provide important habitat along wildlife corridor linkages especially along the ridgelines. Impacts from fragmentation due to urban development, some agriculture, and fuel modification can all be addressed with the priority planting plan.

As shown in Figure 8, scrub oaks are primarily clustered in the central and eastern parts of the SMMNRA at present and future climate projections suggest that they will be able to occur more widely throughout the SMMNRA with additional potential habitat spreading west. The existing distribution and the combined overlay of potentially suitable locations as well as predicted areas suitable given climate predictions, we recommend prioritizing planting of scrub oaks on public lands as noted in Table 7. Selection of actual planting locations will benefit from additional examination of the map online, to get more details of each location.

Table 7. Priority Planting Recommendations for Quercus berberidifolia (Shrub Oak) on public lands (2019).

Location	**Landowner**	**Notes**
Cheseboro Park	NPS	Replace trees lost to wildfire on upper slopes and expand to all but south and southeast facing slope areas.
Las Virgenes Open Space Preserve	MRCA	Replace trees lost to wildfire on upper slopes and expand to all but south and southeast facing slope areas.
Malibu Creek State Park, Bulldog Motorway	CDPR	Replace trees lost to wildfire on upper slopes and expand to all but south and southeast facing slope areas.
Leo Carrillo State Beach	CDPR	Replace areas lost to wildfire in upper watershed.
Malibu Creek State Park, Reagan Ranch	CDPR	Replace trees lost to wildfire on upper slopes and expand to all but south and southeast facing slope areas.
Topanga State Park, Hondo Canyon	CDPR	Replace trees lost to drought on upper slopes and expand to all but south and southeast facing slope areas.
Topanga State Park Trippett Ranch	CDPR	Replace trees lost to drought and beetles
All CDPR, MRCA and NPS lands with suitable habitat	CDPR, MRCA and NPS	Expand woodlands wherever appropriate based on analysis of site conditions.
Griffith Park	City of Los Angeles	Replace trees lost to wildfires and expand existing stands



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community Vegetation Layer from the National Park Service, Major Roads layer from Los Angeles County and Data.gov, RCP 8.5 layer from NASA

Figure 8. PRIORITY PLANTING SITES - Quercus berberidifolia (Scrub Oak).

6.2.3 Quercus lobata (Valley Oak)

Valley oaks reach the southernmost extent of their range in the SMMNRA, are endemic to California and are the largest deciduous oak species in North America (Pavlik et al. 1991). They are associated with deep, well-draining soils in floodplain locations having clay and fine-loamy soils adjacent to drainages providing access to the water table and are able to tolerate periodic flooding and inundation (Granholm et al. 1988). They show slight preference for slopes less than 25^{o} but isolated individuals are also present on ridgelines with northern and western aspects. Their tolerance for average maximum temperatures ranged from 20-24°C and evapotranspiration rates ranged from 238-343 mm.

Acorns are large and mature in one year. Valley oak seedlings take time to become established, with extensive root development occurring prior to above ground growth. Without supplemental water and maintenance of a weed free zone, seedling recruitment is low in natural settings. Browsing damage is common and both above and below ground protections enhance survival. Seedlings planted in association with other native plants that provide shade in the early years fare better (Griffin 1980).

<u>Propagation Notes:</u> Acorns are usually ripe in the fall between September and October depending on weather conditions. The most viable acorns are those gathered directly from the tree by twisting them gently from their cap, or by hitting them with a soft broom and gathering what falls on a tarp below. Each acorn needs to be inspected carefully to make sure there is no infestation or disease. They should be smooth and show no signs of holes or bumps. The next step is to drop them into a bucket of water. Discard any acorns that float to the top. Soak in mild bleach solution, keeping sinkers and removing floaters. Carefully dry those that sink to the bottom and store in a refrigerator until ready to plant within a few months (McCreary 2001).

Let the acorns dry and sow the same day or place into cold stratification in refrigerator, using ziploc bags, mixing acorns with propagation soil and tag with botanic name, collection date and location. Check bag every few weeks and sow when acorns start to germinate in bag in larger liners (3” x 8”), 20 to a tray. Sow acorns with pointed end in soil and blunt cup end above soil level. It is most important to keep freshly sown acorns safe from hungry and persistent rodents, and primarily ground squirrels, using hardware-cloth cages.

Transplant healthy saplings to treepots in spring and plant into oak woodland habitat the following fall. Alternately, direct sowing of acorns into habitat has great value by skipping the year required for the nursery propagation cycle while giving the oak an advantage of a more natural taproot developed w/o pruning. Protection from squirrels with caging is necessary to prevent feeding the grateful bushy tails.

Valley oaks have thick bark that is fire resistant and are able to recover from almost complete top burning, although burning of the root crown and trees with extensive basal cavities are not as resilient (Plumb et al. 1983). Trees under 66 cm can re-sprout from root crown as well as branches (Griffin 1976). Larger diameter trees are not as likely to crown sprout.

Based on the NPS mapping data (2007) valley oaks were found on approximately 1,000 acres throughout the SMMNRA, but further analysis suggests that drought and wildfire impacts have reduced that number in the wake of the Woolsey Fire (RCDSMM unpublished data). Valley oaks are also a keystone species supporting several thousand other plant and animal species (Pavlik et al. 1991). They provide important habitat along wildlife corridor linkages as well as in riparian zones. Impacts from fragmentation due to urban development, some agriculture, and fuel modification can all be addressed with the priority planting plan.

As shown in Figure 9, valley oaks have limited distribution at present and future climate projections suggest that their range will contract throughout the SMMNRA. Changes in extreme temperatures, lowering water tables associated with reduced precipitation and soil moisture suggest that their range will shift northwards and contract closer to accessible water tables (Hoagland et al. 2011).

The existing distribution and the combined overlay of potentially suitable locations as well as predicted areas suitable given climate predictions, we recommend prioritizing planting of valley oaks on public lands as noted in Table 8. Selection of actual planting locations will benefit from additional examination of the map online, to get more details of each location.

Table 8. Priority Planting Recommendations for Quercus lobata (Valley Oak) on public lands (2019).

Location	**Landowner**	**Notes**
Cheseboro Park	NPS	Replace trees lost to wildfire and develop multi aged stand
Las Virgenes Open Space Preserve	MRCA	Replace trees lost to wildfire and develop multi aged stand
Malibu Creek State Park, Bulldog Motorway	CDPR	Replace trees lost to wildfire and develop multi aged stand
Malibu Creek State Park, near Campsite	CDPR	Replace trees lost to wildfire and develop multi aged stand
Malibu Creek State Park, Reagan Ranch	CDPR	Replace trees lost to wildfire and develop multi aged stand
All state parks with suitable habitat	CDPR	Expand distribution
Paramount Ranch	NPS	Replace trees lost to wildfire and develop multi aged stand
Palo Comodo	NPS	Replace trees lost to wildfire and develop multi aged stand
Headwaters Corner	City of Calabasas	Replace trees lost to wildfire and develop multi aged stand
All CDPR, MRCA and NPS lands with suitable habitat	CDPR, MRCA and NPS	Expand woodlands wherever appropriate based on analysis of site conditions.

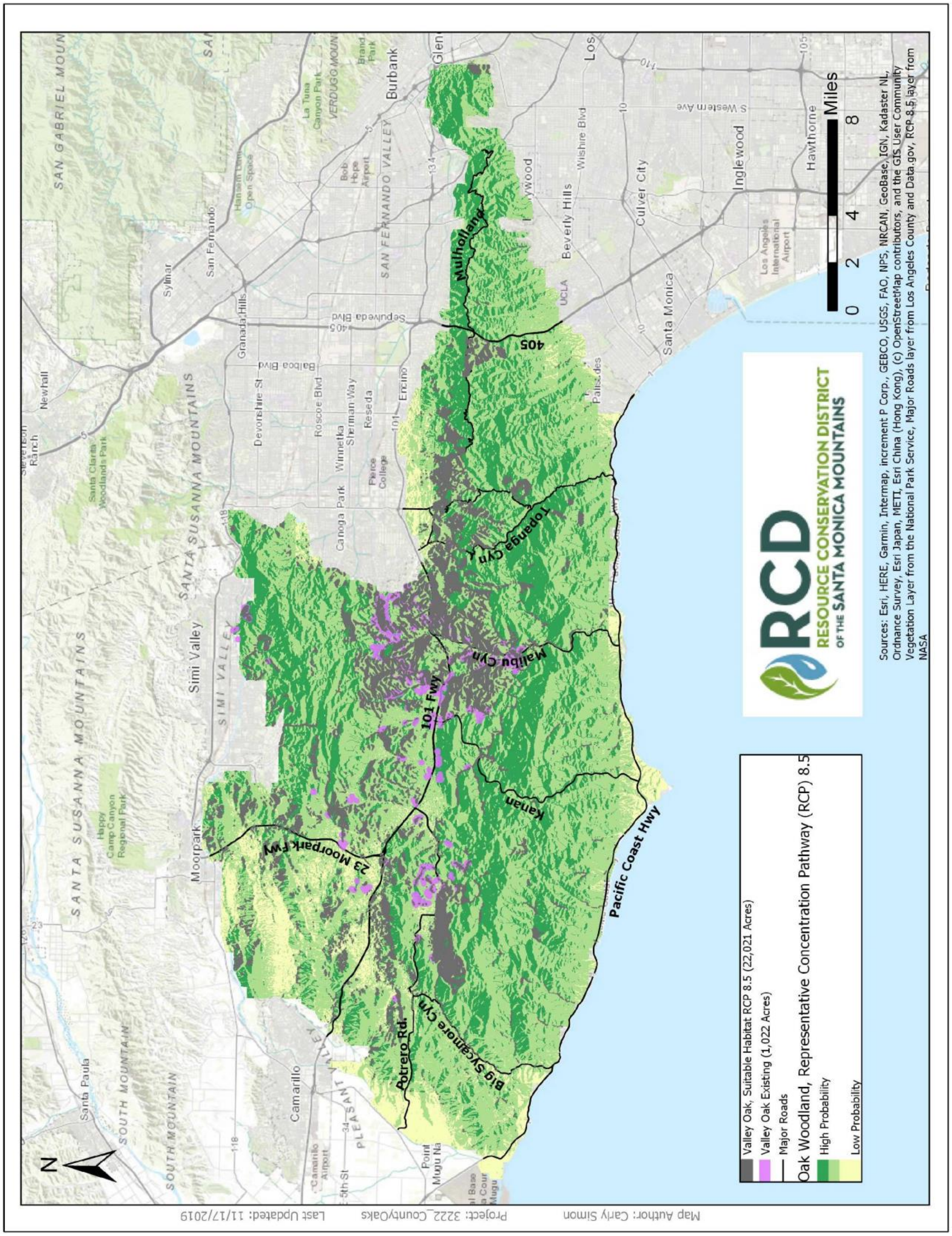


Figure 9. PRIORITY PLANTING SITES - Quercus lobata (Valley Oak).

6.2.4 Juglans californica (California Walnut)

California walnuts are often multi-stemmed bushy deciduous trees found in deep, fine loamy soils on a variety of moderate to steep slopes, and on occasion are also found closer to riparian areas. They have a fairly wide temperature tolerance (17-25^{o}C) and evapotranspiration range of 221-315 mm (Appendix C). Raven et al. (1989) found them widespread throughout oak woodlands and interspersed with chaparral on north slopes. Due to impacts from both development and an introduced disease (1000 canker disease), the California endemic species are listed as one of the rarer and threatened woodland communities (Barbour 1987, Esser 1993). California walnuts provide important habitat for many rodents and birds (Quinn 1990).

California walnut seeds are encased in a hard husk, and mature in the fall, although some fruits may remain attached to the tree year-round. Trees begin bearing fruit at 5-8 years of age and seed production is tied to adequate precipitation. Seeds germinate within 4 weeks of dispersal and gray squirrels may be an important dispersal agent in natural settings (Keeley 1990).

Propagation Notes:

Propagation is from nuts, collected from trees which produce every year, in fall months. Process the nuts by cleaning off husks (use gloves or hands will turn black). Soak nuts in mild bleach solution. Nuts that float are not viable and can be discarded. Sow in deep liners, with nuts placed below soil level to the depth of the seed diameter. Restrict access to rodents. Transplant healthy saplings to treepots in spring and plant into suitable habitat the following fall.

Calscape (CNPS) website recommends at least 22 weeks of stratification although fresh seeds may need less. Once seeds germinate, they should be planted out. California walnuts are excellent landscape trees and can be used for erosion control on slopes and best seedling establishment occurs in partial shade (Horton 1949, Perry 1989). They need space and can tolerate sun heat, smog, and drought. Propagation from nuts, collected from trees which produce every year, in fall months.

Wildfires can top kill California walnuts, but they are able to re-sprout from the root crown following fires (Quinn 1990, Sauer 1977).

Based on the NPS mapping data (2007) California walnuts were found on approximately 3,500 acres throughout the SMMNRA.

As shown in Figure 10, California walnuts have a limited distribution at present, concentrated in the upper watershed of Topanga and to the east towards Griffith Park. There are also fragmented stands in the upper Malibu Creek watershed and in scattered locations along the coastal canyon areas of Solstice Creek west to Trancas Creek. Future climate projections suggest that they will be able to occur more widely on south-west slope aspects in steeper canyons). They are often found in stands mixed with coast live oaks. Outside of the Santa Monica Mountains, California walnuts are concentrated in the Santa Clarita, Simi Hills and San Jose Hills. Their range extends as far north as Santa Barbara and south into San Diego, although stands are small and fragmented.

The existing distribution and the combined overlay of potentially suitable locations as well as predicted areas suitable given climate predictions, we recommend prioritizing planting of California walnuts on public lands as noted in Table 9. Selection of actual planting locations will benefit from additional examination of the map online, to get more details of each location.

Table 9. Priority Planting Recommendations for Juglans californica (California Walnut) on public lands (2019).

Location	**Landowner**	**Notes**
Ed Edelman Park, upper Topanga Canyon	MRCA	Augment shrinking walnut woodlands impacted by car fires.
Wild Walnut Park	City of Calabasas	Augment shrinking walnut woodlands impacted by fires and fuel modification
Dry Creek Canyon Park	MRCA	Augment shrinking walnut woodlands impacted by fires and fuel modification
Areas north of the 101 and east of the 405	Various	Augment shrinking walnut woodlands impacted by fires and fuel modification
All CDPR, MRCA and NPS lands with suitable habitat	CDPR, MRCA and NPS	Expand woodlands wherever appropriate based on analysis of site conditions.
Griffith Park, Vermont Canyon, Fern Canyon, Brush Canyon and Commonwealth Canyon	City of Los Angeles	Replace trees lost to wildfires, especially on east facing slopes and expand existing stands

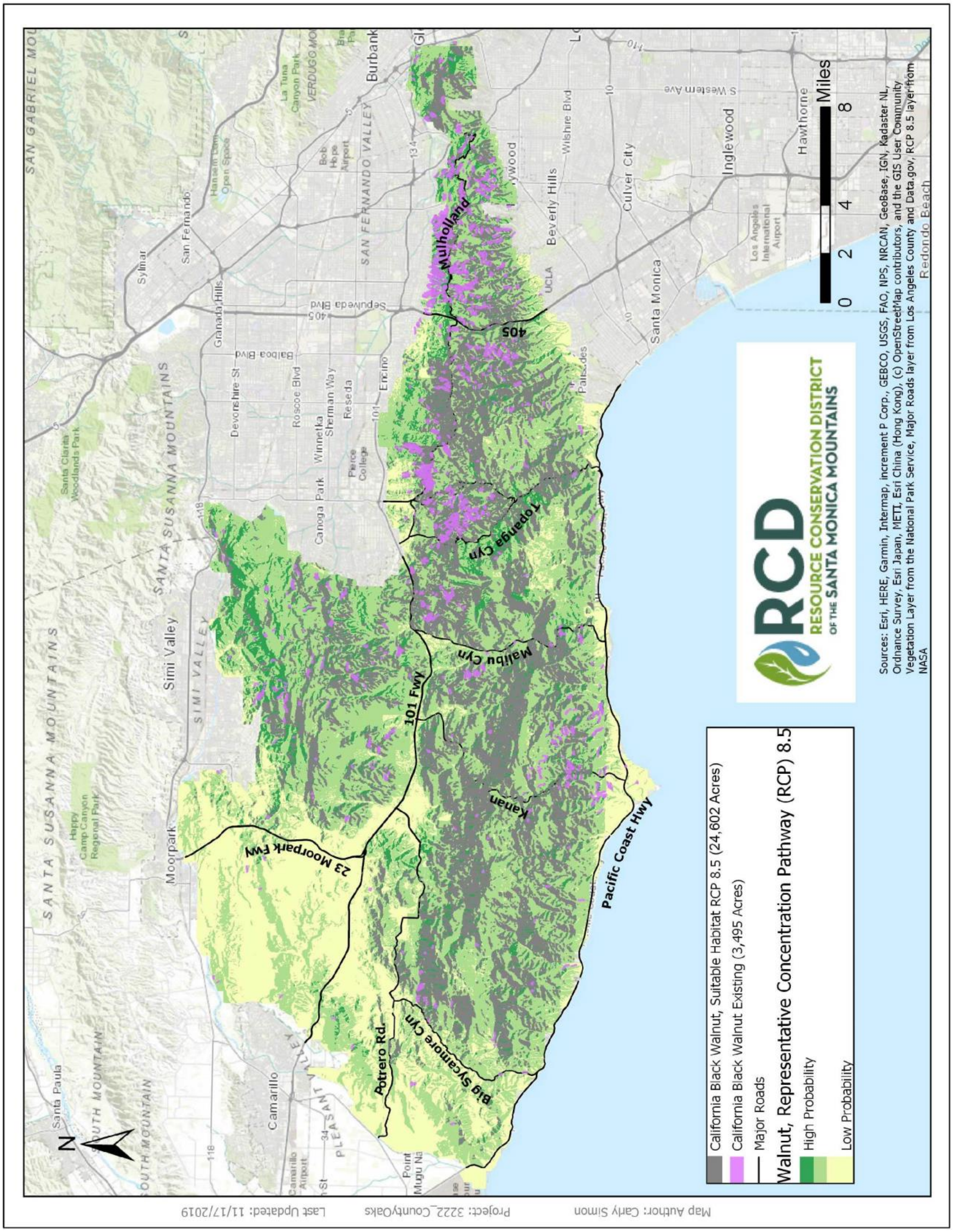


Figure 10. PRIORITY PLANTING SITES - Juglans californica (CA Walnut).

6.2.5 Umbellularia californica (California Bay Laurel)

California bay laurel trees range from southern Oregon south to the central coast of California, where they then become fragmented and are found in suitable drainage areas south to the border with Mexico. There are few pure stands, and in the SMMNRA they are concentrated in upper drainages on steeper slopes mixed with coast live oak and often are a transition between mesic sites and adjacent xeric chaparral, sometimes occurring on more exposed ridges (Raven et al. 1989). They are found in zones with temperatures ranging from 17-22°C and evapotranspiration rates of 228-301 mm.

Fruits of the bay laurel are drupes containing one large seed. Trees do not begin producing seeds until they are more than 30 years old. Seeds are produced in most years ripening in the fall and naturally disseminated over the winter.

Propagation Notes:

Propagation is from bay nuts collected from trees in fall when the fruit is dark purple and seed inside is dark brown. Husk needs to be removed and the seed cracked slightly to encourage faster germination. Remove fruit to expose seed and place cleaned seed into cold stratification until sowing (same method as oaks). Cold stratification in a mix of equal parts slightly moist sphagnum peat and perlite for 3-4 months. Nuts can be sown in deep liners (2” x 7”). Nuts should be buried to depth of seed diameter. Apical germination is delayed for *Umbellularia* until late winter/early spring. Transplant healthy saplings to treepots in late spring or following fall. Seedlings need to be hardened off before installing in a wildland setting. California bay laurel seeds do not require stratification or scarification, but germination rates improve with 2-3 months of cold storage (Stein 1974). Seedlings do better in mesic conditions, outside the driplines of other mature bay laurel trees when transplanted at less than a year.

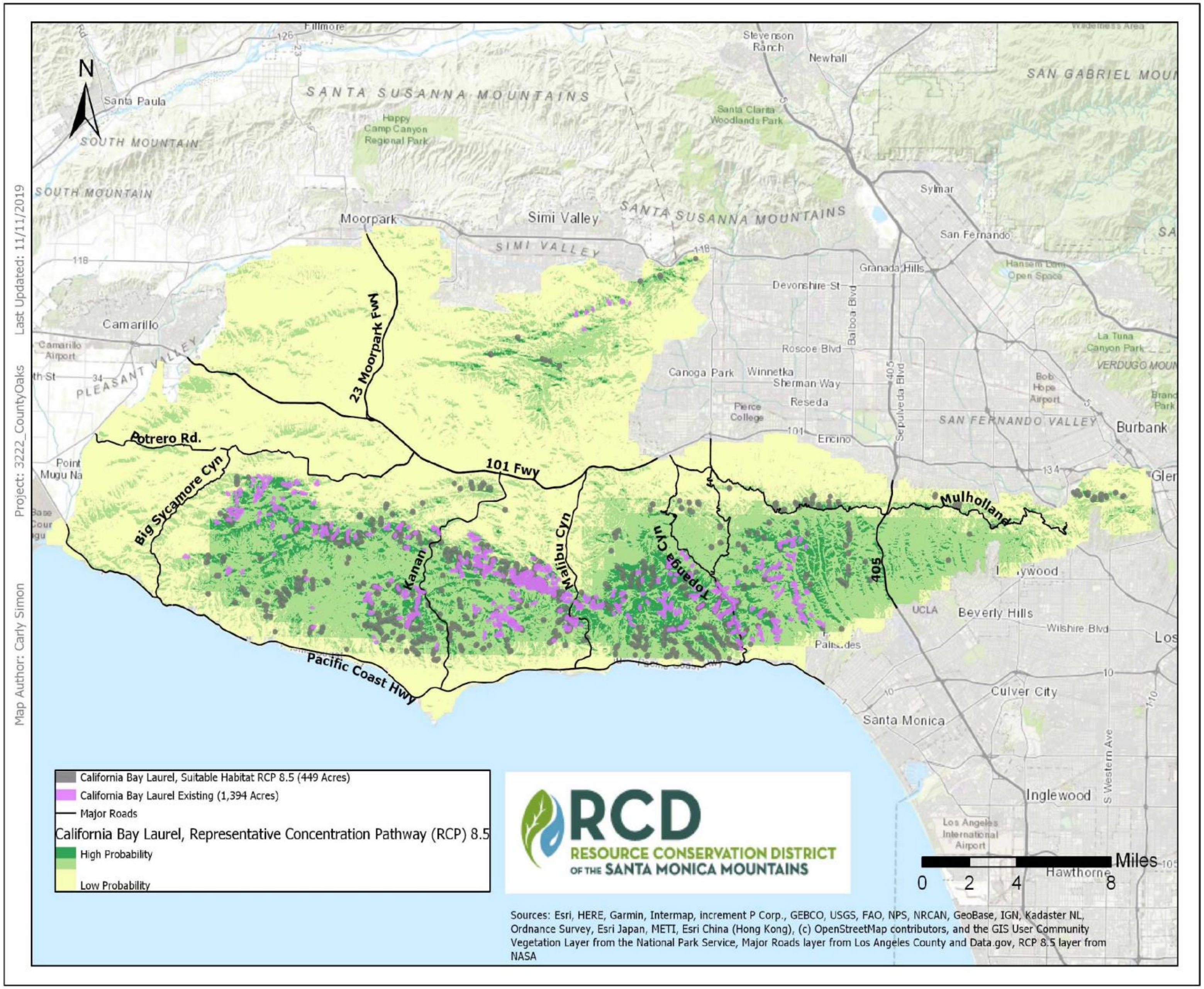
Burned California bay laurel trees can re-sprout from the crowns, and light to moderate fire may slightly increase germination (Mirov et al. 1937). As with coast live oak, bay laurels are less flammable than many other species and their tall, thick canopies can reduce ember spread (Rice 1990).

Based on the NPS mapping data (2007) California bay laurels were found on over 1,300 acres throughout the SMMNRA. As shown in Figure 11, California bay laurels are concentrated in upper watershed interior riparian zones and future climate projections suggest that they will be able to occur in the more mesic north facing slopes throughout the SMMNRA, although the highest suitability areas are found along coastal drainages between Malibu and Topanga Creeks, and in the western watersheds from Zuma to Arroyo Sequit Creeks. Additional healthy stands that appear to be recruiting naturally are found throughout Griffith Park (G. Hans, personal communication December 2019).

The existing distribution and the combined overlay of potentially suitable locations as well as predicted areas suitable given climate predictions, we recommend prioritizing planting of California bay laurels on public lands as noted in Table 10. Selection of actual planting locations will benefit from additional examination of the map online, to get more details of each location.

Table 10. Priority Planting Recommendations for Umbellularia californica (California Bay Laurel) on public lands (2019).

Location	**Landowner**	**Notes**
Malibu Creek State Park, Tapia area	CDPR	Along drainages
Malibu Creek State Park, upper drainages	CDPR	Along drainages
Zuma Creek	NPS	Along drainages
Trancas Creek	NPS	Along drainages
Leo Carrillo State Park	CDPR	Along drainages
Big Sycamore State Park drainages	CDPR	Along drainages
Rancho Sierra Vista Satwiwa	NPS	Along drainages
La Sierra Canyon Preserve	Varied	Along drainages
Cold Creek Valley Preserve	Varied	Along drainages
All CDPR, MRCA and NPS lands with suitable habitat	CDPR, MRCA and NPS	Expand woodlands wherever appropriate based on analysis of site conditions.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community
Vegetation Layer from the National Park Service, Major Roads layer from Los Angeles County and Data.gov, RCP 8.5 layer from NASA

Map Author: Carly Simon Project: 3222_CountyOaks Last Updated: 11/11/2019

Figure 11. PRIORITY PLANTING SITES - Umbellularia californica (CA Bay Laurel).

6.3 Riparian Guild Species Analysis:

The dominant species of native trees found in the riparian areas within the SMMNRA include *Acer macrophyllum, Acer negundo, Alnus rhombifolia, Platanus racemosa, Populus fremontii ssp. fremontii, Populus trichocarpa, Salix gooddingii, S. laevigata, S. lasiandra var. lasiandra,* and *S. lasiolepis* (NPS Vegetation Survey 2007). All of these species prefer canyon bottoms and slopes with deep canyon shading, and require perennial water augmented by rain. They are well adapted to variable hydrologic patterns but if water tables drop too far, recovery can be very slow without intervention (EcoAdapt 2017). Distribution of these species was heavily impacted by the Woolsey Fire (2018) when many riparian areas were significantly burned, resulting in widespread mortality (RCDSMM unpublished data). On-going sediment deposition post fire has impaired recovery within the stream channels and degraded bank stability. These species are widespread from the coast to cismontane but require root access to high water tables, periodic flooding and have associated mesic vegetation assemblages.

Due to little available data on distribution and abundance, *S. gooddingii*, and *S. laevigata* were not individually mapped. Raven et al. (1989) found *S. laevigata* as common in all riparian woodlands but it was not found in the NPS Vegetation Survey (2007) as a dominant vegetation class.

These species typically recruit in pulses following flood events that distribute seeds throughout the flood zone (Boland 2018, Stein 1974). While some recovery and seed recruitment has been observed (Dagit, unpublished data), the massive loss of mature trees may inhibit reproduction until the burned trees recover. Due to the limitations associated with establishing seedlings, riparian species are considered to have low adaptive capacity levels, limited geographic extent, moderate resistance and recovery potential (EcoAdpat 2017, Thorne et al. 2016). Continued monitoring to identify areas where natural recruitment is not occurring is needed.

Riparian habitats are considered to have moderate to high sensitivity to potential climate changes and moderate adaptive capacity (EcoAdapt 2017). Examination of future flow conditions suggests a significant contraction of surface flow, reduced precipitation along the coast and a general retreat to upper drainages (Taylor et al. 2019). As can be seen in the climate maps below prepared for each species, there is an overall loss of potentially suitable habitat in the future. This is a concern as these riparian species are important habitat for a variety of aquatic and bird species. Because the range of suitable parameters for riparian species are more clearly defined, our confidence in the potential range maps is fairly high, especially as the surface flow predictions modeled by Taylor et al. (2019) show similar suitable areas.

Threats identified for riparian species include decreased precipitation, soil moisture, and lower water tables, drought, and wildfires. While land conversion due to development reduces the amount of infiltration, increased impervious surfaces can ironically provide increased surface flows as well.

Calscape (https://calscape.org/) provides a wealth of information on distribution and planting details for each of these species including suggested companion plants and uses by wildlife. Local experts Tom Hayduk (Nursery Manager and Seed Collector, CDPR) and Jack Smith

(TreePeople Nursery Manager) provided additional notes on locally appropriate methods of propagation.

6.3.1 Acer macrophyllum **(Big Leaf Maple)**

Big leaf maples in southern California are at the southern end of their range and typically are found in higher elevation drainages and canyons. Although they prefer mesic soils, they are also found in some higher slope canyon areas that have fine loamy soils. In the SMMNRA they are only mapped in the Topanga Creek Watershed, but records of isolated trees in other watersheds suggest that there is much we are missing about the distribution of this species. Raven et al. 1989 noted a locally abundant distribution from Rustic Canyon on the east, west to Sycamore Canyon. Additional effort to map current locations of these trees is needed. Tom Hayduk knew only of a few trees in Cold Creek (MRCA land) and in lower Topanga Canyon (seed collected by David Ecklund from canyon below lumber yard/RCD office was successfully grown at Soka BRCN ~20 years ago). Big leaf maples provide food and cover for a variety of birds and mammals and can enhance stream structure for steelhead when they become woody debris in the channel (Fryer 2011).

Based on the limited information available, deciduous big leaf maples were found on north facing gentle to steep slopes with average temperature maximums ranging from 21-25^{o}C and evapotranspiration ranging from 262-308 mm.

Seeds are pollinated by a variety of insects including bees, flies and beetles; the trees are dioecious (produce two types of flowers on each individual tree) (Arno 1977) and do not produce seeds until they are about 10 years old. Seeds are samaras dispersed naturally by the wind. They overwinter in the soil and germinate in later winter/spring but seedlings need access to the water table in order to become established (Collingwood and Brush 1964).

Propagation Notes:

Propagation is from seed, which are found in clusters (samaras) in upper tree canopy. Seed is not easy to collect, and trees are not easily found at the right time to harvest. Seed can be placed in cold stratification or sown outdoors in a propagation flat, lightly covered with soil, with some protection from rodents. Fresh seeds do best with 1.5-2 months of stratification. Natural seedling establishment is best in more open areas with mesic soils (Collingwood and Brush 1964).

Adult trees have relatively thin bark and burn easily but they can re-sprout from the crown following top killing by wildfires and grow relatively quickly, especially on more open sites (Pojar and MacKinnon 1994).

Based on the NPS mapping data (2007) and CalFlora herbarium reports big leaf maple were extremely limited in distribution throughout the SMMNRA and were not reported by NPS (2007). Point data from herbarium collections shows that the majority of reports come from the Topanga Creek drainage, although a few trees have been observed in Tuna Creek and scattered in other coastal creeks (RCDSMM unpublished data).

As shown in Figure 12, big leaf maple is rare at present, although future climate projections suggest that they could occur more widely in the coastal drainages throughout the SMMNRA.

The existing distribution and the combined overlay of potentially suitable locations as well as predicted areas suitable given climate predictions, we recommend prioritizing planting of big leaf maple on public lands as noted in Table 11. Selection of actual planting locations will benefit from additional examination of the map online, to get more details of each location.

Table 11. Priority Planting Recommendations for Acer macrophyllum (Big Leaf Maple) on public lands (2019).

Location	**Landowner**	**Notes**
Lower Topanga State Park	CDPR	Adjacent to creek and minor drainages.
Las Flores Creek	Varied	Adjacent to creek and minor drainages.
Solstice Creek	NPS	Adjacent to creek and minor drainages.
Malibu Creek	CDPR	Adjacent to creek and minor drainages.
Arroyo Sequit Creek	CDPR	Adjacent to creek and minor drainages.
Temescal Canyon	MRCA	Adjacent to creek and minor drainages.
Cold Creek Canyon	Various	Adjacent to creek and minor drainages.
Las Virgenes Open Space Preserve	MRCA	Adjacent to creek and minor drainages.
Paramount Ranch	NPS	Adjacent to creek and minor drainages.
Trancas Creek	NPS	Adjacent to creek and minor drainages.
Zuma Creek	NPS	Adjacent to creek and minor drainages.
Mishi Mowka Trail area Sandstone Peak	NPS	Adjacent to creek and minor drainages.
Pt Mugu State Park	CDPR	Adjacent to creek and minor drainages.
La Sierra Canyon Preserve	Varied	Adjacent to creek and minor drainages.
All CDPR, MRCA and NPS lands with suitable habitat	CDPR, MRCA and NPS	Expand woodlands wherever appropriate based on analysis of site conditions.

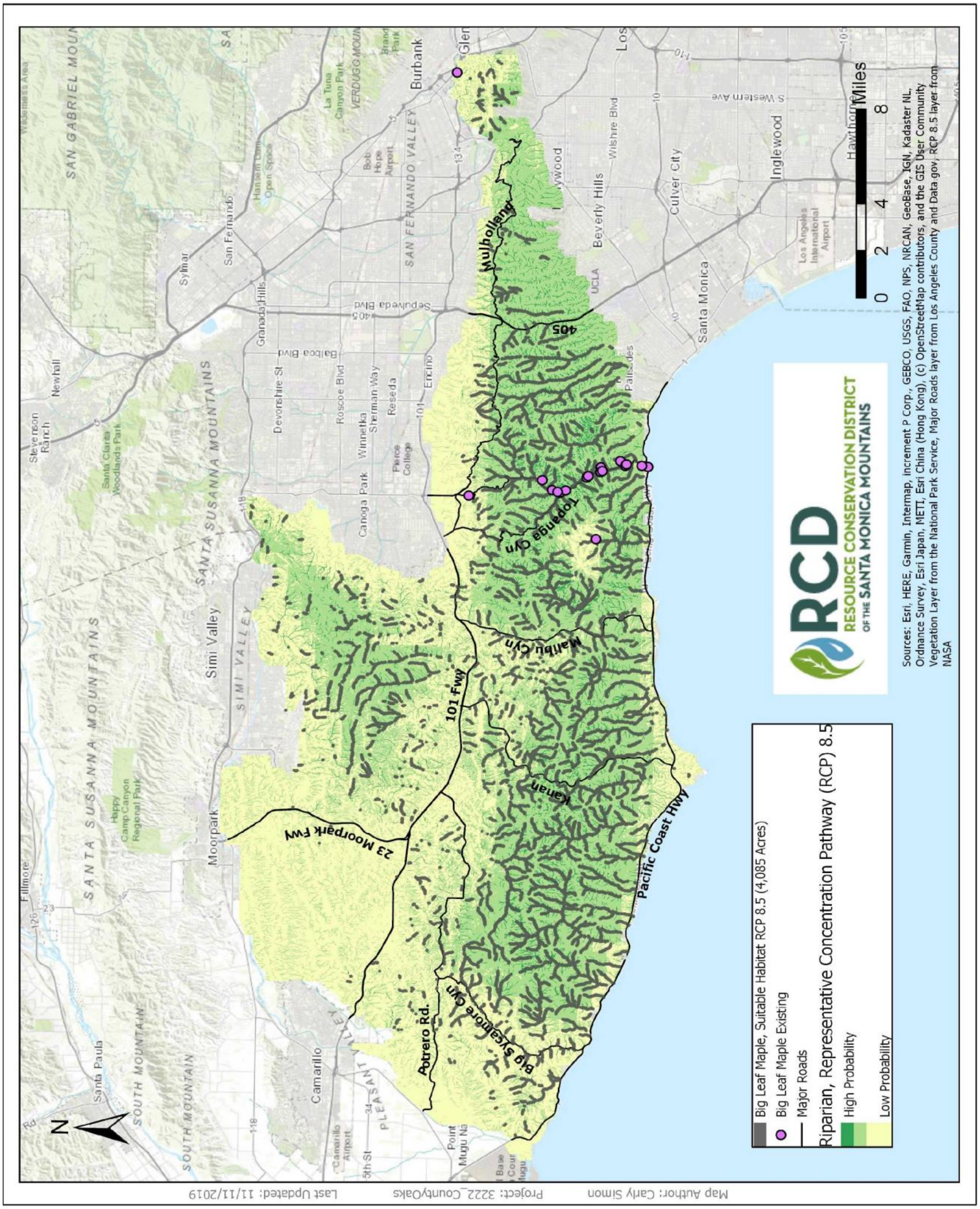


Figure 12. PRIORITY PLANTING SITES - Acer macrophyllum (Big Leaf Maple).

6.3.2 *Acer negundo* (Box Elder)

Records of box elder in the SMMNRA are extremely limited and herbarium records from Topanga Creek were the only ones found, although reports of these trees in other areas of Calabasas suggest that although rare, they are present elsewhere (R. Burnap, S. Goode, personal communication, November 2019). Raven et al. (1989) recorded trees in the Cold Creek and Malibu Creek watersheds but suggest that they may have been introduced. These large drought-tolerant deciduous trees are sometimes used in urban landscapes and are found throughout most of the United States (Rosario 1988). It is the only maple with divided leaves and is not thought to live more than 100 years. Throughout their range they are found primarily in mesic areas along creeks and floodplains where shallow roots can access the water table (Olson and Gabriel 1974). They are found in a variety of climate regimes and are most often found in communities of cottonwood and willow (Rosario 1988).

Box elder reproduces through massive annual seed crops dispersed both by wind and birds. Samaras have two fused winged segments that separate upon shedding when mature in the fall. Each contains a single seed (Olson and Gabriel 1974).

Propagation Notes:

Flowers occur in the spring as the leaves bud out. Seeds ripen by fall. Propagation is similar to that for big-leaf maple. Calscape recommends scarification and 203 months stratification for fresh seeds.

Box elder trees have thin bark and are injured by wildfires but can re-sprout from the root crown or stump but little data on their regeneration in southern California was found.

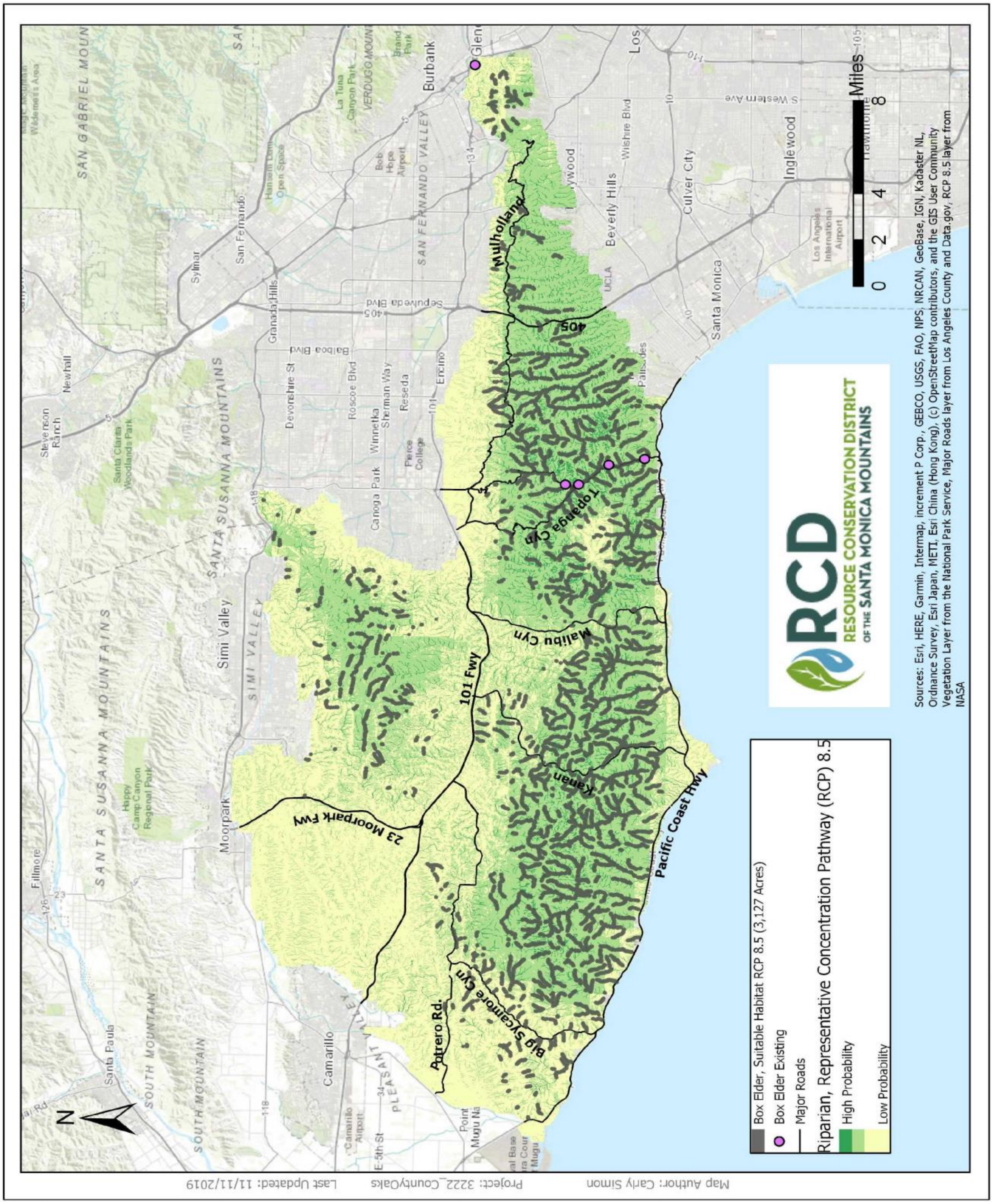
Based on the Calflora data, box elder trees were found at four locations in Topanga Creek (Figure 13) and were not recorded by NPS (2007). Based on the very limited data guiding the habitat suitability model based on those locations, potentially suitable habitat could be found in many of the coastal drainages closer to the beach. However, our confidence in these analyses is low and there needs to be much more analysis to develop better criteria for identifying potential planting sites.

Selection of actual planting locations will benefit from additional examination of the map online, to get more details of each location. Due to the limitations of location data, we recommend co-locating planted trees in shaded riparian corridors with cottonwoods and willows to see how they fare over time.

Table 12. Priority Planting Recommendations for Acer negundo (Box Elder) on public lands (2019).

Location	**Landowner**	**Notes**
Lower Topanga State Park	CDPR	Adjacent to creek and minor drainages.
Las Flores Creek	Varied	Adjacent to creek and minor drainages.
Solstice Creek	NPS	Adjacent to creek and minor drainages.
Arroyo Sequit Creek	CDPR	Adjacent to creek and minor drainages.
Trancas Creek	NPS	Adjacent to creek and minor drainages.
Zuma Creek	NPS	Adjacent to creek and minor drainages.

Sullivan Ridge Fire Road	MRCA	Adjacent to creek and minor drainages.
Encino Reservoir	MRCA	Adjacent to creek and minor drainages.
All CDPR, MRCA and NPS lands with suitable habitat	CDPR, MRCA and NPS	Expand woodlands wherever appropriate based on analysis of site conditions.



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Map Author: Carly Simon Project: 3222_CountyOaks Last Updated: 11/11/2019

Figure 13. PRIORITY PLANTING SITES - Acer negundo (Box Elder).

6.3.3 Alnus rhombifolia (White Alder)

White alders are found throughout the western US and throughout most of California. Raven et al. (1989) found them throughout the central portion of the SMMNRA along permanent streams where they are considered obligate riparian species in drier areas. These are fast growing deciduous trees especially when planted near permanent water sources and often reach 15-25 meters in height. Based on the NPS Vegetation Survey (2007), they were found primarily on north facing slopes in areas with average maximum temperatures of 21-22ºC and a narrow evapotranspiration range of 258-279 mm usually closer to the stream banks.). White alders are limited in distribution in SMMNRA to permanent streams and are common in Solstice Canyon but less common in Malibu Canyon (T. Hayduk, personal communication, December 2019). They are tolerant to flooding and provide important bank stabilization. White alders provide important habitat for many birds, especially least Bell's vireo (Gray and Greaves 1984) and southwestern willow flycatchers (USFWS 2002).

Flowers are produced in catkins in early spring before the leaves emerge. Wind pollinated female catkins are ovoid and male catkins are pendulous. Small winged seeds are held in cone-like fruits dispersing throughout the winter. Seeds are primarily dispersed by wind and typically only last for a few months.

Propagation Notes:

Propagation is from seed, which is easy to collect when the cone-like fruit is found on trees in summer/fall/winter. Seeds germinate well on sunny, wet mineral soils but viability drops rapidly. A 3-month stratification process increased germination (Dill and Heuser 1987). They require continuous moisture and naturally establish above the scour zone. White alder growth rate is associated with access to the water table and they are subject to browsing impacts from deer. According to Tom Hayduk, a recent propagation attempt from cuttings taken in lower Topanga Canyon was unsuccessful.

White alder trees are not fire resistant and while there is some root crown sprouting after being top-killed, studies have shown that it can take many years for stands to recover especially if the mature adult trees are dead (Davis et al. 1989). Many of the adult trees lost to the Woolsey Fire are not showing signs of recovery and few seedlings have been observed (RCDSMM unpublished data). Active restoration of this species post fire is recommended.

Based on the NPS mapping data (2007) white alders were found on only 67 acres throughout the SMMNRA. As shown in Figure 13, white alder trees are quite limited in their present distribution although future climate projections suggest that they will be able to occur more widely throughout the SMMNRA.

The existing distribution and the combined overlay of potentially suitable locations as well as predicted areas suitable given climate predictions, we recommend prioritizing planting of white alder on public lands as noted in Table 12. Selection of actual planting locations will benefit from additional examination of the map online, to get more details of each location.

Table 12. Priority Planting Recommendations for Alnus rhombifolia (White Alder) on public lands (2019).

Location	**Landowner**	**Notes**
Arroyo Sequit Creek	CDPR	Adjacent to creek and minor drainages.
Temescal Canyon	MRCA	Adjacent to creek and minor drainages.
Cold Creek Canyon	Various	Adjacent to creek and minor drainages.
Las Virgenes Open Space Preserve	MRCA	Adjacent to creek and minor drainages.
Cheeseboro/Palo Comado Canyons	NPS	Adjacent to creek and minor drainages.
Oak Park Open Space	RSRPD	Adjacent to creek and minor drainages.
Paramount Ranch	NPS	Adjacent to creek and minor drainages.
Trancas Creek	NPS	Adjacent to creek and minor drainages.
Zuma Creek	NPS	Adjacent to creek and minor drainages.
Mishi Mowka Trail area Sandstone Peak	NPS	Adjacent to creek and minor drainages.
Pt Mugu State Park	CDPR	Adjacent to creek and minor drainages.
Cold Creek Valley Preserve	Varied	Adjacent to creek and minor drainages.
All CDPR, MRCA and NPS lands with suitable habitat	CDPR, MRCA and NPS	Expand woodlands wherever appropriate based on analysis of site conditions.

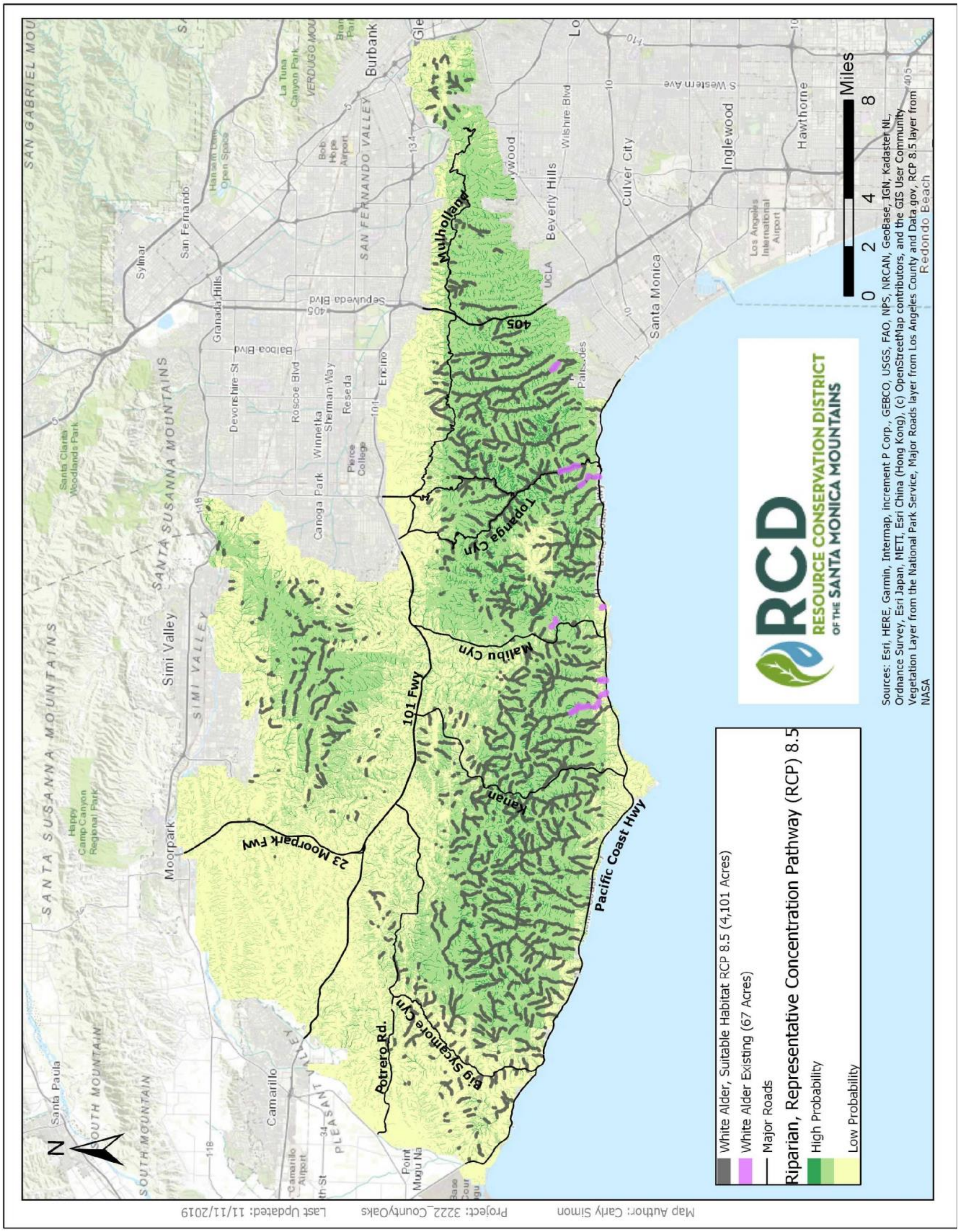


Figure 13. PRIORITY PLANTING SITES – Alnus rhombifolia (White Alder).

6.3.4 Platanus racemosa (California/Western Sycamore)

California sycamores were historically more widespread in riparian areas throughout California and Raven et al. (1989) found them common along stream channels and moist areas throughout the SMMNRA. The abundance and distribution of these large deciduous trees has constricted in the past two decades due to a combination of drought, disease, invasive beetles, and wildfires leaving approximately 3,000 acres where they are the dominant vegetation (NPS Vegetation Survey 2007). Typically found in areas where the water table is accessible, they occur most commonly on gentle to moderate north facing slopes in areas having average maximum temperatures ranging from 18-25°C and evapotranspiration ranging from 226-324 mm.

California sycamores provide important habitat for a variety of nesting birds as well as aquatic species such as western pond turtles and southern steelhead trout. Their roots stabilize creek banks and can survive flooding (SFEI 2017).

Following leaf out, the round and spiny achene fruits form in clusters in the spring. They mature on the trees and disperse nearby when they fall off in the late fall unless carried downstream by winter rains (T. Hyaduk unpublished data).

Propagation Notes:

Propagation of California sycamore is typically done from seed which is easy to collect from trees. Dry seed is best stored in paper bags before cleaning and not plastic ziplocs to avoid mold. The seed balls can be pounded with a mallet or broken up by hand and the seed separated from the fluff. Two months cold stratification will improve germination while sowing outdoors in fall also works well. Good results from sowing in both propagation flats and deep liners. Sycamores can also be grown from cuttings, not surprising given the trees are found in soils that fluctuate in height after each flood event.

Calscape recommends 2-3 months stratification. SFEI (2017) found that sycamores were most likely to naturally establish on gravel bars and along the edges of the banks and recommend that both seedlings and cuttings be installed where there is root access to permanent water.

There was little specific information found regarding the response of sycamores to fire, but observations from the Woolsey Fire (2018) indicate that mature trees can re-sprout both from the root crown, trunk and branches following complete burn.

As shown in Figure 15, California sycamores are not abundant at present and future climate projections suggest that they will be able to occur only in the more north facing drainages along riparian corridors near the coast in the SMMNRA. Although most of the suitable habitat is close to the coast, there is an area within the Las Virgenes Open Space Preserve and along those drainages that also might provide opportunities.

The existing distribution and the combined overlay of potentially suitable locations as well as predicted areas suitable given climate predictions, we recommend prioritizing planting of California sycamores on public lands as noted in Table 14. Selection of actual planting locations will benefit from additional examination of the map online, to get more details of each location.

Table 14. Priority Planting Recommendations for Platanus racemose (California Sycamore) on public lands (2019).

Location	Landowner	Notes
Lower Topanga State Park	CDPR	Adjacent to creek in lower canyon areas.
Las Flores Creek	Varied	Adjacent to creek in lower canyon areas.
Solstice Creek	NPS	Adjacent to creek in lower canyon areas.
Malibu Creek	CDPR	Adjacent to creek in lower canyon areas.
Las Virgenes Open Space Preserve	MRCA	Adjacent to creek in lower canyon areas.
Arroyo Sequit Creek	CDPR	Adjacent to creek in lower canyon areas.
La Sierra Canyon Preserve	Varied	Adjacent to creek in lower canyon areas.
Cold Creek Valley Preserve	Varied	Adjacent to creek in lower canyon areas.
All CDPR, MRCA and NPS lands with suitable habitat	CDPR, MRCA and NPS	Expand woodlands wherever appropriate based on analysis of site conditions.
Griffith Park- canyon areas, such as Brush Canyon	City of Los Angeles	Replace trees lost to wildfires and invasive beetles

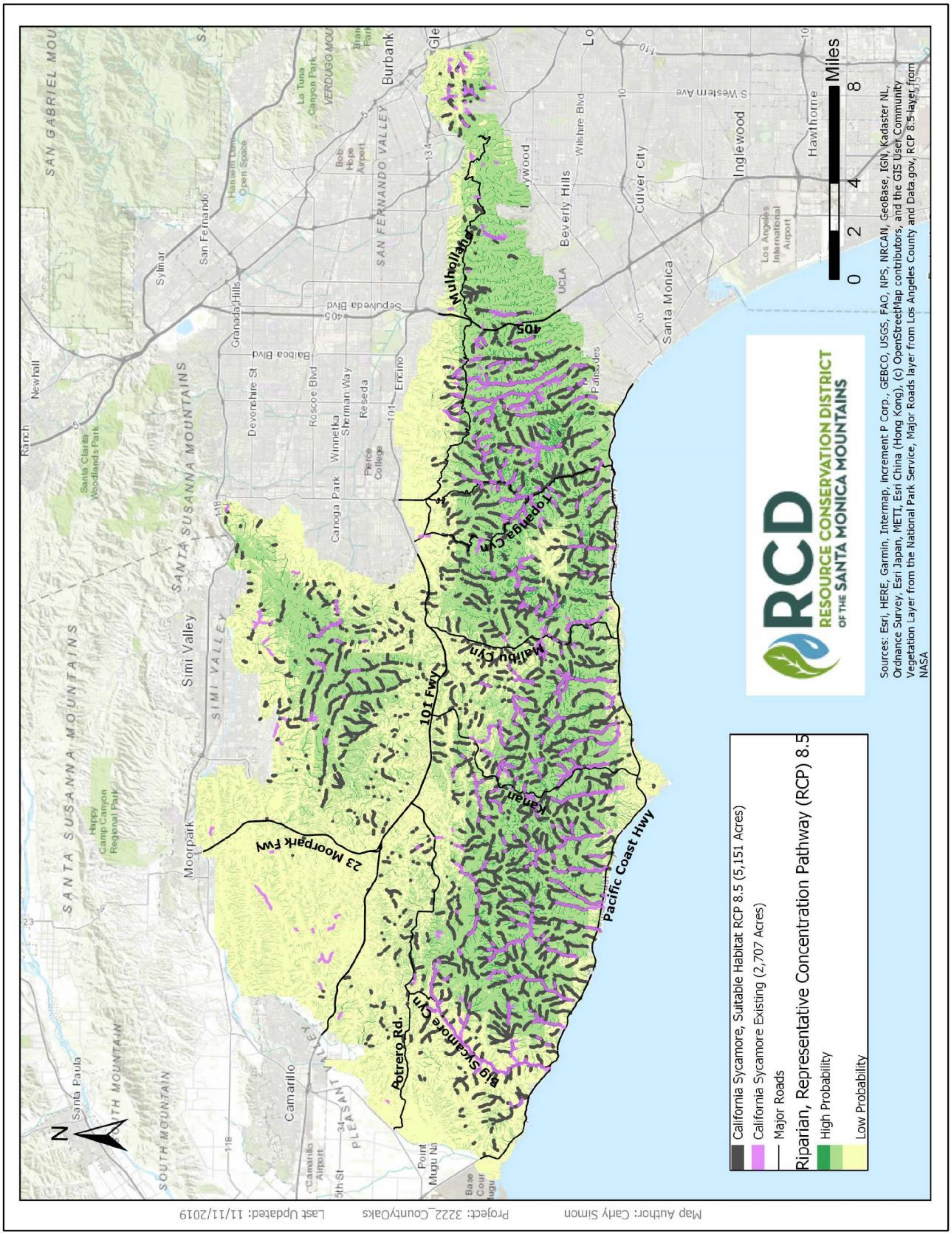


Figure 15. PRIORITY PLANTING SITES - Platanus racemosa (California Sycamore).

6.3.5 Populus fremontii (Fremont Cottonwood)

Fremont cottonwoods are fast growing, large deciduous trees scattered in riparian corridors throughout the SMMNRA (Raven et al. 1989) although they are found throughout much of California coastal ranges and in the central valley. Recent records are very sparse. They tolerate fairly warm temperatures (average maximum from 21-25ºC) and based on the few sample locations documented have evapotranspiration ranging from 232-290 mm. They are mostly found along floodplains and alluvial deposits with good soil drainage. Groves of cottonwoods are often indication of high and available water table.

Raven et al. (1989) also recorded few individuals of *P. trichocarpa* (black cottonwood) in low elevation riparian corridors in Malibu, Topanga and Arroyo Sequit canyons. They are not described individually due to lack of sufficient data on current distribution although they are a possible species for restoration planting.

Cottonwoods are often co-located with a variety of willow species and together provide significant canopy cover used by a wide range of birds, especially for breeding (England et al. 1984). They also provide important bank stabilization and erosion control and depend on episodic flooding for recruitment of new seedlings.

Flowers bloom in catkins in spring on trees that take more than five years to mature, and the fruit is a wind dispersed achene that looks like tufts of cotton on the end of branches. Most reproduction occurs due to seeding following flood events (Brothers 1984).

Propagation Notes:

Propagation is usually from cuttings, either short stem cuttings for rooting in the nursery or longer pole cuttings when planting directly into the ground. All Populus are dioecious with male and female catkins born on separate trees so multiple trees are required to establish both male and female plants. Pole cuttings are generally taken in winter when trees are going dormant. Poles selected should be straight and vigorous, without any deadwood attached, which has been a problem with riparian trees lately in SMMNRA with drought. The bottom cut of pole cutting should be angled to ease pounding the pole into the ground. The length of the pole to be prepped will depend on the depth of the holes to be dug plus one foot left aboveground. After holes are dug and poles are pounded into the ground, the extra length of pole over one foot in length should be cut back to focus growth into lower shoots. Fremont cottonwood are generally found as single specimen trees and black cottonwoods are always found in groves, as trees can also spread by underground rhizomes. Populus can also be potentially grown from cottony seed collected from female plants and sown promptly as seed is short-lived.

Calflora notes that stem cuttings are the easiest method of propagation and that fresh seeds are only viable for a few weeks (Horton and Campbell 1974). They require no treatment and should be placed on top of the saturated growing medium rather than covered or pressed in. These trees do best planted where access to a perennial water table. Cottonwoods are shade intolerant and need full sun for establishment.

Re-sprouting following fire is common and low intensity fires may support seedling recruitment by opening gaps increasing light available (Stromberg 1993).

As shown in Figure 16, Fremont cottonwoods are not commonly recorded at present (a few records in Malibu Creek area and the Topanga Creek watershed) and future climate projections suggest that they will be able to occur in a narrow habitat zone along perennial drainages throughout both the interior and the coastal portion of the SMMNRA.

The existing distribution and the combined overlay of potentially suitable locations as well as predicted areas suitable given climate predictions, we recommend prioritizing planting of Fremont cottonwoods on public lands as noted in Table 15. Selection of actual planting locations will benefit from additional examination of the map online, to get more details of each location.

Table 15. Priority Planting Recommendations for Populus fremontii (Fremont Cottonwood) on public lands (2019).

Location	**Landowner**	**Notes**
Lower Topanga State Park	CDPR	Adjacent to creek in lower canyon areas.
Las Flores Creek	Varied	Adjacent to creek in lower canyon areas.
Solstice Creek	NPS	Adjacent to creek in lower canyon areas.
Malibu Creek	CDPR	Adjacent to creek in lower canyon areas.
Arroyo Sequit Creek	CDPR	Adjacent to creek in lower canyon areas.
Cold Creek Valley Preserve	Varied	Adjacent to creek in lower canyon areas.
All CDPR, MRCA and NPS lands with suitable habitat	CDPR, MRCA and NPS	Expand woodlands wherever appropriate based on analysis of site conditions.

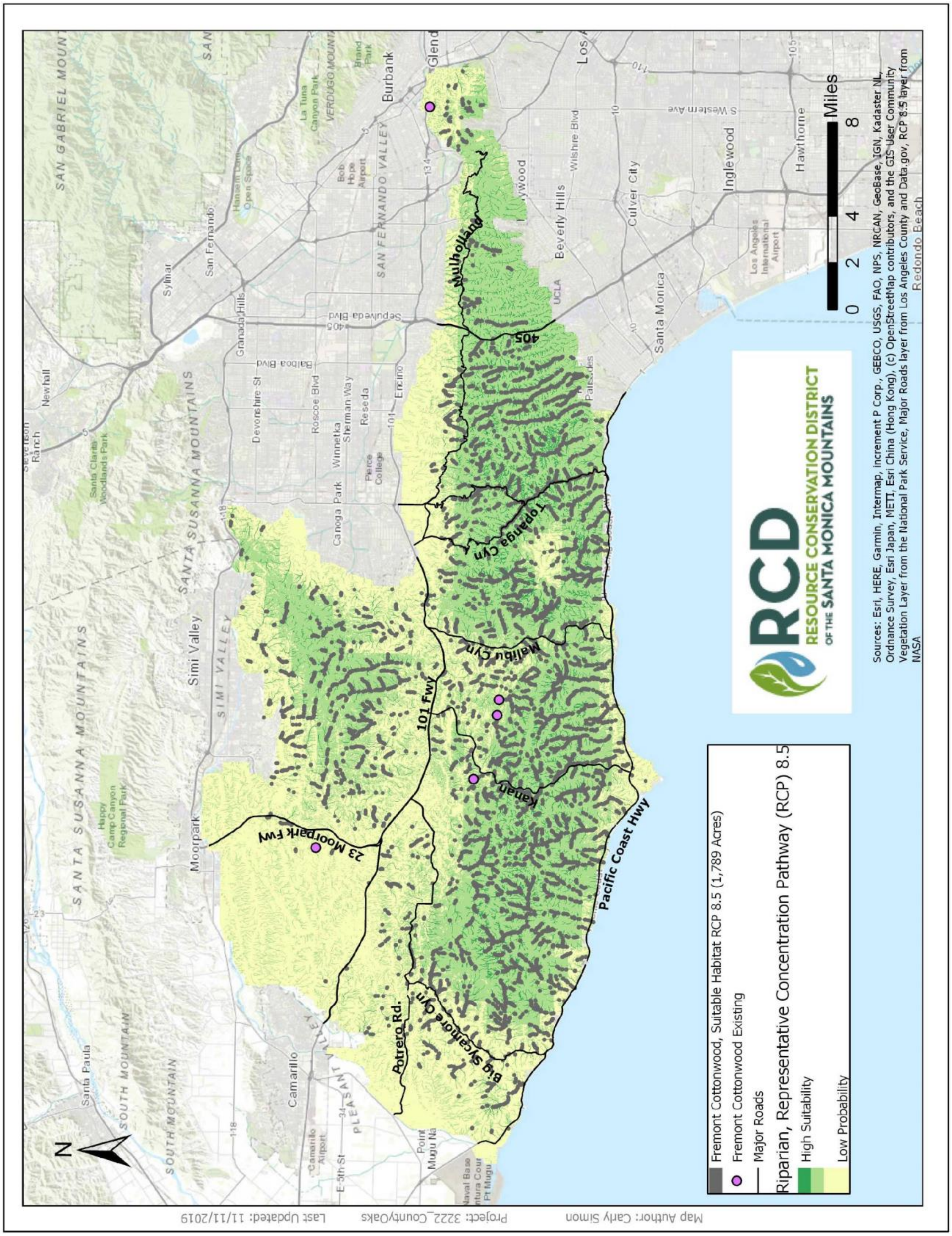


Figure 16. PRIORITY PLANTING SITES - Populus fremontii (Fremont Cottonwood).

6.3.6 *Salix* species

There are several deciduous *Salix* species found within the SMMNRA but few of them are the dominant vegetation type and therefore their abundance and distribution are severely underrepresented. Due to the lack of information there are no individual assessments for *S. gooddingii* (black willow) or *S. lasiandra* (shining willow) although they are known to be present. Willows have both shrubby multi-stem form as well as more single trunk, small tree forms. They have widespread distribution throughout the western United States and are found in a variety of habitats that all have accessible water such as creeks, meadows, freshwater swamps (Flora of the North America Editorial Committee 2018). Due to the limited number of records (3 acres for *S. laevigata* and 53 acres for *S. lasiolepis*) our habitat suitability modeling may not reflect the actual tolerance ranges of these species. It does co-occur with other species (Thorne et al. 2016, Taylor et al. 2019) whose distribution in the future will be limited to areas that retain surface flows and accessible water tables.

Willows are dioecious with individuals bearing either male or female flowers. The fruit is a small capsule coated with soft cottony hairs that facilitate wind dispersal. Flowers bloom in spring and seeds are available for about one month (Zasada et al. 2008).

Propagation Notes:

Propagation is most often from cuttings in winter as willows are going dormant and before spring bud break. Calscape recommends propagation by cuttings. Cuttings are best taken from same creek 1-2 days prior to the restoration event, which allows the cuttings to sit in a bucket of water for a day and fully hydrate. Addition of a few ounces of liquid rooting hormone or some cut willow branches/leaves added to the bucket may increase rooting success. Cuttings should be taken from straight branches and typically 2-3 cuttings prepped per branch. The proper diameter width per branch is 3/4-inch to 1 1/2 inch. The bottom cut of cutting is angled, top cut flush above a branch node. The prepped cuttings should be cut about one foot longer than the depth the cuttings can be dug/driven into the soil, so testing can be done to determine this potential depth. To determine this length, first dig each hole (or if in muddy areas an iron bar can imprint a deep hole) then pound the cutting into the soil with a mallet a few more inches deeper. The cutting tops can be re-cut with loppers to remove any damaged tips. The willows can be protected from browsing deer with plastic mesh cages supported with bamboo stakes.

Stakes can be stored in trashcans of clean water for up to a week although planting soon after cutting is recommended. Some sources recommend use of root hormones to encourage root establishment (NRCS: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_015463.pdf). Stakes are driven into the bank so that the bottom of the cutting is at the water table.

Willows are routinely top killed during wildfires but will vigorously resprout, especially if there are good rains (O'Leary and Bredemeyer 2012). Seedling recruitment post fire is also rainfall dependent.

Salix laevigata (Red Willow)

Only three acres of red willow habitat were recorded by the NPS Vegetation Survey (2007), and Raven et al. (1989) noted that these were uncommon and poorly recorded from riparian woodlands but did find records in the Los Angeles River. We suspect they are sorely underrepresented in the mapping and along with *S. goodingii* and *S. lasiandra* actually more abundant in mixed stands along perennial riparian corridors.

As shown in Figure 17, records for *S. laevigata* are extremely limited at present and the future climate projections are based on an extremely limited sample. Additional mapping for this species is needed in order to increase the confidence level of these maps. However, using surface flow as a guideline, planting of red willows in mixed stands with other willow species, white alder, sycamore, big leaf maple and box elder could address post Woolsey Fire mortality throughout most of the riparian corridors in the burn area.

The existing distribution and the combined overlay of potentially suitable locations as well as predicted areas suitable given climate predictions, we recommend prioritizing planting of both red and arroyo willows on public lands as noted in Table 16. We also recommend planting *S. gooddingii* (black willow) and *S. lasiandra* (Pacific willow) as part of mixed willow stands in these areas and monitoring their success. Selection of actual planting locations will benefit from additional examination of the map online, to get more details of each location.

Table 16. Priority Planting Recommendations for Salix laevigata (Red Willow) and Salix lasiolepis (Arroyo Willow) on public lands (2019).

Location	**Landowner**	**Notes**
Lower Topanga State Park	CDPR	Adjacent to creek in lower canyon areas.
Las Flores Creek	Varied	Adjacent to creek in lower canyon areas.
Solstice Creek	NPS	Adjacent to creek in lower canyon areas.
Malibu Creek	CDPR	Adjacent to creek in lower canyon areas.
Arroyo Sequit Creek	CDPR	Adjacent to creek in lower canyon areas.
All CDPR, MRCA and NPS lands with suitable habitat	CDPR, MRCA and NPS	Expand woodlands wherever appropriate based on analysis of site conditions.

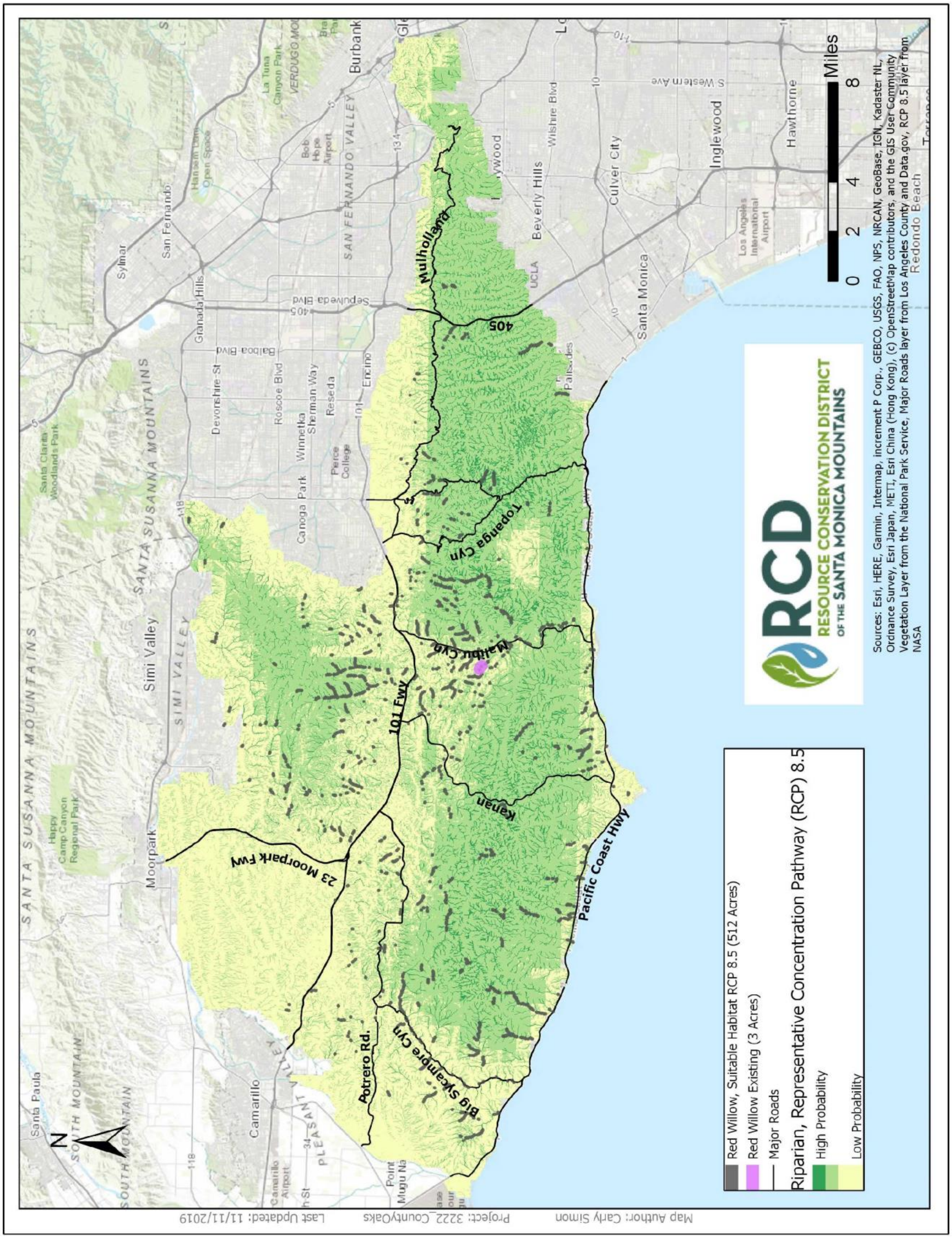
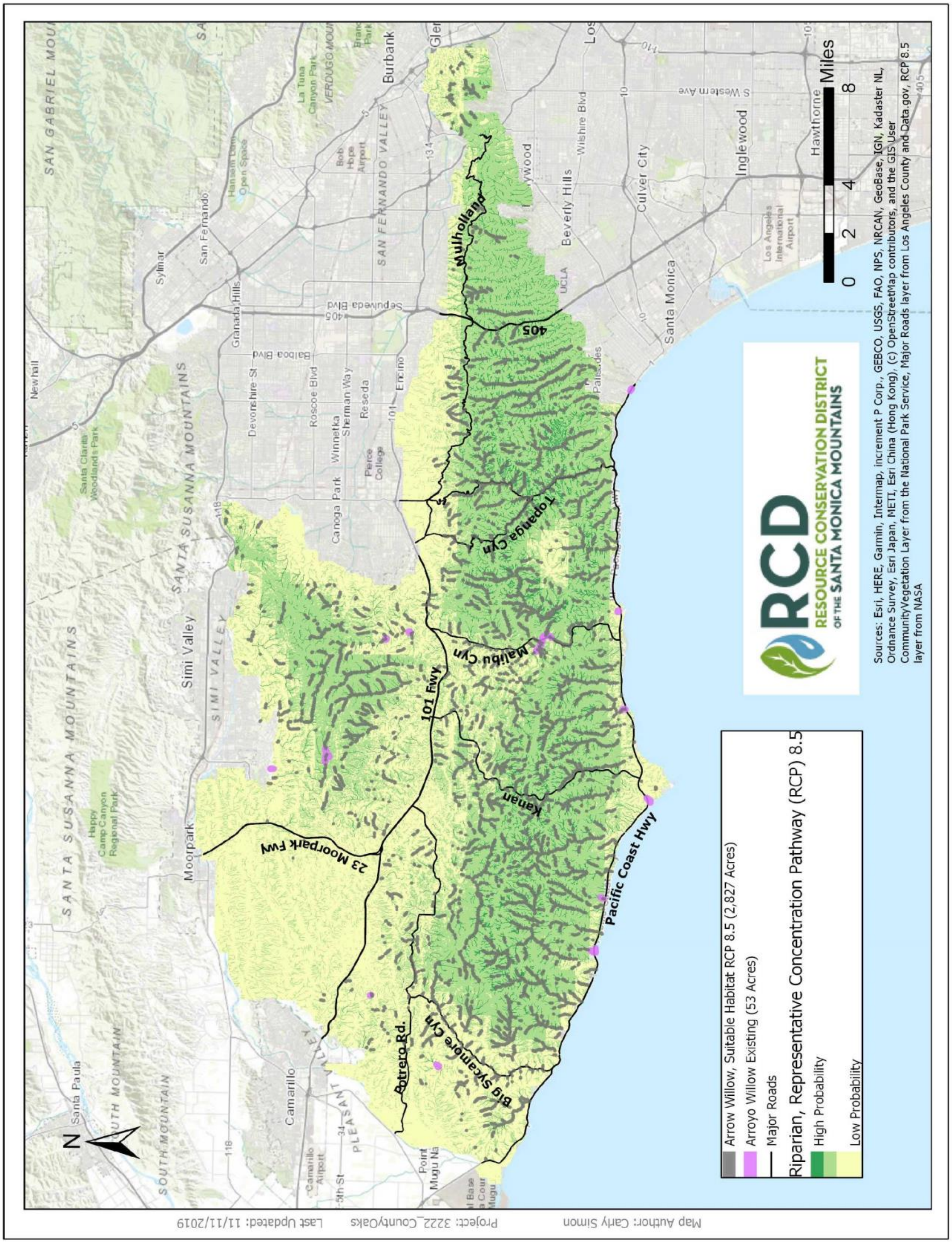


Figure 17. PRIORITY PLANTING SITES - Salix laevigata (Red Willow)



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community Vegetation Layer from the National Park Service, Major Roads layer from Los Angeles County and Data.gov, RCP 8.5 layer from NASA

Map Author: Carly Simon Project: 3222_CountyOaks Last Updated: 11/11/2019

Figure 18. PRIORITY PLANTING SITES - Salix lasiolepis (Arroyo Willow).

7. WHAT TO PLANT?

The first priority is to enhance, expand, and support individuals that have survived both drought and wildfire and existing stands of the native tree species listed in Table 17. These species have been selected based on their abundance and distribution within the SMMNRA (see details in Appendix B). Often standards for restoration planting require that seeds be sourced from within the same watershed, if not from the same site location (LA County Local Coastal Plan 2014, various state park general plans). The rationale behind this is to protect local genetic adaptations based on the assumption that the existing trees have adaptive traits that allow them to survive the conditions at a particular location. In an era of climate change, however, this approach may not confer fitness into the future.

Given that climate conditions are changing rapidly and that most native SMMNRA tree species have limited seed dispersal, we recommend establishment of some experimental trials to test whether seed selections from trees that are surviving more extreme temperature conditions might be more suitable to survive future changes to temperature and precipitation conditions than local seed selections.

Table 17. List of 14 significant native tree species found in the Santa Monica Mountains.

Species	**Family**
Acer macrophyllum (big-leaf maple)	Sapindaceae (soapberry)
Acer negundo (box-elder)	Sapindaceae (soapberry)
Alnus rhombifolia (white alder)	Betulaceae (birch)
Juglans californica (southern California black walnut)	Juglandaceae (walnut)
Platanus racemosa (California sycamore)	Platanaceae (sycamore)
Populus fremontii ssp. fremontii (Fremont cottonwood)	Salicaceae (willow)
Populus trichocarpa (black cottonwood)	Salicaceae (willow)
Quercus agrifolia var. agrifolia (coast live oak)	Fagaceae (beech)
Quercus berberidifolia (California scrub oak)	Fagaceae (beech)
Quercus lobata (valley oak)	Fagaceae (beech)
Salix gooddingii (Goodding's black willow)	Salicaceae (willow)
Salix laevigata (red willow)	Salicaceae (willow)
Salix lasiandra var. lasiandra (shining willow)	Salicaceae (willow)
Salix lasiolepis (arroyo willow)	Salicaceae (willow)

Note that missing from this list are large woody shrubs that are common to the SMMNRA such as *Hertomeles arbutifolia* (toyon), *Malosma laurina* (laurel sumac), *Prunus illicifolia* (hollyleaf cherry), *Rhus integrifolia* (lemonade berry), and *Sambucus nigra* (elderberry). These are all potentially important species to consider planting, but it was beyond the scope of this project to develop habitat suitability models for them.

8. HOW TO PLANT

8.1 Stock Selection and size:

Native stock will be obtained from a reputable source where the provenance of seeds is clearly documented. Various local agencies (Los Angeles County Fire/Forestry) and volunteer groups (TreePeople, SeedLA) are great sources for appropriate seed material. Seeds should be collected from individual trees surviving the drought and wildfires. If container stock is used, they will be inspected before transport to the site to ensure that there is no visible evidence of soil pathogens, insects, non-native frogs or other invasive species present. In Los Angeles County, oaks are required to be mitigated by up to 1-gallon container trees from acorns of the vicinity. However we recommend using a maximum of D-slip size, which is considered to be standard practice for planting in wildland sites. Oak mitigation trees also are required to have an acorn of the same species from the vicinity planted within the irrigation circle and have oak leaf mulch or other mycorrhizal amendment. We recommend using the smallest possible container stock available in order to provide opportunity for site specific establishment of the roots.

Plants shall be healthy with the color, shape, size, and distribution of trunk, stems, branches, buds and leaves normal to the species specified. The size, color, and appearance of leaves shall be typical for the time of year and stage of growth of the species. Plants shall not show signs of prolonged moisture stress or over watering as indicated by wilted, shriveled, or dead leaves. Plant roots shall be normal to the plant type specified. The root system shall be reasonably free of stem girdling roots over the root collar or kinked roots from nursery production practices. At the time of planting, all plants shall have a root system, stem, and branch form that will not restrict normal growth, stability and health for the expected life of the plant.

8.2 Planting Coordination on Public Lands

Restoration and revegetation efforts are currently implemented by private landowners and public land agencies such as local, state, and national parks. Large areas within public ownership have experienced severe tree declines over the past few years due to drought and wildfires. One of the goals of this plan is to identify opportunities for coordinating planting across land ownership and to provide LA County with areas where private property owners can meet any off-site development mitigation requirements. Both restoration and mitigation plantings can contribute to the effort to enhance our native woodlands.

8.3 Preliminary Road Map to Implementation

It is important to focus on growing trees rather than just planting them. Effort will be needed to coordinate actual implementation projects and to develop the required tools such as Memoranda of Understanding (MOU’s) that will provide the legal framework for implementation, as well as a carefully organized maintenance plan. Whether planting is being done by non-governmental organizations (NGO’s) scout groups, or other community groups, Right of Entry Permits are typically required by park agencies in order to cover liabilities and to establish permitted activities. To initiate that effort, the following step by step road map for collaborative planting is provided.

Step 1. Identify areas where parkland restoration or off-site mitigation planting could restore specific native tree species. The maps provided online for this plan are a good starting point.

Step 2. Each agency will need to develop and adopt the necessary MOU's and Right of Entry Permits with Los Angeles County and other interested cities to define the parameters when and where restoration with community groups and off-site mitigation required planting can be done.

Step 3. Identify responsible parties for ensuring that restoration plants survive and requirements for when replanting is needed to replace those that fail. Most native trees require at least monthly watering the first year to become established.

Step 4. Develop a restoration monitoring plan requirement and milestones that will promote documentation of establishment and survival of all plantings. Identify who will receive monitoring reports, timelines (annual, bi-annual), survival goals, triggers for additional planting requirements, response to invasive pests or diseases, and in the case of mitigation plantings, penalties.

Step 5. For any required off-site mitigation planting, identify the agency point of contact to report problems and trigger enforcement actions. Identify who is responsible for any enforcement actions.

8.4 Assisted Migration

One of the popular responses to pending climate change is to explore the potential of assisted migration – the intentional movement of a species either into the extreme edge of its current range, or into an entirely new area where conditions are anticipated to change (Williams and Dumroese 2013). Both national and state parks typically follow the guidelines of preserving existing conditions rather than "playing God" by moving species out of their historic known ranges. We know that over geologic time, climate conditions have forced the movement of many plant and animal species. The difference is that those events occurred over hundreds to thousands of years, allowing evolutionary processes to frame adaptive responses. The premise of assisted migration is that the current changes are happening faster than species life cycles can adapt.

For example, *Quercus engelmanni, Q. tomentella,* and *Quercus wislizeni* are found a few locations within the SMMNRA as well as in other parts of Los Angeles County. It might be worth examining whether these species might be able to thrive in potential future climate conditions, and to perhaps develop some experiments to test this. Testing this in more urban landscape situations could provide insight into potential for expansion into wildlands.

This plan provides an opportunity to initiate specific long-term experiments to examine questions such as:

- What would be the ideal species for specific geographic areas? (Need a decision tree to manage/restore based on where specific species can survive)
- Do we want to suggest areas where different species might be more appropriate?
- Why are we selecting specific species for moving? What is their current function and potential?

Lots of CA natives are invasive in the coastal area and hybridize easily so need to be careful.

Developing a group of interested researchers to delve into these questions is recommended. The Climate Ready Tree Study (http://climatereadytrees.ucdavis.edu/southern-california-coast-trees/) and the plant list being developed by Dr. Arlee Montalvo (Riverside Corona Resource Conservation District).

8.5 Site preparation

Make sure to get pre-project photo documentation points established to show before and after conditions.

All invasive species roots will be removed by hand or mowing (if a large planting area) to clear an area at least six times the width of the planting hole to mineral soil. Make sure that proposed planting locations do not interfere with or impact any existing native plants.

8.6 Planting method

Actual planting shall be performed during those periods when weather and soil conditions are suitable in accordance with locally accepted horticultural practices. Planting soil as used in this specification means the soil at the planting site. No planting shall take place during extremely hot, dry, windy, or freezing weather. No fertilizer supplements shall be applied to the plants during the planting process. Should evidence indicate that the seedlings are being outcompeted by the non-natives, a weed barrier or other application may be placed around the seedling to minimize the impacts of weeds and increase soil moisture.

Hand tools will be used excavate the planting hole which will be a minimum of three times the diameter of the root ball. If an auger is used to dig the initial planting hole, the soil around the auger hole shall be loosened along the sides. The top outer edge of the root ball will be set at the average elevation of the proposed finish grade of surrounding area.

The planting hole will be filled with water and allowed to drain completely, making sure there is no standing water or drainage issue for that hole.

The container/seed will be placed in the center of the planting hole and the crown will be even with the surrounding grade. If a chicken wire cage or other plant protection device is planned, it will be installed according to directions appropriate for that material. In wildland settings, root loss to gophers and ground squirrels, as well as grazing from rabbits and deer can significantly damage new plants and therefore protection is recommended.

The soil is then backfilled in layers, tamping down to remove air pockets and settle the soil. A shallow watering basin approximately the same size as the diameter of the original excavated hole will be created and covered with locally collected mulch material, newspaper, weed control fabric or other approved weed suppression materials.

The plants will be watered thoroughly, provided with a unique aluminum tag that can endure for 10 years with embossed numbers that match the identification number and GPS coordinates on the map (Alphabetic characters may identify tree species, but number will be unique.) Although not required for restoration plantings, this is an important way to track survival.

Tree species will generally be installed on 20’ centers, shrubs on 5-10’ centers, and herbaceous species on 1-2’ centers. The goal is to create a natural growth pattern that blends into the surrounding open space.

8.7 Maintenance

It will be necessary for any planting to provide appropriate care as needed to ensure survival and good growth. For Year 1, this should include daily checks during the first two weeks to assess watering needs, with bi-weekly checks thereafter. Special attention should be paid to periods of invasive weed growth and appropriate irrigation during the dry summer/fall months the first few years. For Years 2-3, monthly maintenance is recommended and can include both watering and weeding. During years 4-10, quarterly maintenance is recommended, unless more intensive maintenance is needed to ensure survival. On-going invasive weed management will be essential.

8.8 Irrigation Methods

All plants will be hand watered as needed based on rainfall, but up to once per week during the dry season for the first year, and then weaned off supplemental water over the following three years. Should drought conditions extend that period of weaning, watering may need to be continued as needed to ensure the survival and health of the plants.

8.9 Monitoring Requirements

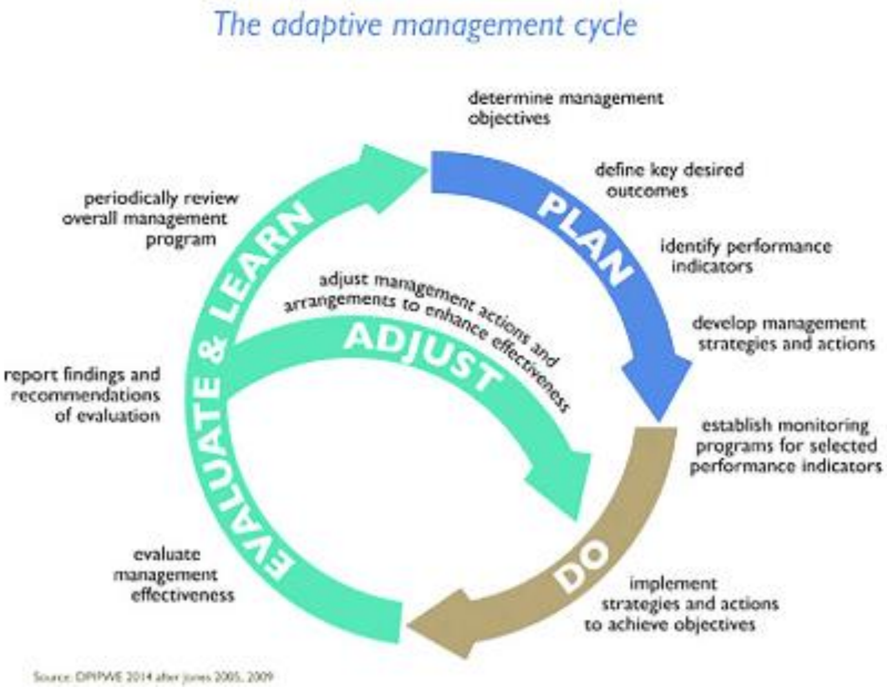
Monitoring should be structured to detect changes in baseline conditions, facilitate timely adaptation actions, and gauge effectiveness of management actions. They should be designed with specific hypotheses in mind and with trigger points that will initiate management decisions and give clear information about possible management actions. Although not required for voluntary restoration planting projects, monitoring is essential to tracking the success of any given project.

A Baseline Native Tree Replacement Report should be prepared following installation of mitigation (or restoration) plants and start the clock ticking for any required mitigation establishment times. The report should provide sources of seeds/stock, container size (if applicable), dates and details of installation, tables and maps showing the locations of all plants, access information, site condition information and any other pertinent details. A series of photo-documentation points should be established to document growth over time. Photos should be taken in fall each year prior to preparation of the annual report to illustrate condition at the end of each monitoring year. The baseline report will also include a map of all tagged plants, species, size, condition, canopy cover, and GPS coordinates. This table will be set up to allow additional notation of growth and condition over time, as well as document any problems. The report should be submitted to the appropriate landowner or agency to document the start of a project.

9. ADAPTIVE MANAGEMENT

Adaptive management is the flexibility to respond to restoration realities in hopes of generating a more positive outcome. Planning for tree restoration and future climate change is inherently uncertain and requires the flexibility to respond to restoration realities and to learn from experience. This could be mortality due to unanticipated events (wildfires, large windstorm, extreme heat, excessive rain, etc.) or less catastrophic but no less damaging loss due to someone inadvertently driving over the planting site.

Adaptive management provides a structured, iterative process designed to reduce uncertainty over time via systematic monitoring (Figure 19). When things go wrong, it is important to examine why and identify possible ways to address the problems. Many events are not foreseeable, so it is essential that regular monitoring is incorporated to detect unexpected outcomes and to adjust as new information is learned. Annual monitoring and reporting is recommended to provide for necessary adjustments to the planting program.



Source: DPIPWE 2014 after Jones 2005, 2009

Figure 19. Adaptive Management cycle summary. Source West 2016, after Jones 2005, 2009.

10. FUTURE RESEARCH QUESTIONS

The recommendations of this plan are based on the assumptions and biases of our current state of knowledge. Due to the level of uncertainty associated with predicting climate changes, some questions we might want to suggest for consideration and testing include but are not limited to:

- How can past evolution patterns and historical distribution help our understanding of potential future patterns?
- What are the demographics of adult survival, seedling and sapling recruitment patterns and success?
- How much does seed source matter and why?
- Are there species exotic to the SMMNRA we want to avoid that could prove problematic in the future?
- How long and far can a seed be transported by various vectors (wind, birds, etc)?
- Is there a way to attract or enhance seed transportation?
- Where are the subsurface water resources available to trees within the SMMNRA?
- Analyze trees based on actual locations in addition to SMMNRA Vegetation Layers, to get a broader perspective of habitat selection for each species.

- Add additional variables, such as water availability, evapotranspiration, and maximum temperatures, to the habitat suitability model to increase to confidence of the model. Consider weighting variables using NASA data on importance of variables to each guild (Ferriter et al. 2019 Appendix D).
- Analyze drought tree death data (where applicable). Determine conditions where trees survived versus conditions where trees died to find the habitat variables that separate the two. Then apply these differences to the model.
- Collect field data on seedling recruitment to determine habitat conditions required for seedlings.
- To more accurately determine water/groundwater availability, collect field data on locations of springs, seeps, and other unmapped water sources in the SMMNRA.
- Collect field data such as tree size and condition metrics to determine the condition of trees in different environments.
- Analyze vegetation associations of each tree species to get a more accurate representation of their preferences in the SMMNRA.
- Lastly, study and monitor the success of the planted trees and habitat characteristics in the potential planting areas and apply to model once enough data is gathered.

11. FUNDING OPPORTUNITIES

11.1 Cap-and-Trade Program

California's cap-and-trade program is an emissions trading system whose goal is to reduce greenhouse gas emissions from regulated industries. California's program is the fourth largest in the world, smaller only than the cap-and-trade programs of the European Union, the Republic of Korea, and the Chinese province of Guangdong (C2ES 2019). Regulated businesses include large electric power plants, large industrial plants, and fuel distributors (e.g. natural gas and oil); altogether, about 450 businesses must comply in California (C2ES 2019). The California Air Resources Board (CARB) is responsible for implementing and enforcing the program. Essentially, in the cap-and-trade program, a "cap" is placed on the amount of emissions each regulated business can produce. Emissions allowances are then distributed to regulated businesses for free and through an auction system. If they don't need all their allowances, companies can sell – i.e. "trade" – their allowances to other businesses or bank a certain amount for future use. Companies therefore have an incentive to cut emissions. In addition, companies can meet a certain percentage (currently 8%) of their compliance obligation through the purchase of offsets. Offsets are greenhouse gas emissions credits that are achieved through an activity outside out of the regulated industries. They should be emission reductions that would not have occurred without the program and must follow CARB-approved protocols.

The offset protocol most applicable to the SMMNRA is the U.S. Forest Projects protocol. The US Forest Projects protocol is available for download from CARB's Compliance Offset Program webpage (https://ww3.arb.ca.gov/cc/capandtrade/protocols/usforest/ forestprotocol2015.pdf). Eligible activities include reforestation, improved forest management, and avoided conversion; each activity has its own set of criteria that must be met to fulfill eligibility. In addition, any forest project on public land must be approved by the managing agency and must involve any necessary public vetting processes. Forest projects on federal lands, unless owned by a Native American tribe, are not eligible for offset credits. In 2018, offset credits were selling for around

$10 per ton (Smith 2018), providing potential revenue of $80,000 per year for one forest management project (Smith 2018) and $100 million for another forest project on tribal land (Bullinger 2018). At these rates, forest offset projects may allow farmers, foresters, and other landowners in the SMMNRA to manage their land sustainably while benefiting financially.

11.2 Cap-and-Trade Funding Sources

In California, the allowance auction revenue has generated a significant funding source. In 2018, nearly $1.4 billion in funding was generated from cap-and-trade funds (CARB 2019). Cap-and-trade funding revenue is distributed through the California Climate Investments Program. Possible forest restoration project funding sources include the Wildlife Conservation Board's Climate Adaptation and Resiliency Program and CAL FIRE's Forest Health Program.

The CAL FIRE Forest Health Program's goal is to solicit projects that work to prevent wildfires while restoring forests and sequestering carbon. It was funded in 2018 and again in 2019. The CAL FIRE Forest Health Grants website provides current funding opportunities. Eligible applicants include local, state, and federal agencies, universities, special districts, Native American tribes, private forest landowners, special districts, and nonprofit 501(c)(3) organizations. Reforestation projects are included in the project activities list, as well as pest management, research, and conservation easements. Projects must focus on landscape-scale forestlands, maintain a net reduction of established greenhouse gas emissions levels as calculated by CARB's methodology, and be designed to provide permanent benefits (CAL FIRE 2019).

The Wildlife Conservation Board's Climate Adaptation and Resiliency Program's goal is to fund projects that support climate adaptation and resilience on natural and working lands. Previous funding (in May 2019) for the program was through legislative action; future funding is uncertain and depends on similar legislative action or another source (WCB 2019).

11.3 CA Coastal Conservancy

The CA Coastal Conservancy is another possible source of funding for forest restoration projects that have an impact on coastal watersheds, which includes all the SMMNRA watersheds. The CA Coastal Conservancy accepts pre-proposals on an ongoing basis, though prospective applicants are encouraged to discuss their project with Conservancy staff before completing the pre-proposal. Eligible applicants include public agencies, federally recognized tribes, and nonprofit 501(c)(3) organizations. The Conservancy funds projects that help achieve the goals of its strategic plan. Strategic plan goals that align with the efforts of the Native Tree Priority Planting Plan include "Protect significant coastal resource properties, including farmland, rangeland, and forests," "Enhance biological diversity, improve water quality, habitat, and other natural resources within coastal watersheds," "Enhance coastal working lands, including farmland, rangeland, and forests," and "Enhance the resiliency of coastal communities and ecosystems to the impacts of climate change (SCC 2019)." In addition, in the pre-proposal instructions, the Conservancy also includes projects that "sequester carbon or reduce greenhouse gas emissions." Therefore, the CA Coastal Conservancy's ongoing grants may be a possible source of funding for certain reforestation projects, particularly those that have a strong impact on water quality, biodiversity, or resiliency.

In addition, the Conservancy administers grant funds through the Water Quality, Supply, and Infrastructure Improvement Act of 2014 (Proposition 1). The purposes of Prop 1 include water quality, water supply, and watershed protection and restoration. According to the Coastal Conservancy website, priority projects include water sustainability improvements, anadromous fish habitat enhancement, wetland restoration, and urban greening (SCC 2019). Eligible grantees include public agencies, nonprofit 501(c)(3) organizations, and Native American tribes. Planting and restoration efforts that align with this Plan may also align with the anadromous fish habitat enhancement and possibly urban greening goals of the Coastal Conservancy's Prop 1 grants.

12. POLICY RECOMMENDATIONS

- Establish Best Management Practices for both voluntary and mitigation planting.
- Identify responsible parties for review and implementation of any mitigation planting.
- Establish MOU's among all landowners to implement the plan – LA and Ventura County, park agencies, RCDSMM, TreePeople, etc.

13. ACTIONS RECOMMENDED

- Identify funding sources for voluntary planting.
- Identify a lead agency to coordinate updating the maps and plan as more information is developed.
- Initiate annual meeting with all agencies, scientists, and public landowners in the SMMNRA to review new ideas, planting and funding opportunities and coordinate efforts.
- Coordinate planting efforts with City of Los Angeles.
- Connect planners responsible for directing mitigation requirements with public landowners.
- Develop outreach to provide private landowners with information on how to participate.
- Establish test plots for other potential native tree species that might survive into the future.
- Identify locations of natural seedling recruitment.
- Coordinate seed gathering and propagation with local agencies and non-profits.
- Engage local researchers in refining and developing additional models and addressing research questions identified.
- Improve and update mapping of species distribution.
- Evaluate opportunities to use native tree planting efforts to increase wildfire resilience.
- Evaluate opportunities to use native tree planting efforts to expand and support wildlife linkages.
- Develop better tools to identify potential groundwater resources.

14. MEASURING SUCCESS

The goal of this plan is to foster persistence and expansion of native trees in the SMMNRA. It is crucial that regular evaluation of the planting program is undertaken to identify problems and opportunities and therefore annual and five-year assessments should be prepared and shared with all stakeholders. At the least, it is recommended that the following metrics are examined and reported to track implementation over time. These should include but not be limited to:

- Annual rapid assessment of mortality and potential pathogens, pests or environmental stressors (e.g. extreme temperatures, drought, catastrophic events).
- Annual assessment of seed germination and seedling success.
- Annual assessment of number of trees planted of each species and document changes in overall tree canopy extent over time.
- Establish additional tree plots in planting areas to monitor long term survival and compare with existing tree plots monitored by RCDSMM and NPS.
- Five years assessment should include comparison of remote sensing productivity (NDVI). Lidar may be incorporated as it becomes more commonly available as a standard product in the future. Even Google Earth images can be helpful!
- Evaluate improvements/changes to connectivity and linkages.
- Provide for rapid response monitoring following extreme events with the potential to impact target populations.

14.1 Carbon Sequestration and Storage Values

Monitoring carbon sequestration and storage is an evolving process, with preliminary assessment tools such as iTree most frequently used in a landscaped setting. Additional tools utilizing a variety of remote sensing analyses are developing to identify the current net carbon removal by trees and chaparral, compared to net emissions. The California Forest Health Quantification Method is being revised and updated to incorporate estimations of the carbon benefits from oak woodlands based on an extensive database of geo-referenced plots that provided known age data used to generate a 100-year biomass growth curve (V. Matzek, personal communication, December 2019). These calculations would enable projects to qualify for cap and trade funds for projects that improve forest health.

Gonzalez et al. (2015) examined the aboveground vegetation carbon using Landfire data throughout the state. Figure 20 illustrates the results for the SMMNRA. Much of the carbon loss observed was due to wildfire impacts.

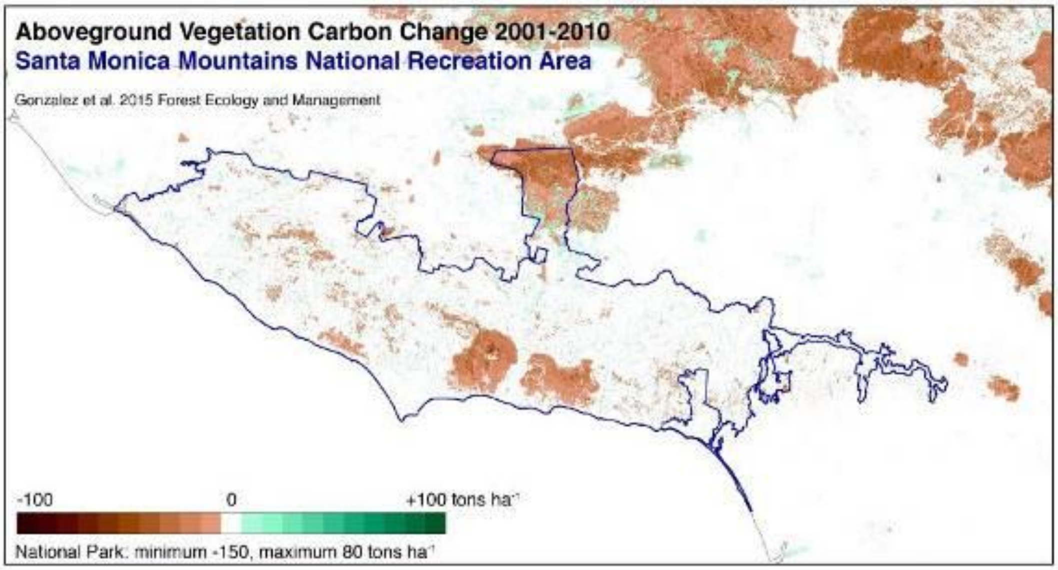


Figure 20. Aboveground Vegetation Carbon 2010 Gonzalez et al. (2015).

The Los Angeles County Community Climate Action Plan (2020) identifies tree planting as a key strategy for reducing carbon levels locally. Decreases in aboveground live carbon storage are often associated with wildfire and drought associated mortality (Gonzalez et al. 2015), although agricultural expansion and urbanization are also factors, especially when both trees and chaparral communities are both included. While this plan summarized carbon sequestration and storage based on iTree analysis, further examination of this important process is needed to capture the benefits associated with new plantings over time.

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APPENDIX A

CONCEPTUAL FRAMEWORK FOR PRIORITY PLANTING PLAN IN THE SMMNRA

Abstract

Conserving native trees into an uncertain future needs a plan to be flexible and based on a defensible set of assumptions within a realistic conceptual framework, while recognizing that there are unknowns that could influence stand diversity, reproductive patterns, and spatial patterns. The principle is to build upon existing stands of trees where saplings are being naturally recruited (Habitat Suitability Model Appendix C), and then to identify locations where temperature and drainage conditions, as well as topography, are anticipated to be suitable in coming years 2070-2099 (Appendix D). Using a decision making guide based on increasing redundancy and buffers to reduce risk to existing oak and riparian woodlands, managing for asynchrony, and using disturbances to develop multi-age stands, we hope to promote connected landscapes that promote dispersal and establishment in suitable areas as conditions change. This framework identified and assessed threats to native tree species and examined potential adaptive strategies that will provide guidance on where to plant, what species to plant, when to plant, and outline long term monitoring strategies to evaluate success of the effort.

Introduction

Climate associated threats to biodiversity and persistence of our native trees and riparian corridors in the Santa Monica Mountains National Recreation Area (SMMNRA) require an immediate and thoughtful approach for restoring and preserving long term ecosystem stability. Potential impacts to ecosystem services, biodiversity, and ecological processes are not only related to climate shifts, but also to other natural and human impacts such as droughts, wildfires, pollution, introduced pathogens and invasive species, and changes in land use and development. The impacts of these stressors are both direct and indirect, and the responses of each tree species can be different.

Identifying these potential impacts and translating responses into preventative, pro-active actions is the focus of the SMMNRA priority planting plan process. Our goal is to:

a) Provide a scientifically sound rationale for identifying potentially suitable planting areas where native tree and shrub species could be expected to grow under future climate scenarios; and,

b) Provide guidance on species selection criteria.

Realistically, this is a long-term experiment, where the results of our choices will not be evident for another 10 -50 years. Therefore, we anticipate that these proffered criteria will need to be adapted over time and will need the flexibility and capacity to change in light of additional information.

Another key element of this conceptual framework is that it does not differentiate between public and private land ownership in identifying potentially suitable planting sites. Voluntary restoration planting will be critical, but there is also opportunity to integrate off-site mitigation planting requirements into the effort to enhance the future resilience of our native woodlands.

Development in the SMMNRA is not anticipated to be exponential, but incremental build out of remaining private lands, as well as re-development of existing built sites will result in the need for mitigation planting to replace native trees and shrubs that are impacted. The current mitigation planting program requires that replacement plants be located either on-site, or off-site on public lands within the same watershed. However, on-site planting is often impractical due to lack of space and highly altered site conditions and the guidelines for off-site planting provides few realistically helpful alternatives. In-lieu fees directed to the LA County Oak Mitigation Fund are another alternative that is sometimes used, but to date has resulted in little restoration of oak woodland habitat.

We propose shifting the current paradigm to direct any off-site mitigation planting or funds towards locations that are potentially the most likely to provide appropriate conditions supporting growth and survival of native trees into the future. This will allow us to maximize the opportunities to preserve and expand native trees and shrub survival. But if we are going to revise mitigation regulations, there needs to be a strong scientifically defensible rationale guiding that redirection. We also need to build in flexibility, willingness to take risks, and procedures for assessing conditions as they evolve and respond appropriately if changes are needed. By expanding our perspective on where, what, and when to plant, we can encourage a suite of desirable outcomes including but not limited to greater spatial heterogeneity, improved connectivity, mixed age stands created by interval planting over time, enhanced carbon sequestration/storage, and expanded ecosystem services.

Forest management plans are being used as tools to guide the long-term resilience and sustainability of both urban and wildland forests throughout the world (Millar et al. 2007). A variety of conceptual frameworks have been proposed, each tailored to address site-specific problems by incorporating both biological and socio-economic goals and objectives. Incorporating resilience to drought, introduced species and wildfires by diversifying species, spatial patterns and identifying potentials to maximize seed dispersal ranges that varies with micro-refugias can help (North et al. 2019). There is no silver bullet solution, and it is critical to tailor criteria for identifying priority planting locations based on conditions found in the SMMNRA. Developing both a short and long-term suite of potential approaches provides opportunities for changing course in a dynamic manner.

Millar et al. (2007) developed a framework focusing on adaptation strategies (actions that can respond to condition changes over time) that can enable mitigation efforts to respond to anthropogenic impacts and provide opportunity to enhance carbon sequestration and storage, as well as strengthen ecosystem services, reduce fragmentation, and support biodiversity. Climate uncertainty means we need to stay flexible and incorporate flexibility in planting strategies by taking incremental steps and adaptively responding over time.

Threat Assessment

The first step in developing a conceptual planting framework for the SMMNRA is to examine the potential suite of threats and the various ways they could impact native tree and shrub species survivability in the face of an uncertain future. Thorne et al. (2016) and Magness et al. (2011) describe these threats in terms of vulnerability, exposure, sensitivity, and resilience/adaptive capacity.

- Vulnerability is the likelihood of decline in ecosystem services, species diversity and demographics, and has temporal and spatial variability.
- Exposure describes the magnitude, frequency, duration and spatial extent of stressors and disturbances (including temperature changes, altered hydrology, land use conversion, wildfires, drought, etc.)
- Sensitivity describes the relative level of response to these stressors determined by intrinsic characteristics of the system or species. For instance, demographics of the species makes a difference. Older, even age stands are more susceptible to storm damage, windthrow, insects and diseases. Seedlings are more sensitive to water stress, competition from invasive herbaceous annuals, browsing, etc.).
  It is not known for our local native species whether specific climate thresholds (minimum amount of precipitation, proximity to water table, maximum temperature tolerance) would impact recruitment. This is an important priority for future study.
- Resilience/Adaptive capacity reflects the ability of each species to shift or alter its condition and distribution to reduce vulnerability or improve ability to function under stress.

Each species responds to these climate related stressors such as extreme temperature days, altered precipitation patterns, increased wildfire intensity, pests, diseases and winds in slightly different ways and the loss of ecosystem services can be both local and global (Costanza 2008). The potential cumulative impacts include undesirable changes (i.e. dieback, mortality, lack of recruitment, etc.) that lead to increased urbanization/ fragmentation and decreased adaptive strategies that foster resistance to change, resilience that allows accommodation to change, and encourages responses that foster long term survival. Anderegg et al. (2012) noted that while tree mortality is a natural process, the extent of impacts on tree density and spatial arrangement associated with fire and drought induced mortality can cause a variety of tree community responses. Encouraging spatial and age diversity also supports drought resilience by encouraging differing rooting depths that comes with mixed age stands (Anderegg et al. 2018). Trophic level shifts of foodwebs and fungal microbial communities can directly affect habitat structure and function by loss of foundation species, which can exacerbate biodiversity loss as well. Despite their apparent longevity, trees are a fragile resource and it is critical to reduce the risk of catastrophic loss by increasing resilience (McPherson et al. 2017).

Tree species that currently occupy the Santa Monica Mountains have a proven ability to survive cyclic climate changes (ie., Pacific Decadal Oscillation) and weather (ie., Madden-Julian Oscillation, Atmospheric Rivers), as well as the cycle of annual summer drought that defines Mediterranean climates. From this perspective, questions of tree species persistence in the SMMNRA can be framed by how much change these trees can tolerate, rather than modeling shifts in ideal conditions. Each species has responded to climate-related stressors in different ways, but some generalities can be applied. First, Riparian (guild) species have a narrower envelope of responses than Upland (guild) species, and hence the distributions of riparian trees are easier to link to stressor variables across the SMMNRA. Upland species (such as *Quercus agrifolia*) have a broader envelop of responses and maintain distributions that are more difficult to link to habitat and other environmental variables across the SMMNRA.

Second, mature trees can exercise a number of responses (leaf drop, biomass dieback, re-sprouting, deep rooting in reliable moisture, and soil and mycorrhizal develop) that are unavailable to seeds, seedlings, saplings, and other stages of tree life history required for recruitment of full-sized trees over time. Hence long-lived, mature trees can often exist in conditions where recruitment cannot occur (for example, on the Channel Island oaks are not recruiting where goat damage has destroyed understory conditions). Special conditions may be needed for recruitment and replacement of existing trees, even in the absence of climate change. In some cases, mature trees provide these conditions under their canopies; however, the expansion, recovery, or movement of tree species distributions often require conditions that are episodic or relatively rare (McCreary 2009), further complicating models of where to plant trees in the future.

Third, all models of current species distributions (and secondarily their abilities to respond to threats) are based on information gathered over the last 150 years – less than the upper life expectancy of many tree species in the study, and a window of observation that is <1% of the time that the current climate has been in place. In addition, historical accounts hint that some species distributions have undergone remarkable, anthropogenically induced changes since European colonization of the SMMNRA. Given that models of species distributions and responses to stressors are based on available, recent data, they carry an element of unknowable variations. As discussed, (Adaptive Management: pg 71) an uncertain future created by the unknowable can only be addressed by a strongly adaptive management structure, which monitors and corrects model errors.

Finally, climate change can be amplified or confounded by other forces, as shown by invasive exotic tree pests and pathogens, smog, imported irrigation water, and other recent external threats. The uncertainty introduced by these factors has a knowable component, shown by the predictable wave of damage caused by the infestation shot hole borer (*Euwallacea spp.)/Fusarium* complex (McPhearson et al. 2017). But this problem is only one trans-boundary process that may cross into the SMMNRA from the constellation of problems emanating from the surrounding urban landscape. Again, these predictable and as yet unknowable problems reinforce the need for a strong adaptive component to any management action that grows out of this plan.

Adaptive Strategies

Tree live for 20 to over 100 years, so any proposed adaptive strategies need to flexibly respond to both short term and long-term challenges and opportunities. The information provided in this plan is the first attempt to provide guidance and will need to be revised as additional information comes to light.

Suggested Short-term Strategies:

- Prevent further loss of existing resources by protecting existing trees from wildfires, insects, and diseases as much as possible.
- Encourage natural recruitment and provide maintenance support if needed to support seedling survival.

- Improve resilience and capacity of oak and riparian woodlands to recover from natural disturbances such as fire and drought using intensive restoration support including watering, weeding, etc. to facilitate recovery.
- Support heterogeneity by leaving space for natural recruitment from existing "founder" trees in remote locations, encourage recruitment in areas supported by natural seed dispersal and support clusters of trees that are beyond the range of natural seed dispersal (North et al. 2019).
- Expand ranges of existing native stands to reduce fragmentation.

Suggested Long-term Strategies:

- Facilitate gradual transition from current to new conditions by mimicking natural adaptive processes of seed dispersal and migrations.
- Study the limiting factors for seedling dispersal and establishment for each species.
- Reduce the risk of catastrophic type conversion or species community extirpation as feasible.

Where to plant?

In order to better understand the range of potential climate shifts for the SMMNRA, we reviewed numerous data sources at several scales. While we might feel somewhat confident in the broad-scale environmental shifts predicted, such as that modeled by Hall et al. (2018) at a 250 m scale, it is really difficult to integrate topographic factors (slope, aspect, soils, etc.) with sufficiently fine scale temperature and precipitation data to pinpoint how we might anticipate conditions to change at a specific geographic location. Our analysis identified future potential distribution areas consistent with those identified by more inclusive models (Thorne et al. 2016, Taylor et al. 2019). However, modeling plant distributions is inherently complex and limited due to current data available. This preliminary effort applied current models, but additional expanded analysis will be needed.

Using ARC GIS to integrate vegetation cover (NPS Vegetation Survey 2007) and point data on individual species distribution provided the basis for mapping the current distribution of adult trees. This was further refined using remote sensing data (Dagit et al. 2017). As explained further in Appendix D, MAXENT software was used to build models to help resolve different spatial scales using linear quadratic and "hinge only" features (Raes and ter Steege 2007). The occurrence data was sub-sampled using 60% for training and 40% for testing each of 10 replicate runs. The regularization multiplier was set at 2.5 to reduce overfitting (James 2014).

Information on seedling locations is less available and requires additional field work. The physical and meteorological conditions associated with current distribution were examined and used to establish the range of tolerance for each species. Additional analysis was done to identify other areas having those same conditions where the species is not presently documented to map areas of potential suitability for the present. Details on the results of these analyses are found in Appendix C. A systems approach to identifying potential planting sites integrated current information on site conditions (microclimate, topography, drainage) and landscape level conditions (extreme temperatures, drought, wildfire) to generate suitability maps.

The decision making framework developed uses site variability and exposure to define management actions (Magness et al. 2011). Refugia can be created or maintained in high resilience and low exposure areas. Ecosystem maintenance is the appropriate management decision under low resilience and low exposure conditions. Ecosystem maintenance can include maintaining current conditions by managing stressors such as invasive species, fragmentation, or restoring the site. These sites may transition into other states due to low resilience, and could become stepping stones for shifts to new states. High resilience and high exposure sites are likely to develop natural adaptation processes. Low resilience and high exposure sites are candidates for facilitated transitions.

General guidelines for decision-making are to:

- Increase redundancy and buffers to spread risk;
- Manage for asynchrony and use establishment phase to reset succession (i.e. disturbances can be triggers for planting new species);
- Use disturbances and diebacks due to drought, beetles, or fire to promote diverse age classes, species mixes and genetic diversity;
- Promote connected landscapes to promote dispersal and migration.

With these general concepts in mind, the following decision tree is proposed to guide selection of priority planting sites based on maps of projected future habitat suitability:

1. **Habitat that will remain suitable:**
    - Create resistance to change:
        - Reduce anthropogenic stressors (erosion, invasive plants, fire effects, invasive beetles)
    - Promote resilience to change
        - Determine most sensitive life stages
        - Intensive management during establishment phase
        - Promote diverse age classes, genetic diversity and seed mixes
        - Manage sites to decrease fire impacts (ladder fuels, buffer around sites)

2. **Habitat that will be less suitable (wholly or in part) in the future:**
    - Create resistance to change by focusing on:
        - Reduce anthropogenic stressors (erosion, invasive plants, fire effects, invasive beetles)
        - Plant with high tolerance propagules
        - Prioritize larger sites and sites in close proximity to facilitate dispersal and create stepping stones to future suitable sites
        - Prioritize sites least likely to be impacted by fire

3. **Habitat that currently is not suitable may become more suitable in the future:**
    - Prioritize sites:
        - that have been impacted by disturbance (ex: fire, pests, drought)
        - that have been identified in other models as no longer suitable to the existing vegetation type
        - based on connectivity

  - identify sites that are more buffered against disturbance

- Treatments mimic, assist or enable ongoing adaptive processes:
  - Seed dispersal and migration
  - Changes in species dominance and community composition
  - Changing disturbance regimes.
  - Encourage gradual adaptation and transition; mimic succession

For all of these potential conditions it is critical to articulate clear goals at the start of each project and for each location. Developing restoration designs with specific hypotheses in mind and with trigger points that will initiate management decisions/actions will be critical to evaluation the success of the project. Examples of potential goals include maintaining ecosystem integrity, achieving restoration cover goals, preserving ecosystem services, and protecting wildlife.

What to plant?

The overarching goal is to identify which individuals and species are most resilient in the face of climate shifts to maintain and potentially increase genetic diversity among common tree species native to SMMNRA. A variety of resources were used to identify the most abundant tree species within the SMMNRA but was narrowed down to focus on those species that were most abundant and widely distributed as well as those that are most at risk. The list of current tree species is found in Appendix B.

The short–term emphasis of the Priority Planting Plan is on expanding and supporting recovery of tree species presently occurring in the SMMNRA. Monitoring natural range shifts and documenting opportunities for range expansion will be a critical element of this effort. Species selection and density may also need adjustment in fuel modification zones that provide defensible space around existing or proposed structures, especially where private property abuts public open spaces.

For the long-term, the goal is to explore the use of seeds from the same species for assisted regeneration that are collected outside a given watershed or even the SMMNRA, but that are present in locations where they currently experience conditions that are anticipated to occur in the SMMNRA. The concept of assisted migration should be considered and experimental plans based on defensible rationales be developed.

When to plant?

In order to maximize survivability and promote diverse age structures, planting timelines will need to be implemented on a site-by-site basis. By mimicking natural recruitment pulses typical of each species, we can foster multi-age stand development as well as take advantage of rainy years to support establishment. Planting site prioritization should incorporate a landscape level approach to reducing habitat fragmentation and promote wildlife movement by improving connectivity. Additionally, coast live oaks in particular have been identified as potential buffers reducing wildfire risk (North et al. 2019). Prioritizing planting this species in order to reduce downwind ember spread and provide additional buffering between wildlands and urban developments is recommended.

In the short-term, this should include prioritizing planting sites based on ability to expand an existing stand and begin restoring connectivity across the landscape, especially expanding into areas identified as having suitable conditions into the future.

Trees take between 10-20 years to reach reproductive maturity, and life expectancies range from 20-50 years for some riparian species such as willows and alders, to over 200 years for oaks. The long-term goal of this plan is to have continuous persistence of all of the native trees species for at least the next 100 years. To achieve that goal, it will be necessary to expand the existing ranges for each species into locations where conditions will be suitable in the future.

Long-term Monitoring and Adaptive Management Plan

As with any plan based on modeled and uncertain future conditions, we should expect surprises. The implementation of this plan needs consistent monitoring and flexibility to shift course if needed based on observed results. At minimum, a long-term monitoring and adaptive management plan should be designed to detect changes in baseline conditions, facilitate timely adaptive actions and gauge the effectiveness of the actions in achieving overall planting goals.

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APPENDIX B
CRITERIA FOR SPECIES SELECTION PRIORITY PLANTING PLAN IN THE SMMNRA

The following list of focal native tree species was developed by a team of local biologists and botanists with expertise in the flora of the Santa Monica Mountains National Recreation Area. The evaluation process included:

1. Reviewing the vegetation survey compiled by NPS (2007) to identify the most abundant trees and those that were dominant.
2. Literature review of species distribution.
3. CalFlora and other herbarium review sources
4. Examining physical environment preferences based on existing distribution with the assumption that these parameters (temperature range, precipitation range, proximity to surface water, soil type, aspect, slope) supported seedling germination, recruitment and eventual maturation and reproductive processes of each species.
5. Examined distribution patterns and associations.
6. Evaluated areas impacted by drought, invasive pests and wildfire to prioritize species that were most severely at risk.

Factors noted for each species were grouped into the following categories:

Position: landscape setting where the species typically occurs.	
cyn btm	canyon bottom, i.e., of steep-side V-shaped canyons
fldpln	floodplain, meandering or braided streams, subject to seasonal scouring and occasional realignment
nf slp	north-facing slope
sf slp	south-facing slope
val fl	valley floor, relatively dry sites of broad valley bottoms not subject to flood processes and with full sun exposure

Water source: the mode of water availability which can provide the minimum amount required for the species’ persistence.	
psw	perennial surface water, available only in year-round streams or ponds
ssw	seasonal surface water, available in seasonal streams or rivers where surface water is not present for some or most of the year; these systems have subsurface flowing or perched groundwater accessible to phreatophytes
rain	water is only present on the surface during storms and is not retained via subsurface flows or perched groundwater

Climate regime: the general geographical character of the climate where the species is usually encountered.	
cis	cismontane—coastal slope and plain
warm int val	warm interior valleys-interior valleys that don’t typically experience freezing winter temperatures; these lie generally south of Santa Clarita Valley and include the San Fernando, San Gabriel, and Pomona Valleys
cold int val	cold interior valley—interior valleys that usually experience freezing winter weather; Santa Clarita and San Joaquin Valleys
coast	coastal zone
dsrt	the Mojave Desert
mtn	higher mountains, including the San Gabriel, Liebre, Topatopa, and Tehachapi Mountains

Based on these variables, the following species listed in Table 1 were selected for prioritization.

		position					water source				climate regime				
species	family	cyn btm	fldpln	nf slp	sf slp	val fl	psw	ssw	rain	cis	coast	warm int val	cold int val	dsrt	mtn
Acer macrophyllum (big-leaf maple)	Sapindaceae (soapberry)	X					X			X	x				X
Acer negundo (box-elder)	Sapindaceae (soapberry)	X					X			X					X
Alnus rhombifolia (white alder)	Betulaceae (birch)	X					X			X	x				X
Juglans californica (southern California black walnut)	Juglandaceae (walnut)	X		X					X	X	x				
Platanus racemosa (California sycamore)	Platanaceae (sycamore)	X	X					X		X	x	X	X		X
Populus fremontii ssp. fremontii (Fremont cottonwood)	Salicaceae (willow)	X	X					X			x	X	X	X	
Populus trichocarpa (black cottonwood)	Salicaceae (willow)	X	X					X		X	x				X
Quercus agrifolia var. agrifolia (coast live oak)	Fagaceae (beech)	X	X	X		X			X	X	x				
Quercus berberidifolia (California scrub oak)	Fagaceae (beech)			X	X	X			X	X	x				
Quercus engelmannii (Engelmann oak)	Fagaceae (beech)				X	X			X			X			
Quercus lobata (valley oak)	Fagaceae (beech)	X	X	X	X	X			X		x	X	X		
Quercus wislizeni (interior live oak)	Fagaceae (beech)			X					X				X		X
Salix gooddingii (Goodding's black willow)	Salicaceae (willow)	X	X					X			x	X	X	X	
Salix laevigata (red willow)	Salicaceae (willow)	X	X					X			x	X	X		X
Salix lasiandra var. lasiandra (shining willow)	Salicaceae (willow)	X	X					X		X	x	X	X		
Salix lasiolepis (arroyo willow)	Salicaceae (willow)	X	X					X			x	X	X		X
Umbellularia californica (California bay-laurel)	Lauraceae (laurel)	X		X					X	X	x				

Species were then clustered into guilds based on similarity of preferences and following the designations in the CDFW California Wildlife Habitat Model (Thorne et al. 2016) to facilitate climate modeling efforts described in Appendix D. These guilds were divided into upslope and Canyon Guild and Riparian Guild. Coast live oaks (*Quercus agrifolia*) and valley oaks (*Quercus lobata*) were included in both guilds as they can be found as dominant species in all locations. California bay laurel (*Umbellularia californica)* and California walnut (*Juglans californica)* were analyzed individually as they did not fit well into either guild.

UPSLOPE and Canyon Guild:
These species occur within the same climate envelope and share numerous habitat characteristics: *Quercus agrifolia, Q. berberidifolia, Q. lobata,* as well as *Juglans californica* and *Umbellularia californica.*

Common preferences: Are located on slopes with various aspects, and seasonal surface water, although known to extend roots deep in rock cracks to access the water table. They extend from coastal areas to warm interior valleys, and have widespread distribution in lower canyons as well as along more exposed upper slopes.

Recruitment patterns: Need high mast year followed by good rains for seed to germinate. Pulses of recruitment are episodic, known pulses occurred in 1940-1979, 2018-2019. It takes 10-20 years before trees reach reproductive maturity, and mature adults persist for 100+ years.

The species in the Upslope and Canyon Guild are widely distributed and tolerate a broad range of site conditions. Due to the limitations of our modeling, we are not as confident that we captured all potential locations for these species.

RIPARIAN Guild:
These species occur within the same climate envelope and share numerous habitat characteristics: *Acer macrophyllum, Acer negundo, Alnus rhombifolia, Platanus racemosa, Populus fremontii ssp. fremontii, Populus trichocarpa, Salix gooddingii, S. laevigata, S. lasiandra var. lasiandra,* and *S. lasiolepis.* Due to these commonalities, the predictive ability of the model is more robust.

Common preferences: Prefer canyon bottoms and slopes with deep canyon shading. Require perennial water (groundwater) augmented by rain. They tolerate widespread climate regimes from coast to cismontane, but require root access to water table.

Recruitment patterns: Seeds germinate following flood events and are often concentrated in the flood zone areas along drainages. It takes only 5-10 years for these species to reach reproductive maturity, and mature adults are often more short lived although individuals are known to persist for 50-100+ years.

APPENDIX C

HABITAT SUITABILITY MODEL

Prepared by Tanessa Hartwig and Carly Simon, RCDSMM

Purpose

The Santa Monica Mountains (SMM) have been described as an island of natural habitat within coastal Southern California, particularly within the greater Los Angeles region (Tiszler and Rundel 2007). Despite the fact they are enveloped and fragmented by development, the mountains retain greater than 80% of their native vegetated land cover (Tiszler and Rundel 2007) and provide habitat for 184 vertebrate species (breeding birds, reptiles, amphibians, and mammals), 894 vascular plants, including two endemic plants (Rundel and Tiszler 2007), approximately 300 lichens and lichen allies (Knudsen and Kocourkova 2009), and an unknown number of invertebrate species. Native trees are a limited yet key part of the SMM landscape, providing habitat for many of these species and a diversity of other ecosystem services detailed in Section 3 (pg 17; Environmental and Ecosystem Services Benefits Dagit et al. 2019).

However, primary and secondary effects of climate change are already changing the landscape and will likely continue regardless of global, federal, or state policy decisions regarding carbon or carbon equivalent emissions. Current projected climate changes in the Los Angeles region include: average maximum temperatures expected to rise 4-5°F by mid-century, extreme temperatures expected to increase, dry and wet extremes expected to increase, and wildfires may also increase (Hall et al. 2018). For native trees, impacts associated with climate change include increased wildfire frequency and intensity, long-term drought and other extreme weather events, invasive beetles, and even increased vigor of certain non-native grasses. Because trees are long-lived and sessile organisms, their response to rapid changes in climate in combination with the above-mentioned impacts and fragmentation may not be adequate for the continued success of some species. The goal of the habitat suitability modeling was to determine where suitable habitat for each native tree species significant to the SMM currently is, so that this information could then be analyzed in conjunction with projected climate layers to determine potential planting areas that will enahnce current or planned corridors.

The dominant native trees in this analysis included *Acer macrophyllum* (big leaf maple), *Acer negundo* (box elder), *Alnus rhombifolia* (white alder), *Juglans californica* (California black walnut), *Platanus racemosa* (California sycamore), *Populus fremontii* (Fremont cottonwood), *Quercus agrifolia* (coast live oak), *Quercus berberidifolia* (scrub oak), *Quercus lobata* (valley oak), *Salix lasiolepsis* (arroyo willow), *Salix laevigata* (red willow), and *Umbellularia californica* (California bay laurel). We focused on these trees because they are significant to the SMMNRA for the habitat (including food, shelter, nesting material) and other ecosystem services they provide or due to their rarity or biogeographical significance (for instance, the SMMNRA is at the southern edge of the valley oak’s range).

Existing Conditions in Study Area

Native Tree Species Abundance and Distribution

Native trees provide extensive environmental and ecosystem services benefits directly to the landowners within the SMMNRA, but the ripple effects of publically owned open space extend well beyond the boundaries of the SMMNRA to provide regional wildlife linkages, meta-population genetic reservoirs, and moderate the conditions for adjacent urbanized areas.

Data on the status of existing vegetation was compiled from the NPS Vegetation Survey (2007) and Figure 1 illustrates the pattern of vegetation coverage as classified using remote sensing tools to identify areas where native oaks and riparian woodlands remain following the Woolsey Fire (2018).

The SMMNRA landscape is characterized by a limited acreage of woodlands and savannahs; shrubland, especially chaparral, is the more dominant component of the landscape (Tizler and Rundel 2007). Woodlands (including coast live oak woodland, riparian woodland, California walnut woodland, and valley oak savannah) only comprise about 5.6% of the vegetated landscape of the SMM and Simi Hills (Tizler and Rundel 2007). The woodlands and valley oak savannahs are typically distributed in areas with higher than average moisture levels – north slopes or ravines, deep soils with available moisture, or nearby streams, springs, or subsurface waters (Tizler and Rundel 2007).

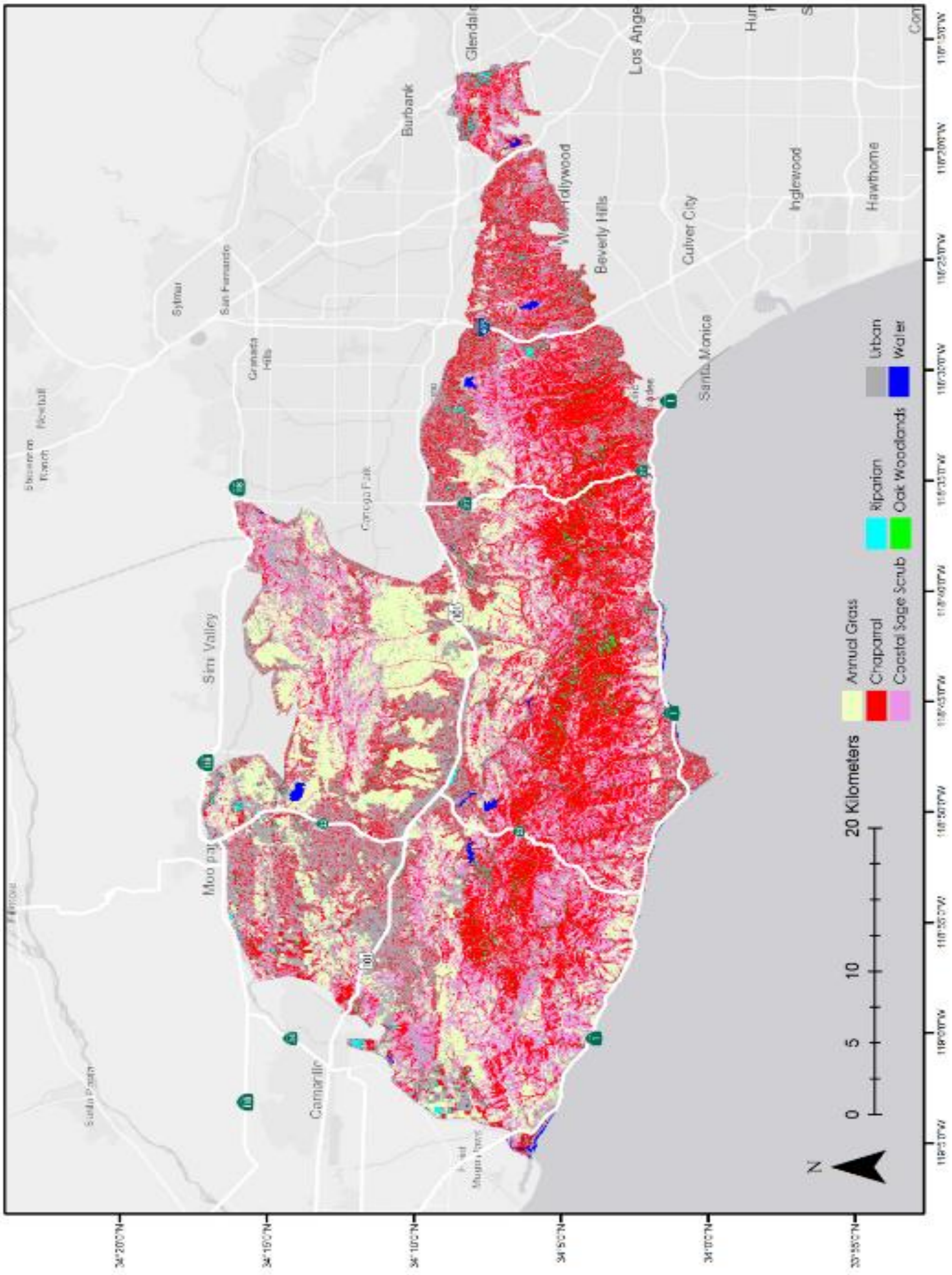


Figure 1. 2019 distribution of remaining surviving native trees in the SMMNRA Species distribution based on AVIRIS MESMA Classification of imagery acquired 06/25/2018 (excerpted from Appendix D NASA DEVELOP Technical Report).

Drought, Wildfire and Invasive Beetle Impacts

Long-term drought in combination with other anthropogenic-driven factors such as invasive beetles and increased wildfires, seems to be causing a decline in an already-limited resource. In 2017, a NASA DEVELOP team analyzed the effects of drought on natural vegetation in the Santa Monica Mountain National Recreation Area (Dagit et al. 2017). They found that of 110,183 acres of vegetation (not including annual grasslands) alive in 2013, only 77,840 acres remained alive in 2016. Riparian woodlands were hit particularly hard, experiencing a 31% dieback in three years (*Table 1, Alive versus Dead Vegetation Acreage in the SMMNRA 2013-2016, excerpted from Dagit et al. 2017*).

Table 1. Alive versus Dead Vegetation Acreage in the SMMNRA 2013-2016. Data excerpted and amended from Dagit et al 2017.

Vegetation Type	Acres Alive 2013	Number of Trees Alive 2013	Acres Dead 2013-2016	Number of Trees Dead 2013-2016	Percent Dieback by Vegetation Type
Annual Grass	26,634	--	16,391	--	61.5%
Shrub	70,335	--	12,531	--	17.8%
Oak Woodland	2,700	151,200	163	9,128	6%
Riparian Woodland	10,514	367,990	3,258	114,030	31%
Total Acres	110,183		32,343		

Trees within certain topographic conditions fared better than other trees, however. Those trees on south-facing slopes or slopes greater than 10° were of lower condition rating than those in other locations (Dagit et al. 2017). In oak woodlands, the Relative Fraction Alive (RFAL, analyzed remotely by the NASA DEVELOP team) decreased to the east, and the fraction of dead oak increased between 2013-2016 (*Figure 2, Fraction of Dead Oak Woodland Pixels by Aspect and Year*)

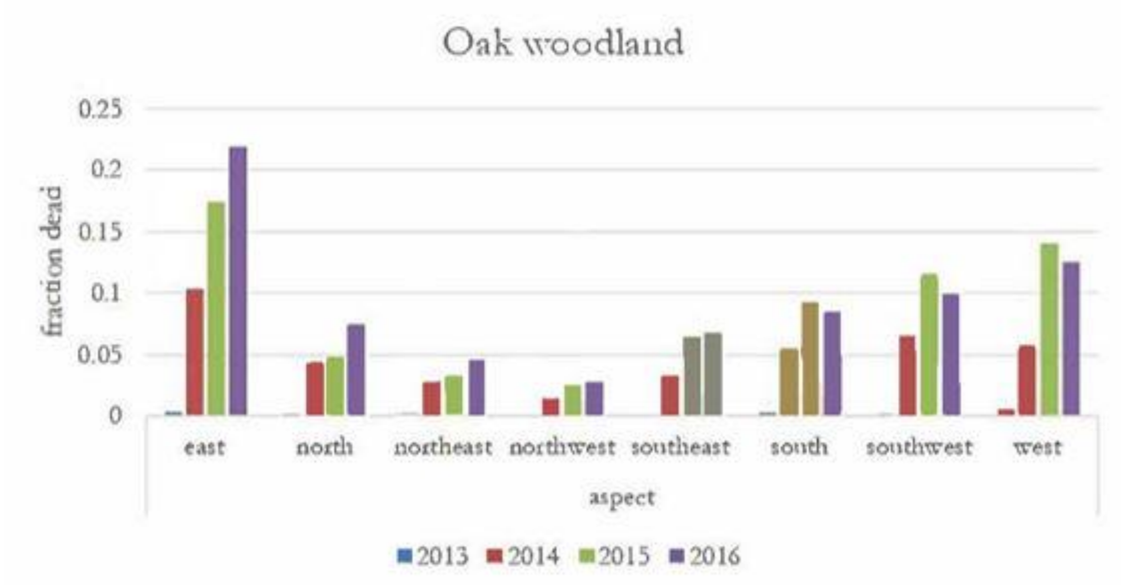


Figure 2. Fraction of Dead Oak Woodland Pixels by Aspect and Year (Data excerpted and amended from Dagit et al 2017).

Although drought appears to be the main stressor causing the current dieback of trees, the synergistic effects of invasive beetles and increasingly frequent wildfires may exacerbate the problem. According to trapping conducted by RCDSMM staff, partners, and volunteers from 2015-2017, the distribution of ISHB (Invasive Shot Hole Borer) and WOBB (Western Oak Bark Beetle) in the SMMNRA appears to be patchy and possibly associated with green waste facilities (Dagit et al. 2017). Where established, however, invasive beetles have resulted in severely declining tree health over a short time frame. For instance, WOBB has caused over 20 acres of oak mortality in upper Topanga State Park (Dagit et al. 2017). The most recent wildfire in the SMMNRA, the Woolsey Fire, burned about 90,000 acres. Many of the locations burned in the Woolsey Fire had burned at least once, and often more than once in the recent past (NPS 2018; *Figure 3, Woolsey Fire and Fire Return Interval*). Recent fires in the San Gabriel and San Jacinto Mountains have converted former pine forest areas to drier chaparral; fire has also been implicated in the conversion of chaparral to nonnative grasslands (Hall et al. 2018, Rundel 2018). It is likely that broadleaf woodlands may also convert to another vegetation type if fire intervals are too frequent.

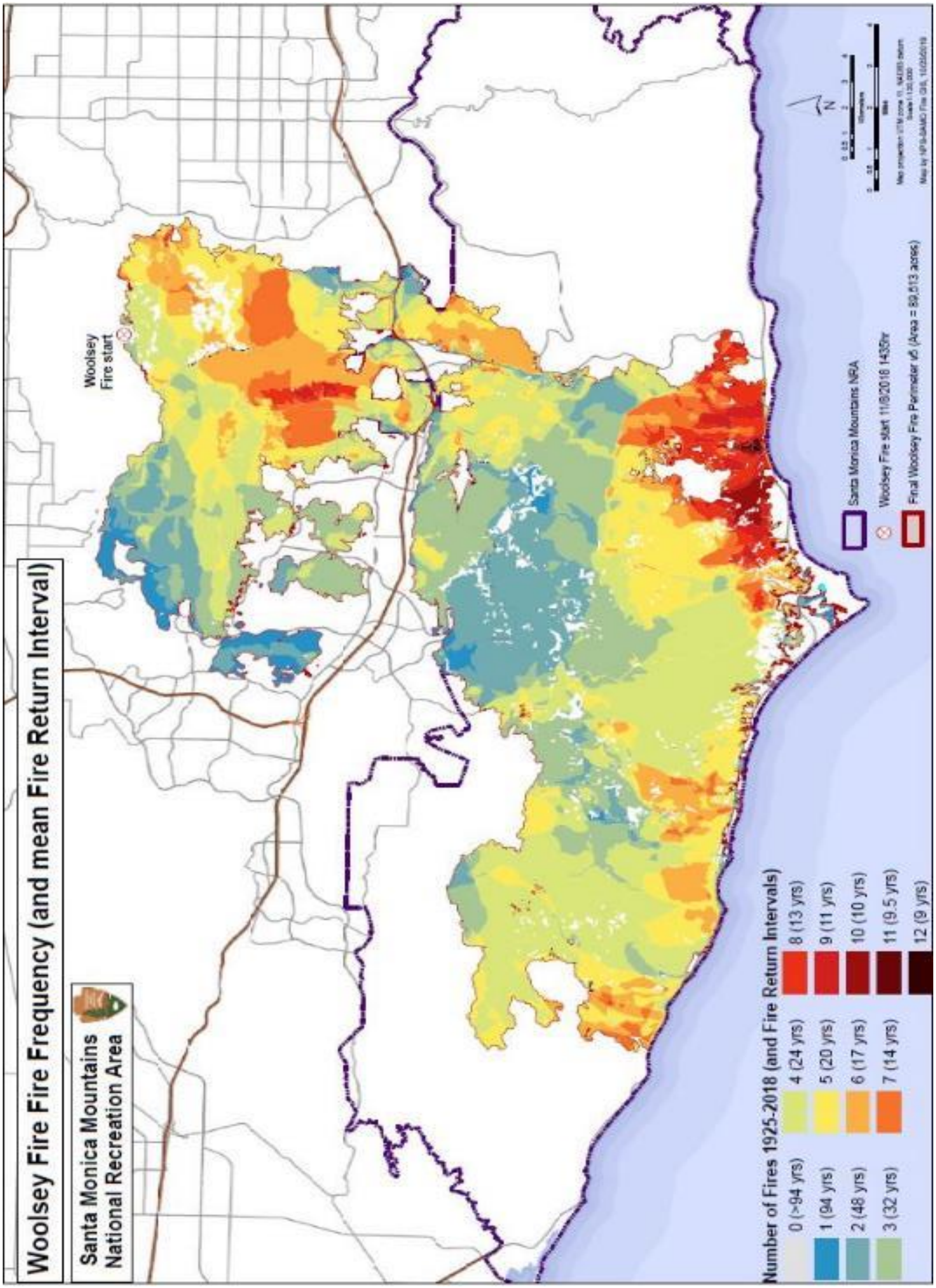
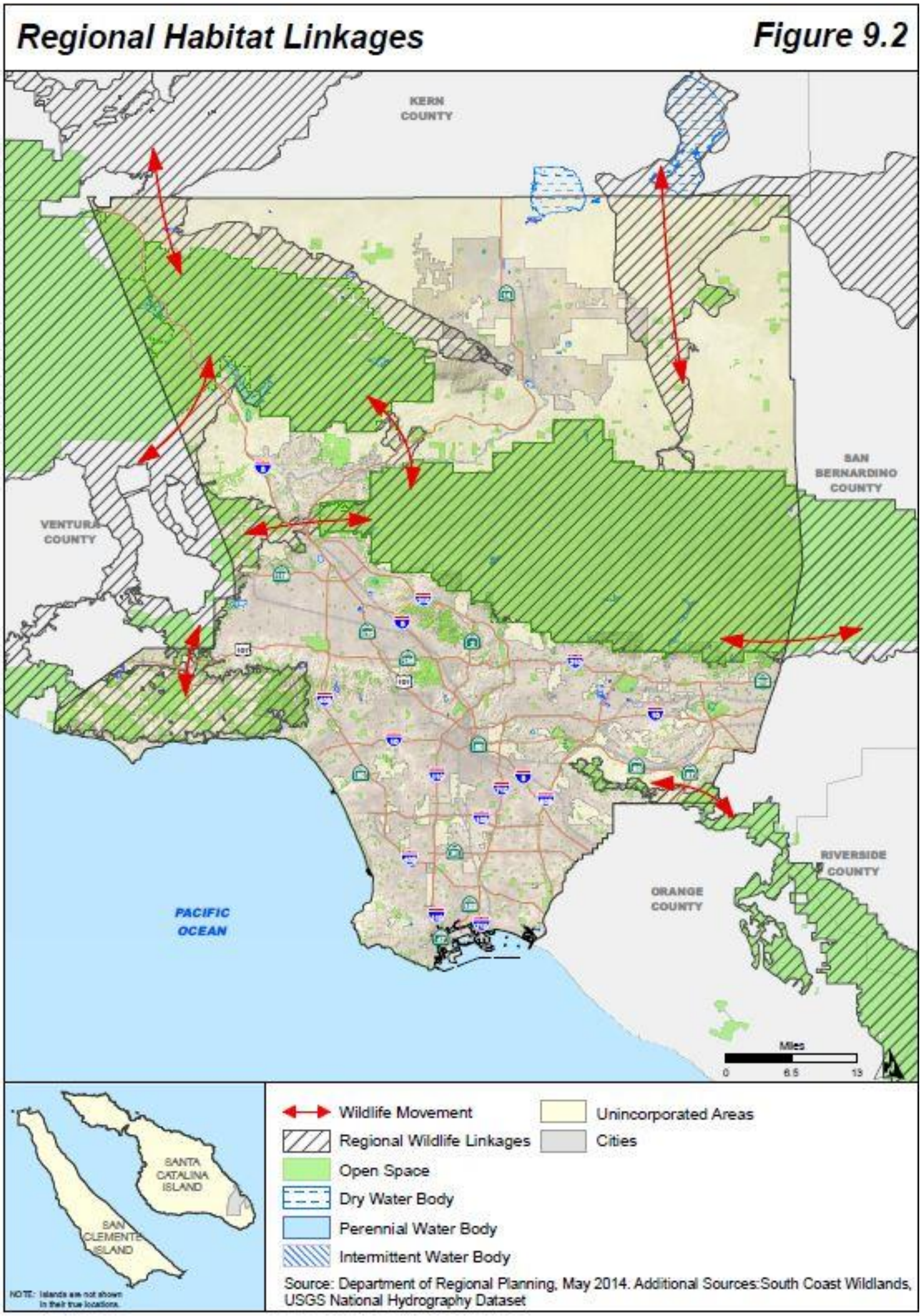


Figure 3. Woolsey Fire and Fire Return Intervals (Courtesy of NPS).
Wildlife Habitat and Connectivity.

The relatively large amount of remaining natural vegetation in the SMMNRA provides linkages and corridors for wildlife and flora to move between preferred habitats, although urbanization and fragmentation has had profound implications for wildlife (Delaney et al. 2010, Riley et al. 2003). Additionally, as a relatively intact and large area of open space, the SMMNRA is identified as important to connectivity and wildlife movement regionally in regional planning documents (*Figure 4, Regional Wildlife Linkages LACDRP 2019).* As the climate changes and species require room to move, existing fragmentation will become even more problematic. Current barriers to movement throughout the SMMNRA have not yet been thoroughly evaluated and vary by species or taxa. However, typical barriers include areas of intense urban development associated with high-traffic roads, certain types of fencing, night-lighting, high levels of noise, or other influences that cause animals to avoid an area. The Santa Monica Mountains North Area Plan Biological Resources Assessment (Aspen Environmental Group 2018) provides an overview of corridors and barriers to movements with that planning region.



Source: Department of Regional Planning, May 2014. Additional Sources:South Coast Wildlands, USGS National Hydrography Dataset

Figure 4. Regional Wildlife Linkages LACDRP 2019.

Methods

Current Distribution Maps

Using the SMMNRA 2007 Vegetation layer, we selected each tree species listed above by its community (e.g., Coast Live Oak Woodland) and created a new layer. By creating our species layers using this method, we selected those locations where the trees were most dominant and, correspondingly, most successful. Since Fremont cottonwood, big leaf maple, and box elder never reach dominant status in the SMMNRA, we used the Consortium of California Herbaria website to retrieve point data for these tree species. We then selected each species individually and created separate layers.

We chose to focus solely on locations from the SMMNRA for our model rather than locations from the entire range. We made this choice for several reasons. First, it allowed us to use the SMMNRA 2007 Vegetation layer, which contains accurate, partially ground-truthed, high-resolution data. Second, for this model we wanted to capture the unique habitats trees in the SMMNRA succeed in, rather than capturing the full range of conditions throughout their distribution. Third, trees in the SMMNRA may be genetically distinct from trees of the same species in other locales, particularly north or east of the Transverse Ranges. Genetic studies of valley oaks from the SMMNRA indicate that they comprise a separate genetic cluster from the rest of the species, indicating that the Transverse Ranges (San Gabriel Mountains) may limit gene flow (Ashley 2015). Nonetheless, genetic differentiation is individual from species to species; the same may not hold true for all SMMNRA tree species.

Potential Expansion Maps

To determine potential habitat within the SMMNRA, we analyzed the habitat at the existing locations of each tree species. Based on a literature review and field experience, we used slope, aspect, soil type, and drainage distance as our habitat parameters. We determined the habitat most often used (one standard deviation) by each tree within existing habitat, and then modeled where else that habitat occurred within the SMMNRA.

The Los Angeles DEM and Ventura DEM were 32-bit floats, therefore we could not use them in the analysis because it would have involved decimals which are harder for computers to work with. We used the copy raster tool (data management tools > raster > raster dataset > copy raster) which uses positive and negative integers to for easier computing, to create 32-bit signed DEMs. We used the slope tool (toolbox > spatial analyst tools > surface > slope) with the new Los Angeles DEM and Ventura DEM to obtain slope data. We then used the reclassify tool (toolbox > spatial analyst tools > reclass > reclassify) to convert the slope data to a polygon. We then converted each slope raster derived from Los Angeles DEM and Ventura DEM to polygons with the raster to polygon tool (conversion tools > from raster > raster to polygon), merged them, and clipped them to the study area. Next, we used the tabulate intersection tool (toolbox > analysis tools > statistics > tabulate intersection) for slope along with each individual tree species to get standalone tables. This helped us determine the slope where trees were located. We then copied this standalone table into Excel, added the area column, and divided each number by the total to get the percentages. We repeated this same process for aspect using the aspect tool (toolbox > spatial analyst tools > surface > aspect).

Since the soil data was already vector data, we simply used the tabulate intersection tool to get the percentage of trees that grow in each soil type. We then selected the occupied soil types for each individual tree species and made a new layer.

We integrated the percentages of slope, aspect, and soil to find the areas of suitable habitat for each tree species. We used one standard deviation from the mean of each parameter to define the most suitable areas. Assuming normal distribution, one standard deviation included 68% of the occupied areas for each parameter. This resulted in a broad (yet restricted enough) zone to ascertain those areas with conditions that the most trees of each species were tolerant of, or perhaps even selected. Next, we used the reclassify tool (toolbox > spatial analyst tools > reclass > reclassify) on the slope and aspect rasters derived from Los Angeles DEM and Ventura DEM. This tool allowed us to give values of 0 or 1 to the slope and aspect. A 0 indicated a particular slope or aspect contained limited or no trees of that species. A 1 indicated that slope or aspect contained tree percentages within 1 standard deviation from the mean. We converted the reclassified slope and aspect DEMs to polygons. We selected for all values of 1 for slope and aspect to get new layers of suitable areas for each species.

For all trees except black walnut, scrub oak, and valley oak, we then intersected the occupied soil, aspect, and slope with the drainages layer. This provided the potential existing suitable habitats of each tree species. This potential suitable habitat layer was displayed as line data. Therefore, we added a 25-meter buffer around the potential suitable areas to give us an area to work within when deciding where to plant.

Because black walnut, scrub oak, and valley oak are not as water dependent as the other trees in our analysis, we chose to substitute evapotranspiration data for the riparian layer. The evapotranspiration data consisted of a raster of 1981-2010 annual normal evapotranspiration in mm. We used the raster to polygon tool (conversion tools>from raster>raster to polygon) to create a polygon of the evapotranspiration data. We then intersected the occupied soil, aspect, and slope with the evapotranspiration data. This provided the potential existing suitable habitats for these tree species.

Climate Variables

To develop the climate limited distribution maps found in the main plan, we integrated existing conditions, potentially suitable areas and overlaid that with the RPS 8.5 business as usual envelopes developed by our NASA partners (Appendix D). Temperature and evapotranspiration are also variables that greatly influence tree health. To get a range of maximum average temperatures and evapotranspiration, we obtained 250-meter topofire data from our partners at NASA. This data consisted of 1981-2010 annual normal for maximum average temperature and evapotranspiration. Maximum average temperature was in degrees C and evapotranspiration was in units of mm. We used the raster to point tool (conversion tools > from raster > raster to point) for the maximum average temperature and evapotranspiration rasters to add points inside each raster cell. For the tree polygons, we used the feature to point tool (data management tools > features > feature to point) to get points inside each of the polygons. We then used the extract values to point tool (spatial analyst tools > extraction > extract values to points) to intersect the raster points values with the polygon points. This gave us the values for each tree polygon. We then got the range of maximum average temperatures and evapotranspiration for each tree species. We used this same method to get maximum average temperature and evapotranspiration for potential tree species habitats.

We also explored using precipitation as a habitat variable; however, we could not find a precipitation layer at the appropriate scale within the timeframe of the study.

Data Layers

To determine the most suitable habitat for the significant tree species, we performed a vector-based suitability analysis in ArcGIS Pro 2.3.0. We also examined other suitability analysis methods, such as Maxent and Wallace, but decided ArcGIS Pro best fit our needs. Vector data is a spatial data type represented through points, lines, or polygons. Our first step was to gather our data layers from a variety of sources (*Table 2, GIS Layers Used in the Habitat Suitability Model*). We obtained the Santa Monica Mountains National Recreation Area (SMMNRA) boundary and SMMNRA 2007 vegetation layers from our partners at the National Park Service (NPS). We retrieved 1/3 arc-second (10 meter) Digital Elevation Models (DEMs) (grdn35w119_13 and grdn35w120_13; hereafter Los Angeles DEM and Ventura DEM) for the Los Angeles and Ventura County areas from the United States Geological Survey's Earth Explorer website. Digital Elevation Models (DEMs) provide 3D visuals of any surface in a cell-based format. These models can be used for analyses such as determining slope and aspect for a given area. Maximum average temperatures DEM in degrees Celsius (250 meter), evapotranspiration DEM in mm (250 meter), and RCP 4.5 and 8.5 (30 meter) future climate data were provided by our partners at NASA. Soil data was retrieved from the United States Department of Agriculture's Web Soil Survey website. Stream data was retrieved from CalFish's California Hydrography website. Major roads were obtained through LA County.

Table 2. GIS Layers Used in the Habitat Suitability Model. Provides a description of the layer, our source, and layer's scale if appropriate.

Layer Short Description	Long Description	Source	Scale
Los Angeles DEM (grdn35w119_13)	Digital Elevation Model of Los Angeles County portion of study area	United States Geological Survey's Earth Explorer website (earthexplorer.usgs.gov)	⅓ arc-second (10 meters)
Ventura DEM (grdn35w120_13)	Digital Elevation Model of Ventura County portion of study area	United States Geological Survey's Earth Explorer website (earthexplorer.usgs.gov)	⅓ arc-second (10 meters)
Soil	USDA soil types	United States Department of Agriculture's Web Soil Survey website (websoilsurvey.nrcs.usda.gov)	N/A

Layer Short Description	Long Description	Source	Scale
California Streams (Drainages)	Streams, rivers, and watersheds	CalFish's California Hydrography website (https://www.calfish.org/)	N/A
2010 TIGER Roads (Los Angeles Major Roads)	Los Angeles major roads	Los Angeles County GIS Data Portal (egis3.lacounty.gov/dataportal/)	N/A
2013 Tiger/Line Shapefile (Ventura County Major Roads)	Ventura County major roads	Data.Gov (https://catalog.data.gov/)	N/A
Maximum Average Temperature	Digital Elevation Model (annual normals in degrees Celsius 1981-2010)	NASA (via email)	250 meters
Evapo-Transpiration	Digital Elevation Model (units in mm, 1981-2010)	NASA (via email)	250 meters
SMMNRA 2007 Vegetation	Vegetation layers used to determine tree species locations	National Park Service, Santa Monica Mountains National Recreation Area (via email)	N/A
SMMNRA Boundary	Study area	National Park Service, Santa Monica Mountains National Recreation Area (via email)	N/A

Results

Existing Conditions

Most species were found in fine-loamy to loamy soils (*Table 3, Existing Habitat Characteristics for Significant Tree Species in the Santa Monica Mountains*). The exception was valley oak, which was found in fine-loamy and clayey-skeletal soils. Aspects varied by species, as did slopes. However, no tree species were found on slopes greater than 45 degrees. In addition, coast live oak was found on steeper slopes than valley oak. The trees were found in average maximum temperatures ranging from 17 to 25°C. Evapotranspiration rates within the existing habitat of the trees ranged from 217 to 343 mm. Existing acreage for each species ranged from 32 acres (red willow) to 11,538 acres (coast live oak). *Table 3*, below, describes existing habitat characteristics for each tree species.

Potential Habitat

Average maximum temperatures in potential habitats generally agreed with average maximum temperatures in existing habitats (*Table 4, Potential Habitat Characteristics for Significant Tree Species in the Santa Monica Mountains*). The exception was white alder, which was found in a narrow range of 21-22°C in its existing habitat but a broader range of 17-25°C in the modeled potential habitat. Overall, evapotranspiration rates in potential habitat ranged from 216-346 mm, similar to the evapotranspiration rates range within existing habitat. A number of individual species, however, had greater than 10 mm higher evapotranspiration rates in their modeled potential habitats, including arroyo willow, big leaf maple, California bay laurel, California sycamore, Fremont cottonwood, red willow, and white alder. Potential acreage for each species ranged from 948 acres (California bay laurel) to 55,480 acres (valley oak). Two trees' (California bay laurel, coast live oak) potential habitats comprised less acreage than their respective existing habitats. All other species' potential habitats comprised more acreage than their existing habitats.

Table 4 below, describes potential habitat characteristics for each tree species. *Figures 5-16* also below, graphically depict potential and existing habitat within the study area for each tree species. Online interactive maps will be hosted by Los Angeles County GIS Data Portal (https://egis3.lacounty.gov/dataportal/2019/12/12/native-tree-restoration-priority-planning-areas/).

Table 3. Existing Habitat Characteristics for Significant Tree Species in the Santa Monica Mountains. These parameters were used to determine potential habitat for each significant tree species in the Santa Monica Mountains.

Species	**Soil**	**Aspect**	**Slope (degrees)[2]**	**Avg Max Temp (°C)[1]**	**Evapotranspiration (mm)[1]**	**Area (acres)**
Acer macrophyllum **(big leaf maple) [point data]**	Fine-Loamy, Loamy	All aspects except flat, NE, NW	3, 8, 16-45	21-25	262-308	-
Acer negundo **(box elder) [point data]**	Loamy	All aspects except flat, N, NE, SE, SW	8, 16, 21, 30	-	-	-
Alnus rhombifolia **(white alder)**	Loamy	All aspects except flat, N, NW	5-11, 21-45	21-22	258-279	67
Juglans californica **(California black walnut)**	Fine-Loamy	All aspects except flat, SE, S, SW, W	21-45	17-25	221-315	3495
Platanus racemosa **(California sycamore)**	Fine-Loamy, Loamy	All aspects except flat, N, NW	5-9, 21-30	18-25	226-324	2707
Populus fremontii **(Fremont cottonwood) [point data]**	Fine-Loamy, Loamy	N, NE, SW	3-5, 30	21-25	232-290	-
Quercus agrifolia **(coast live oak)**	Fine-Loamy, Loamy	All Aspects except flat, SE, S, SW, W	21-45	17-25	217-342	11538
Quercus berberidifolia **(scrub oak)**	Fine-Loamy, Loamy	All aspects except SE, S, and SW	14-45	18-25	228-324	3166
Quercus lobata **(valley oak)**	Clayey-Skeletal, Fine-Loamy	N, NE, W, NW	3-21	20-24	238-343	1022
Salix laevigata **(red willow)**	Fine-Loamy	S, SW	1-6, 21	2	273	3
Salix lasiolepis **(arroyo willow)**	Fine-Loamy, Loamy	All aspects except flat, N, E	1-8	20-23	258-315	53
Umbellularia californica **(California bay laurel)**	Loamy	All aspects except flat, E, SE, S, SW, W	21-45	17-22	228-301	1394

[1] 1981-2010 Annual Normals

[2] Slopes are derived from where tree polygons intersect with slope polygons in ArcPro; it is assumed that actual slopes will fall within a range based on these numbers.

Table 4. Potential Habitat Characteristics for Significant Tree Species in the Santa Monica Mountains. These parameters describe characteristics of potential habitat for each significant tree species in the Santa Monica Mountains given current climate conditions.

Species	Potential Max Avg Temp[1] (°C)	Potential Evapotranspiration[1] (mm)	Potential Area (with 25m buffer) (acres)
***Acer macrophyllum (*big leaf maple) [point data]**	17-25	218-346	10441
***Acer negundo* (box elder) [point data]**	18-25	217-324	-
***Alnus rhombifolia* (white alder)**	17-25	218-327	9178
***Juglans californica* (California black walnut)**	17-25	216-353	103454
***Platanus racemosa* (California sycamore)**	17-25	217-338	14643
***Populus fremontii* (Fremont cottonwood) (point data)**	17-25	216-338	5595
***Quercus agrifolia* (coast live oak)**	17-24	217- 338	5034
***Quercus berberidifolia* (scrub oak)**	17-25	216-336	123309
***Quercus lobata* (valley oak)**	17-24	223-353	55480[2]
***Salix laevigata* (red willow)**	21-22	234-290	2515
***Salix lasiolepis* (arroyo willow)**	17-24	217-338	8767
***Umbellularia californica* (California bay laurel)**	18-24	224-322	948

[1] 1981-2010 Annual Normal [2] Does not include 25 m riparian buffer.

The maps generated below are a compromise between most accurately predicting habitat and including all possible locations where the trees might occur within the SMMNRA. There could be additional areas outside the ranges created by the model (*Table 3*, *Table 4*) that could also be suitable and there could also be areas identified as potentially suitable for some reason unknown to date. Based on the limitations, there is higher confidence in the projected suitable habitat for the riparian guild species due their limited habitat constraints and less confident for upland species.

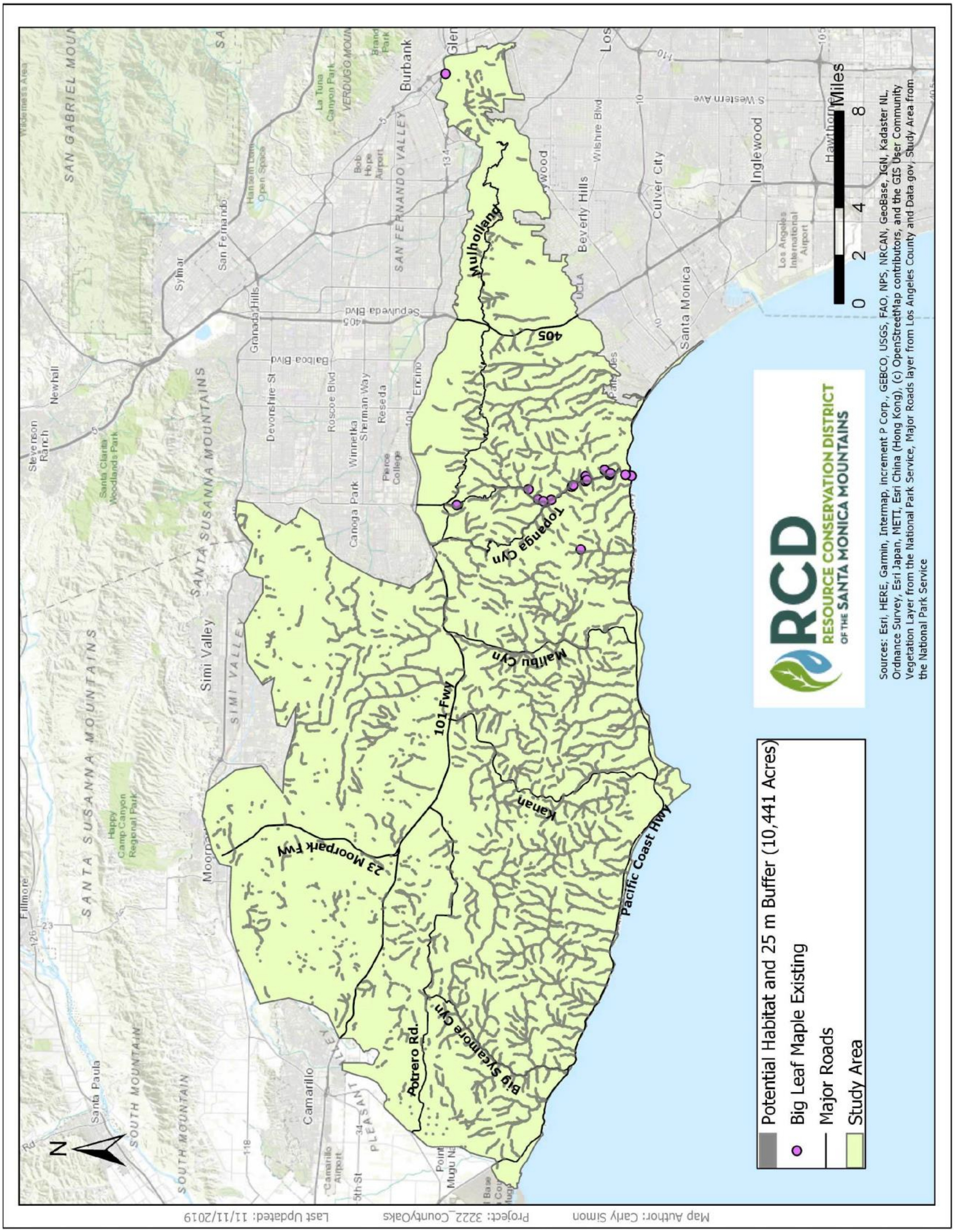
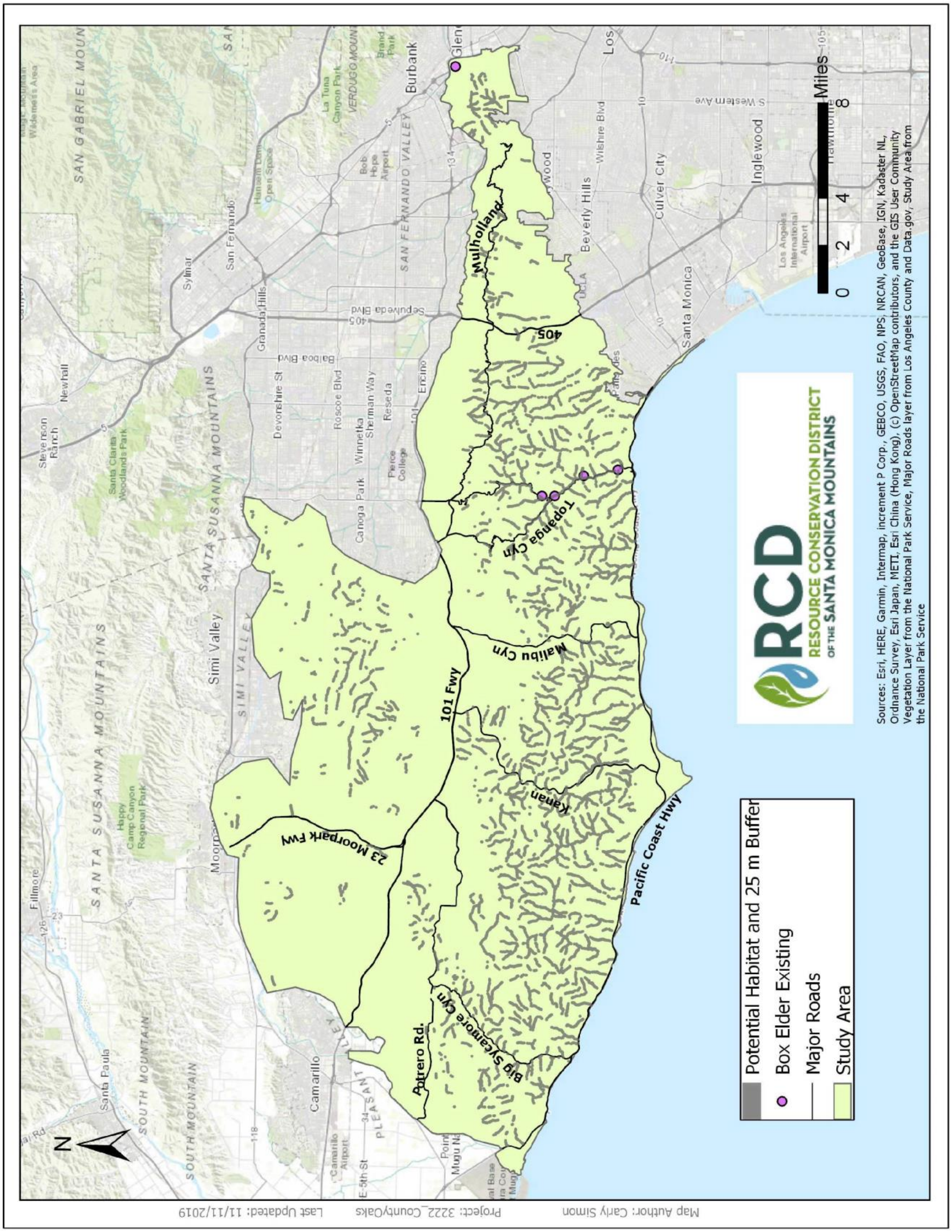


Figure 5. Acer macrophyllum (Big Leaf Maple).



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community Vegetation Layer from the National Park Service, Major Roads layer from Los Angeles County and Data.gov, Study Area from the National Park Service

Figure 6. Acer negundo (Box Elder).

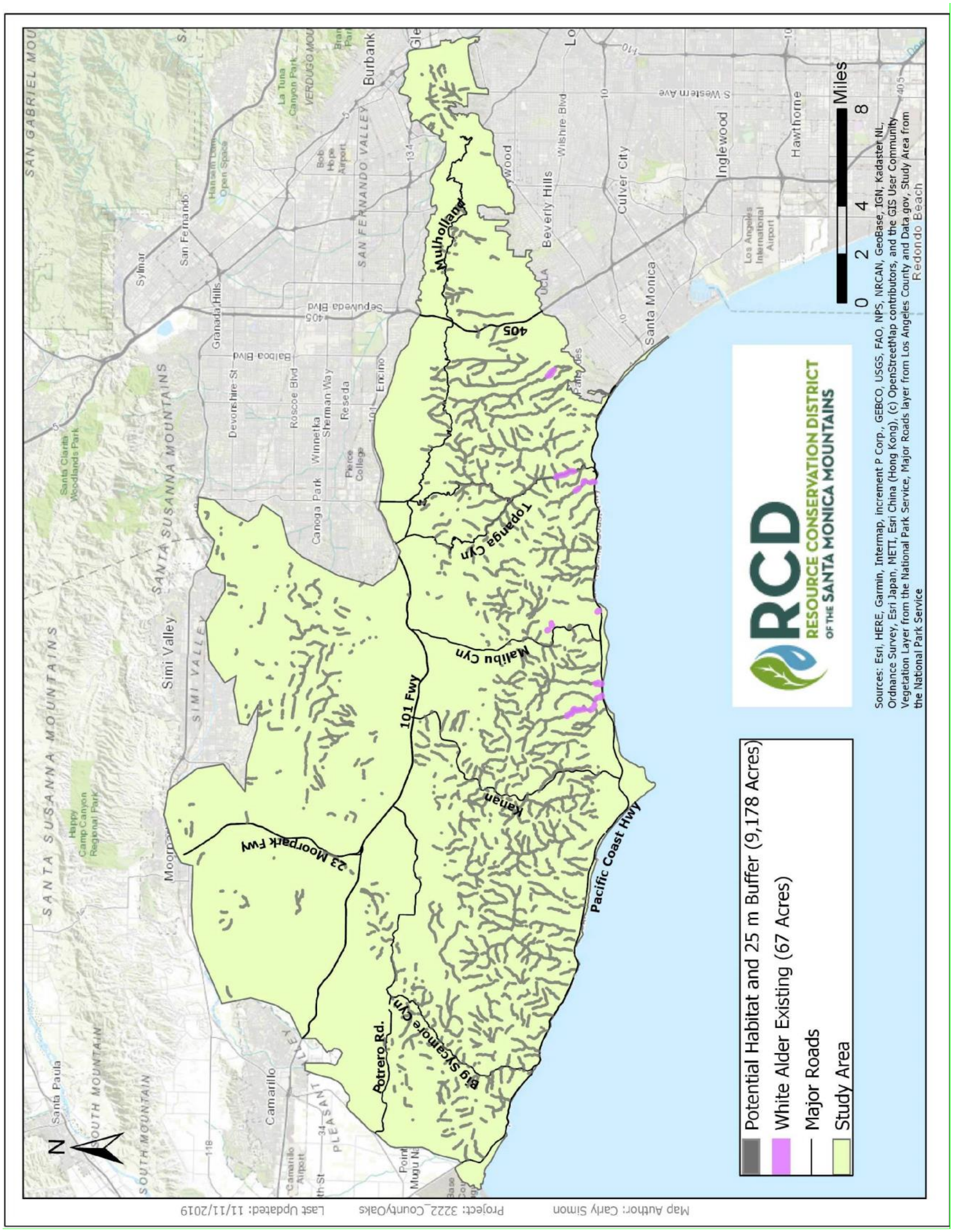
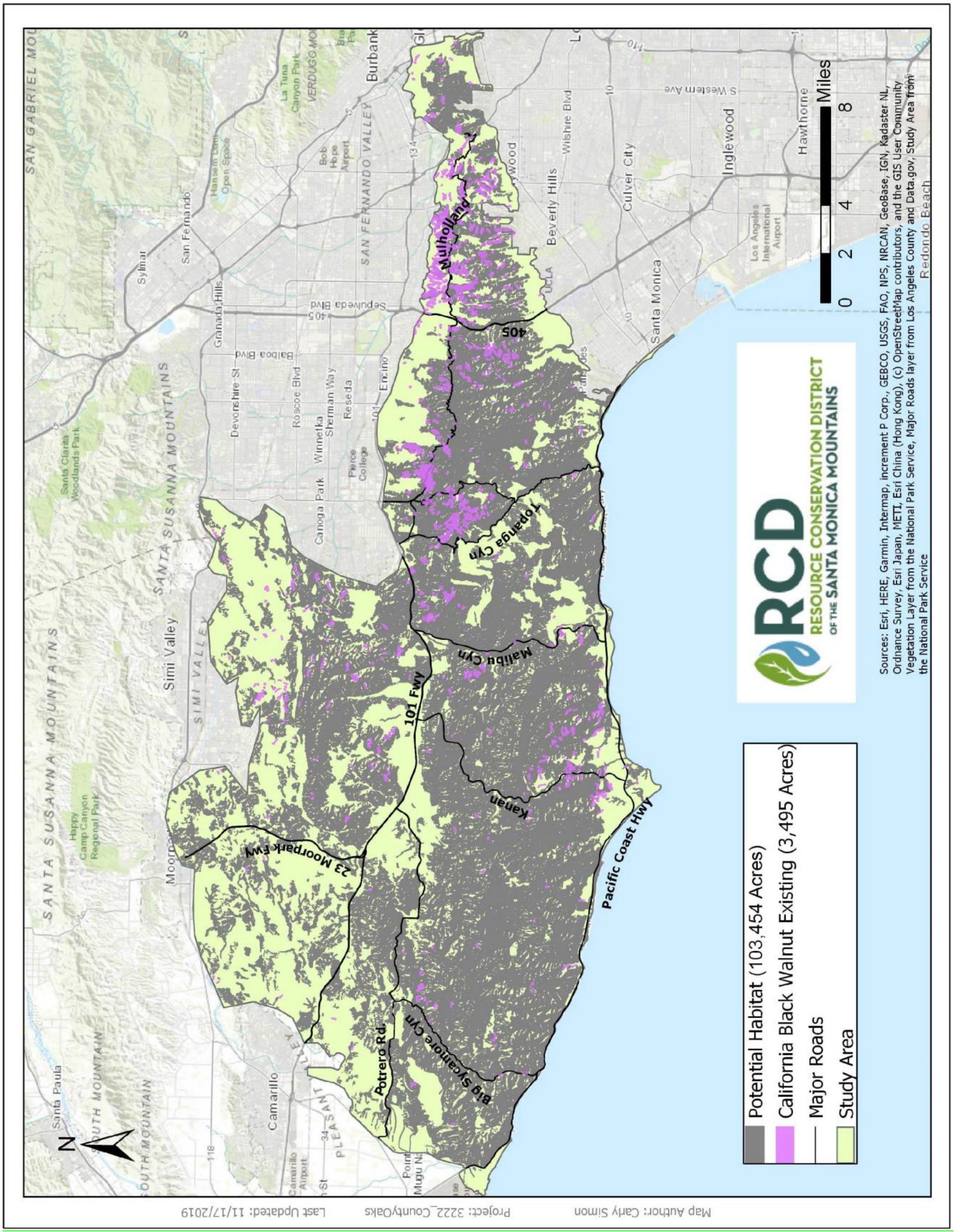
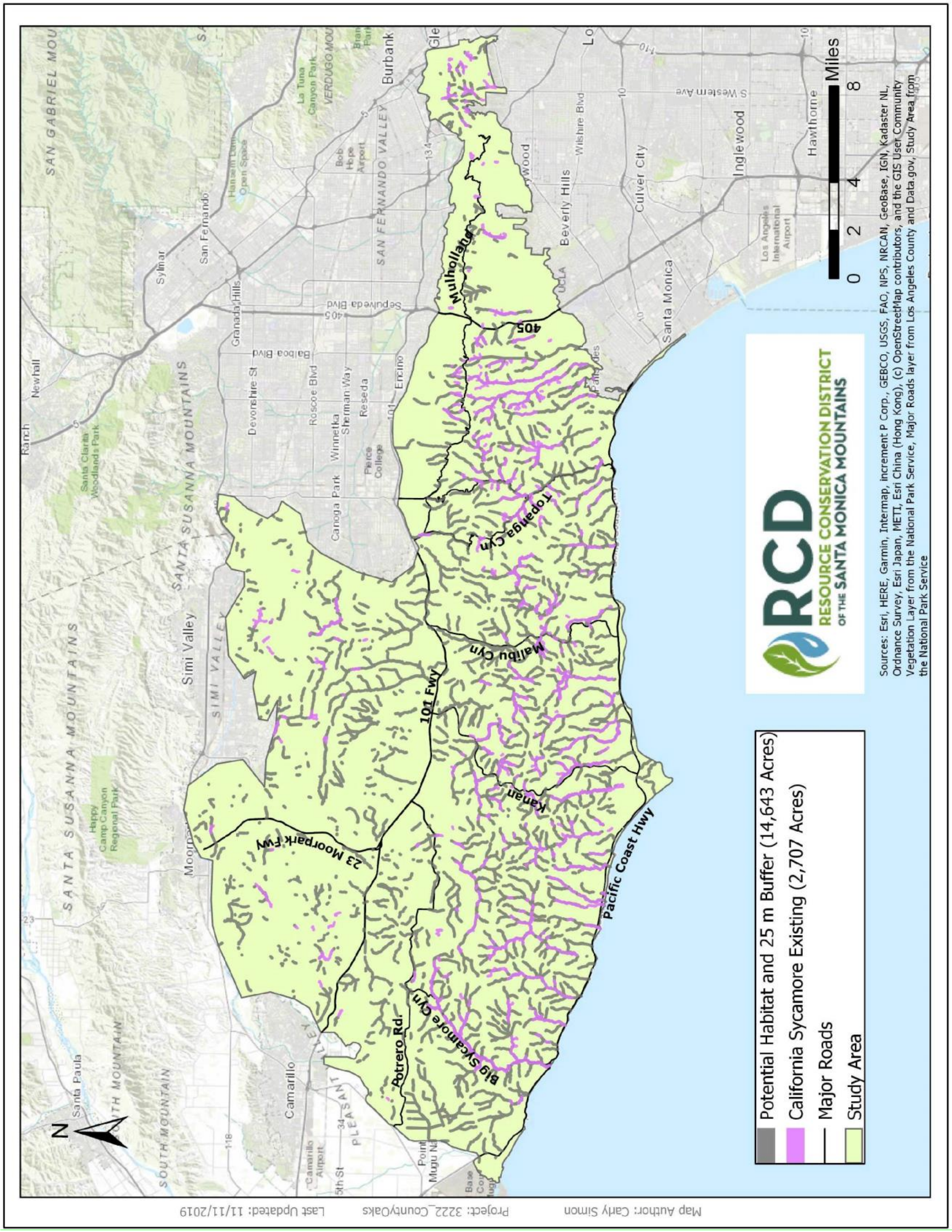


Figure 7. Alnus rhombifolia (White Alder).



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community Vegetation Layer from the National Park Service, Major Roads layer from Los Angeles County and Data.gov, Study Area from the National Park Service

Figure 8. Juglans californica (California Walnut).



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community
Vegetation Layer from the National Park Service, Major Roads layer from Los Angeles County and Data.gov, Study Area from the National Park Service

Map Author: Carly Simon Project: 3222_County/Oaks Last Updated: 11/11/2019

Figure 9. Platenus racemosa (California Sycamore).

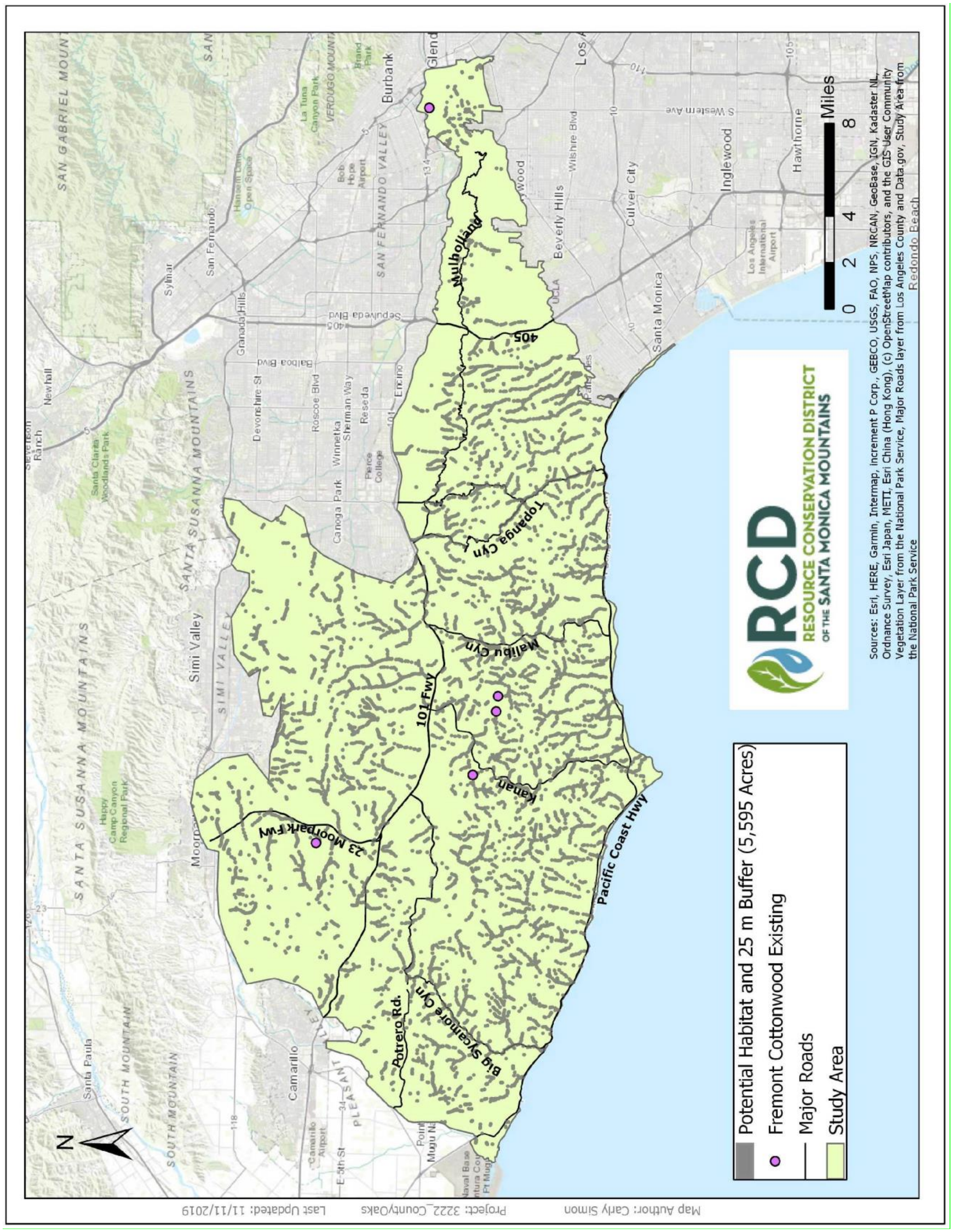
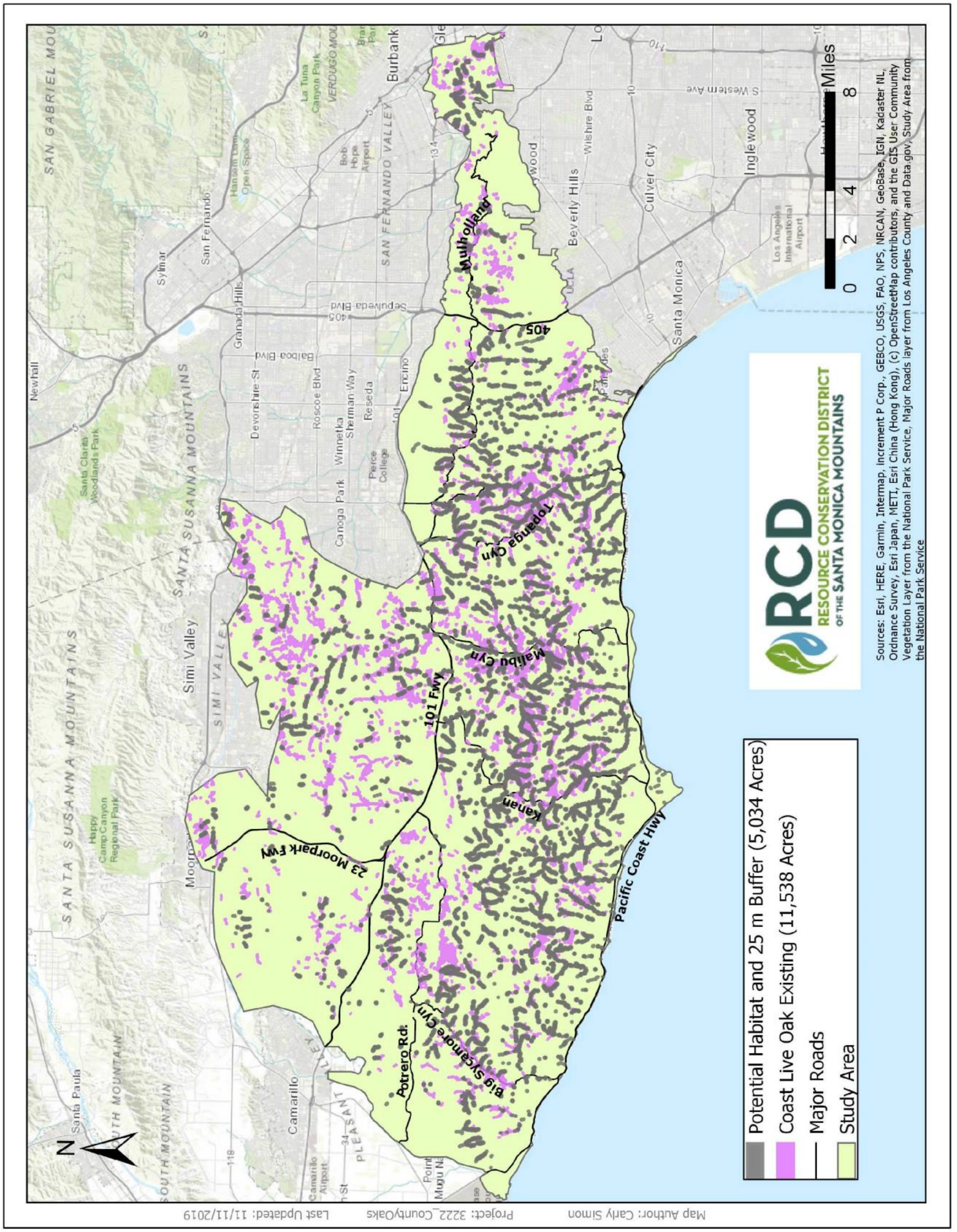


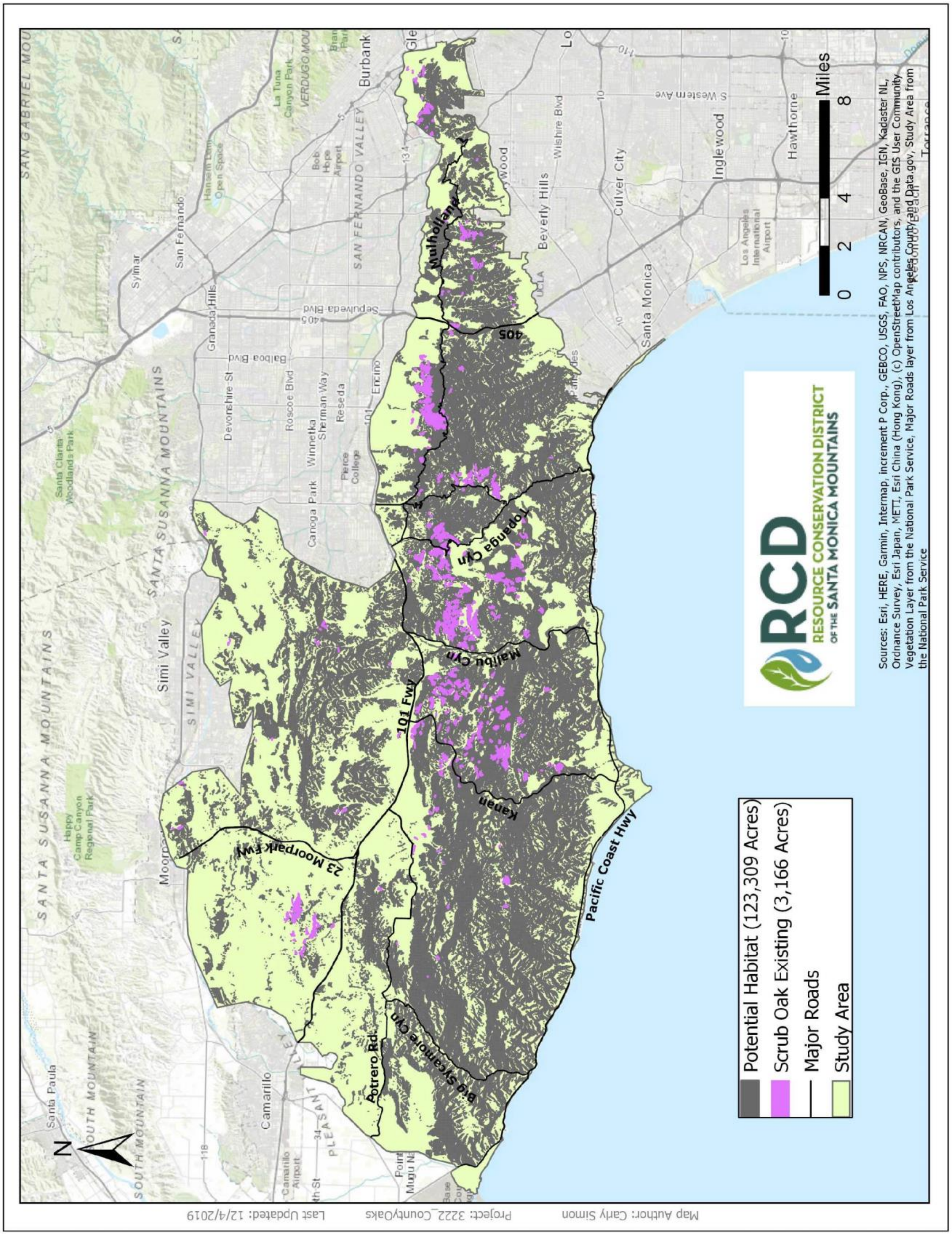
Figure 10. Populus fremontii (Fremont Cottonwood).



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community Vegetation Layer from the National Park Service, Major Roads layer from Los Angeles County and Data.gov, Study Area from the National Park Service

Map Author: Carly Simon Project: 3222_CountyOaks Last Updated: 11/11/2019

Figure 11. Quercus agrifolia (Coast Live Oak)



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community Vegetation Layer from the National Park Service, Major Roads layer from Los Angeles County and Data.gov, Study Area from the National Park Service

Figure 12. Quercus berberidifolia (Scrub Oak.)

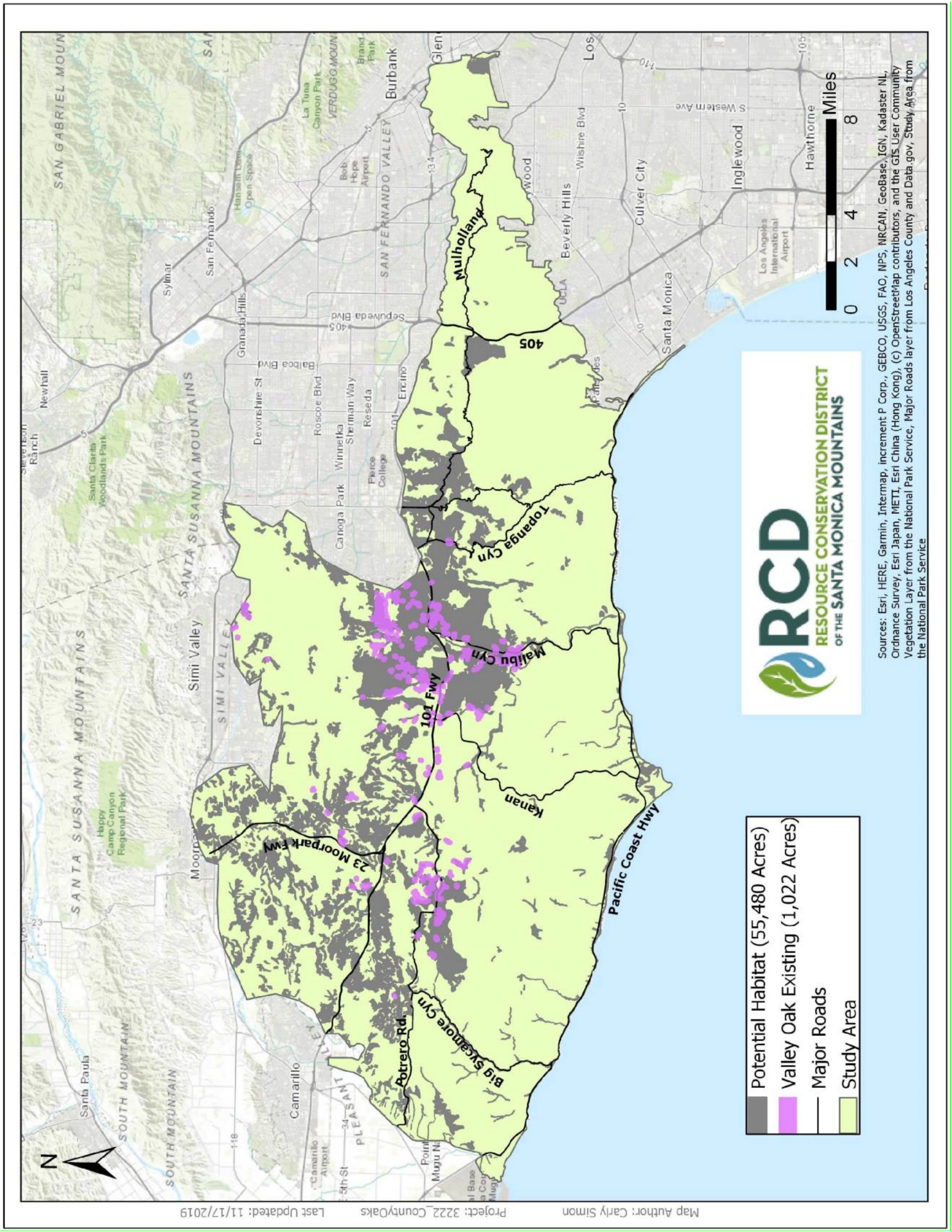


Figure 13. Quercus lobata (Valley Oak).

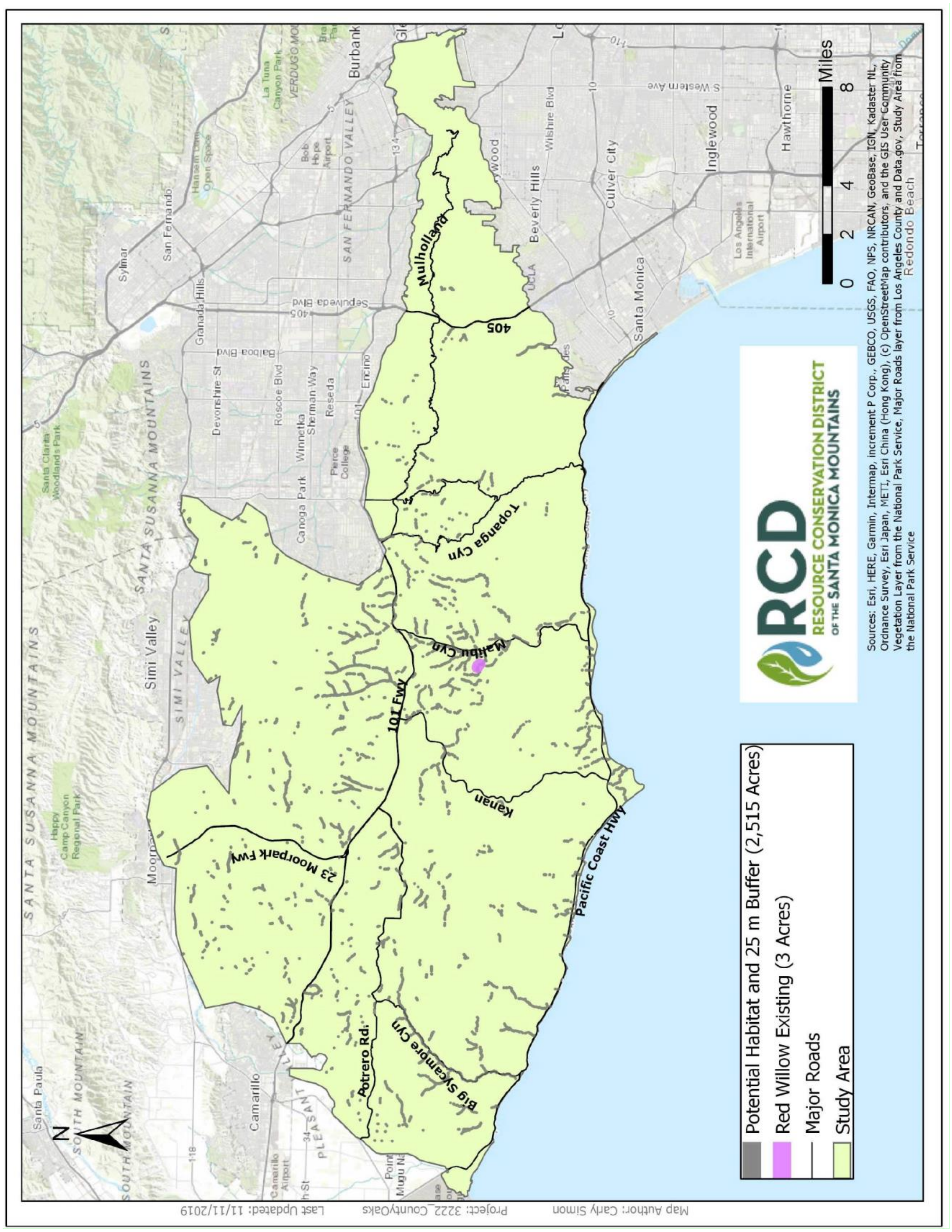
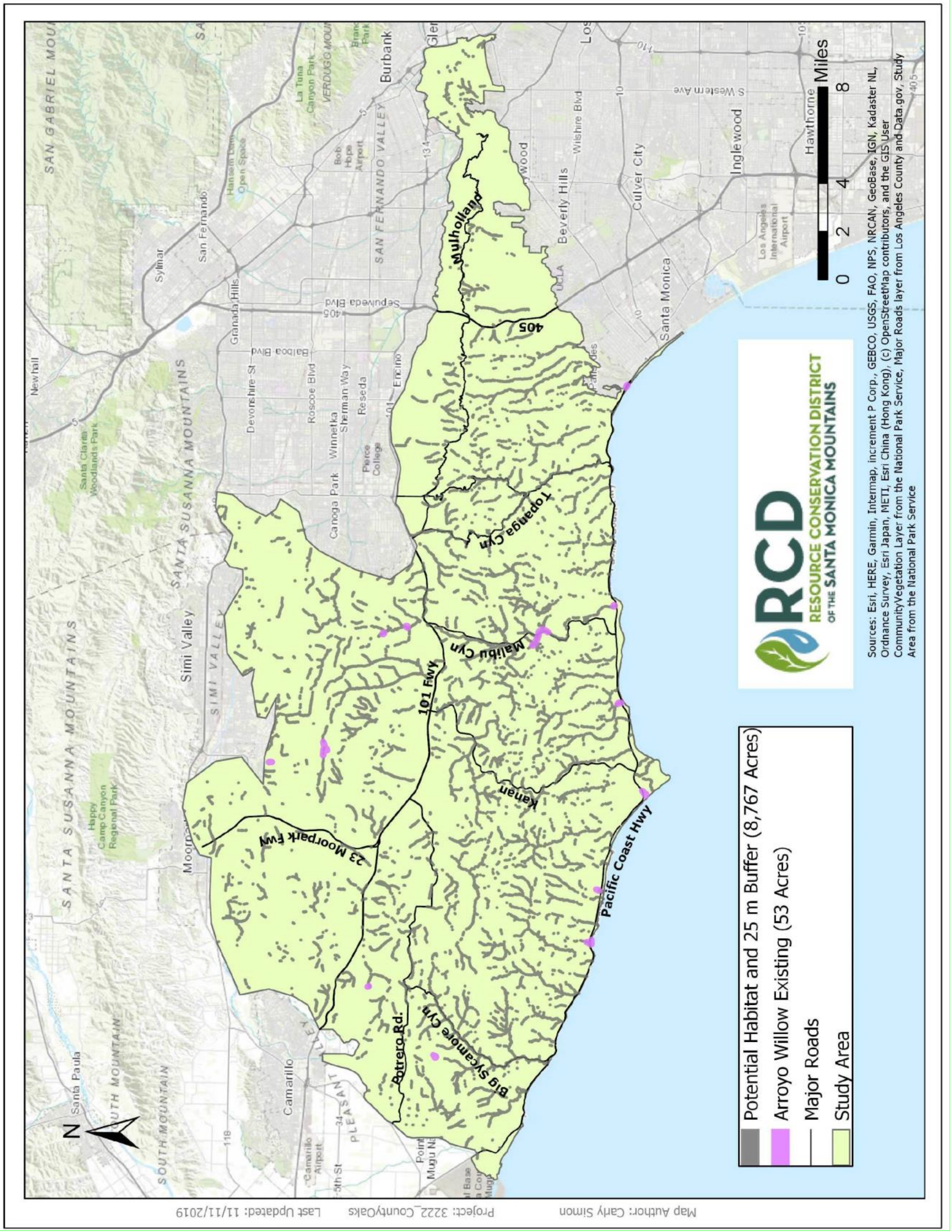


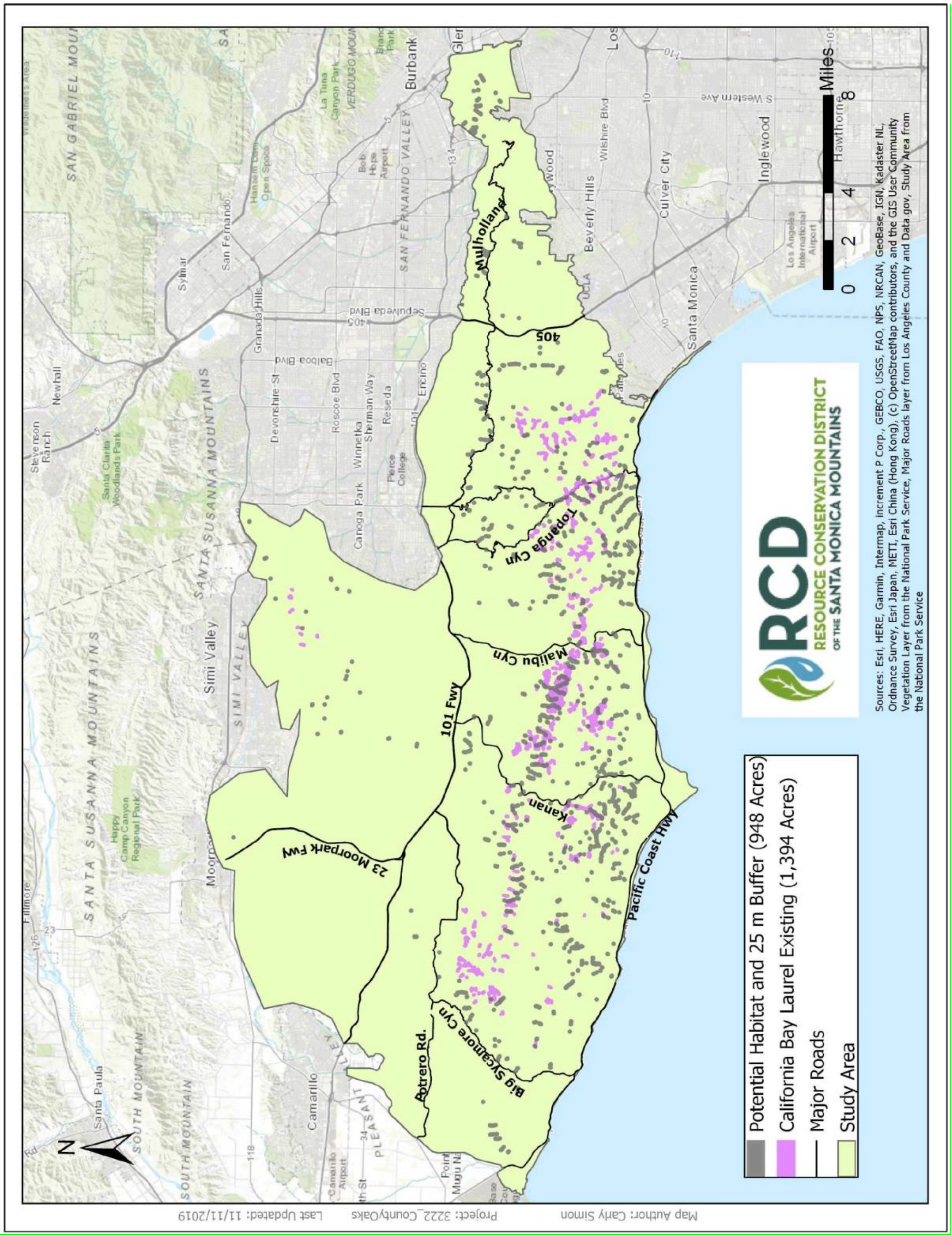
Figure 14. Salix lasiandra (Red Willow).



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community Vegetation Layer from the National Park Service, Major Roads layer from Los Angeles County and Data.gov, Study Area from the National Park Service

Map Author: Cally Simon Project: 3222_CountyOaks Last Updated: 11/11/2019

Figure 15. Salix lasiolepis (Arroyo Willow).



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community Vegetation Layer from the National Park Service, Major Roads layer from Los Angeles County and Data.gov, Study Area from the National Park Service

Map Author: Cary Simon Project: 3222_CountyOaks Last Updated: 11/11/2019

Figure 16. Umbellularia californica (California Bay Laurel)

Discussion

These maps provide guidelines for potential areas to consider planting trees for voluntary restoration or mitigation purposes in the SMMNRA based on existing conditions. In the main document, these maps are overlaid with NASA's climate suitability models to provide a visual of optimal planting areas for each species given climate change. However, potential suitable habitats have not yet been field-checked. We recommend ground-truthing of any suggested suitable habitats depicted on the maps to determine actual field conditions before planning any restoration or planting project. These areas may already contain a mature native vegetation community of another type (e.g. chaparral or sage scrub), may have mature trees of the target species that were not represented in our vegetation layers, or may be too altered for restoration purposes.

These concerns may also explain the much larger acreages of potential than existing habitat that we saw for many species (*Figures 5-16; Tables 3, 4*). Arroyo willow, for example, had 53 acres of existing habitat within the study area, but 8,767 acres of potential habitat. In addition, these species are mostly riparian species, and require mesic habitats or deep subsurface waters. It is likely that some of the riparian areas included as potential habitat do not meet these requirements. It was, however, beyond the scope of our study to analyze this further.

We chose to integrate drainages into our model because we believe water availability is already and will continue to have a large influence on tree survival and recruitment in the SMMNRA as the climate continues to change. Therefore, areas with more water availability may act as microrefugia for many tree species (Ferriter et al. 2019, Hayes and Donnelly 2017, McLaughlin and Zavaleta 2012). Microrefugia, which contain locally favorable conditions within broader unfavorable conditions, may allow populations of species to persist as the earth continues to warm (Dobrowski 2010). In addition, riparian areas are commonly used as movement corridors by wildlife and often provide a cooler microclimate than the surrounding landscape, making them important tools for climate-smart connectivity planning (Keeley et al. 2018). However, it was beyond the scope of our study to incorporate other sources of water into our model, such as springs, seeps, and aquifers or other underground sources. We also did not incorporate wetlands and waterbodies into our model. These other water sources, if incorporated, could broaden the distribution of potential suitable habitat for some species.

For example, coast live oak's potential habitat may be less than the existing habitat due to our focus on riparian habitats in the model. Since coast live oak is so widely distributed, but not always a riparian species, limiting our model to riparian areas skewed the model towards these corridors and limited the potential acreage. California bay laurel, although not as widely distributed in the SMMNRA, has similar ecological characteristics. However, given the potential habitat maps' ultimate integration with climate change data, we feel that focusing on riparian corridors, where these trees will have better access to water, is appropriate.

In addition, although we know we have been losing trees at a rapid rate in recent years, we do not yet have data on tree recruitment rates or locations in the SMMNRA. It has been demonstrated that seedling and saplings have narrower requirements than mature trees, at least for certain species (McLaughlin and Zavaleta 2012). Additional data on tree recruitment is desperately needed and could potentially be obtained with assistance from community volunteers. Although beyond the scope of this project, the RCDSMM hopes to further develop this in the future. Having more locally specific information on recruitment patterns that can be incorporated into the next phase of this effort could result in a model that more accurately reflects the habitat requirements of the size classes that will be grown at restoration or planting sites.

Limitations

This initial effort to examine habitat suitability for native tree species used the best available data, but we recognize the following limitations that could affect the results. We recommend that further studies address these issues to refine the models.

-The 2007 SMMNRA Vegetation layers that provided the tree species data were collected between 2001 and 2004. While it is the best available at this time, this data may not accurately display the current distribution of trees and does not take into account the seven-year drought that damaged thousands of trees in the Santa Monica Mountains.

-The 2007 SMMNRA Vegetation data only displayed the dominant trees in the polygon area. This does not accurately represent the full extent of each species range in the SMMNRA. However, the model represents those habitats where each species is a dominant part of the vegetation, and, presumably, is most successful in the SMMNRA.

-The 2007 SMMNRA Vegetation data only contained one polygon for the red willow species, though we know they are established elsewhere through field studies in the SMMNRA. There were most likely other dominant tree species in these areas, rather than red willow. Therefore, the red willow suitability models in particular may not capture the full extent of their potential planting area.

-Most of our tree species had polygon data, but box elder, big leaf maple, and Fremont cottonwood were displayed using point data. Each point represented one tree. This is because there are so few of these species present in the study area, they are never a dominant species in the SMMNRA Vegetation data layer. Therefore, since there are only a few data points, we may not have an accurate representation of these species' potential habitats.

-The box elder point data kept crashing when we tried to obtain the range for maximum average temperature and evapotranspiration; therefore, we could not acquire these ranges. Fremont cottonwood also crashed when we tried to obtain the potential acreage, so no values are provided.

-We do not currently have data on tree size in our layers. Therefore, we could not assess recruitment levels or tree maturity within our suitable habitats. As a result, our model is most likely biased toward the habitat requirements of adult trees.

-The maximum average temperature obtained from 1981-2010 does not provide the absolute highest temperature; therefore, we could not determine the most accurate maximum temperature these trees can withstand. It also does not include the drought temperatures from 2012-2016, which damaged thousands of native woodland and riparian trees (Dagit et al. 2017).

-We had map scale sizes ranging from 10 meters to 250 meters, which may not provide us with the most detailed and consistent information. Inconsistent map scales may bias spatial models.

Future Research Needs

-Analyze trees based on actual locations in addition to SMMNRA Vegetation Layers, to get a broader perspective of habitat selection for each species.

-Add additional variables, such as water availability, evapotranspiration, and maximum temperatures, to the habitat suitability model to increase to confidence of the model. Consider weighting variables using NASA data on importance of variables to each guild (Ferriter et al. 2019: Appendix D).

-Analyze drought tree death data (where applicable). Determine conditions where trees survived versus conditions where trees died to find the habitat variables that separate the two. Then apply these differences to the model.

-Collect field data on seedling recruitment to determine habitat conditions required for seedlings.

-To more accurately determine water/groundwater availability, collect field data on locations of springs, seeps, and other unmapped water sources in the SMMNRA.

-Collect field data such as tree size and condition metrics to determine the condition of trees in different environments.

-Analyze vegetation associations of each tree species to get a more accurate representation of their preferences in the SMMNRA.

-Lastly, study and monitor the success of the planted trees and habitat characteristics in the potential planting areas and apply to model once enough data is gathered.

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APPENDIX D

NASA DEVELOP TECHNICAL REPORT

Santa Monica Mountains Ecological Forecasting III
Analyzing Recent Wildfire Impacts to Assist the Resource Conservation District of the Santa Monica Mountains in Identifying
Tree Species to Replant

DEVELOP Technical Report

Final Draft – August 9th, 2019

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1. Abstract

The Woolsey Fire began on November 8, 2018, and lasted for almost two weeks, during which it burned almost 100,000 acres of valuable landscape and habitat, including a vast area of woodland. The persistence of key woodland species provides aesthetic, monetary, and ecological value to the landscape through carbon sequestration, air temperature moderation, and erosion mitigation, among other ecosystem services. This study investigated the impact of the Woolsey Fire on native woodland species distributions and identified areas suitable for restoration within the Santa Monica Mountains National Recreation Area. The team partnered with the Resource Conservation District of the Santa Monica Mountains; National Park Service, Santa Monica Mountains National Recreation Area; California Department of Parks and Recreation, Los Angeles County Division; County of Los Angeles Fire Department, Prevention Services Bureau, Forestry Division; County of Los Angeles Department of Regional Planning; and the University of Montana. The Earth observations used include data from Landsat 8 Operational Land Imager, NASA ER-2 Jet Airborne Visible InfraRed Imaging Spectrometer, Shuttle Radar Topography Mission, and RapidEye. The team produced maps of burn severity from the Woolsey Fire, its impact on plant species distributions, and habitat suitability projections for 2060 and 2099 to assist partners in prioritizing areas for restoration. A plant community classification was successfully created using Multiple Endmember Spectral Mixture Analysis (MESMA). Overall accuracy was assessed at 90.54% by comparing the classification to validation pixels derived from ground truth information provided by our partners.

Keywords

remote sensing, MESMA, fire, climate scenarios, habitat suitability, Maxent

2. Introduction

2.1 Background Information

The Santa Monica Mountains (SMM) are a small mountain range (61,000 ha) northwest of Los Angeles, CA. Despite their size, the SMM hold great ecological and cultural significance (Tiszler & Rundel, 2007). The Mediterranean climate combined with topographical diversity and a variable fire regime create a dynamic landscape that supports rich floral and faunal diversity, including rare habitats like coastal sage scrub, chaparral, and salt marsh (Radtke, Arndt, & Wakimoto, 1982; Tiszler & Rundel, 2007). In particular, native oak and riparian woodlands are a limited and valuable part of the landscape that provide habitat, connectivity, and fundamental ecosystem services. Although native tree species are adapted to the periodic droughts and fires characteristic of the area, prolonged drought and increasing fire frequency compounded with the effects of fragmentation, urbanization, and invasive species are causing extensive dieback and decreased recruitment (Beltrán et al., 2014; Clark et al., 2016; Grunzweig et al., 2008; Mclaughlin & Zavaleta, 2012; Park, Hooper, Flegal, & Jenerette, 2018; Riano et al., 2002; Swenson & Franklin, 2000; Westerling, Hidalgo, Cayan, & Swetnam, 2006). As the climate fluctuates and exacerbates these environmental stressors, it is necessary for land managers to maintain biodiversity and resilience and restore native species in areas that will remain suitable even under the worst-case climate scenarios (Millar, Stephenson, & Stephens, 2007).

Traditionally, restoration efforts have focused on replanting trees in their contemporary distributions without regard to how future climate will shift suitable habitat and where microrefugia could occur. Microrefugia, which offer protection against our rapidly changing climate, are microclimates that support very small populations of species in areas that are beyond the climatic limits of their main distributions (Mclaughlin & Zavaleta, 2012). Species distribution models (SDMs) are an effective way of incorporating future climate conditions into restoration management to account for these shifts in species' ranges and distributions (Riordan, Montalvo, & Beyers, 2018). Extensive dieback of native species in the SMM attributed to the recent severe droughts in California suggests that the vegetation will be vulnerable to a hotter and drier future climate, confirming the need for identification and protection of suitable habitat and microrefugia (Mclaughlin et al., 2017). Although *in situ* monitoring provides high-quality data, remote sensing provides a means of rapid mapping of species occurrence and environmental characteristics that can be used in SDMs (Buermann et al., 2008). A technique called multiple endmember spectral mixture analysis (MESMA) characterizes vegetation in hyperspectral imagery as a unique set of pure spectra that can be used to derive occurrence data by species (Roberts et al., 1998). Previous efforts to predict future habitat suitability in the SMMs have used field data to model single vegetation types with variable success (James, 2014). Additionally, studies assessing SDM inputs have demonstrated the benefits of using a combination of field data and remote sensing data to capture both regional and continental scale processes that affect species distribution (Buermann et al., 2008; Mclaughlin & Zalveta, 2012).

This study focused on the Santa Monica Mountains National Recreation Area (SMMNRA), a 62,360-hectare region that lies within Ventura and Los Angeles Counties. Paralleling the Pacific coast, the SMMNRA is characterized by rugged terrain interspersed with urban areas and woodlands. The study period of the project was June 2017 to June 2019, with model forecasts extending to 2099. Although precipitation falls largely between October and March, most imagery outside the summer months is obscured by clouds and fog due to the coastal location (Radtke et al., 1982). This study builds upon previous DEVELOP work that mapped vegetation mortality, climate variables, fire severity, and topographical influence in order to understand dieback patterns largely attributed to the 2011 to 2017 drought.

2.2 Project Partners & Objectives

The NASA DEVELOP Santa Monica Mountains Ecological Forecasting III team partnered with the Resource Conservation District of the Santa Monica Mountains (RCDSMM), National Park Service (NPS), Santa Monica Mountains National Recreation Area, California Department of Parks and Recreation, numerous departments in Los Angeles County including Fire Department, Prevention Services Bureau, Forestry Division, Regional Planning; Information Services, and the University of Montana Department of Geography. Our primary partner, the RCDSMM, has a mission to promote land stewardship and resource conservation through ecological research, conservation planning, habitat restoration, and environmental education. Currently, the RCDSMM is collecting data about the impacts that drought, pest infestation, and fire are having on Oak Woodlands using survey plots and citizen science programs. While these methods allow for an in-depth understanding of oak conditions from the ground, the survey plots cover a relatively small area of the Santa Monica Mountains. The development of a large scale overview and projection of future suitable habitat of oak woodland conditions can aid restoration ecologists in mapping areas burned in the Woolsey Fire (11/08/2019 to 11/21/2018) (Appendix A Figure A1), locating remaining woodland populations, and prioritizing areas for replanting efforts. The objectives of this project were to: (1) determine where and what species were still alive after the recent fires and drought, (2) map existing topographical and environmental conditions, and (3) map areas where native trees have survived both fire and drought to identify where conditions might be suitable to support native woodlands in the next 100 years.

3. Methodology

3.1 Data Acquisition

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) is an optical sensor flown on NASA’s ER-2 Jet at an elevation of approximately 20 km. AVIRIS has a spectral bandwidth of 10 nm, and each pixel produced by the instrument covers about a 20-meter diameter, yielding a ground swath 11 km wide. The team downloaded AVIRIS Level-2 Atmospheric Surface Reflectance imagery from the AVIRIS data portal for June 25, 2018. We selected this date because it was the most recent image available prior to the Woolsey Fire which occurred in November 2018. Specifically, we acquired rows 08, 10, 11, and 12 from AVIRIS flight f180625t01, which encompassed our study area.

The team downloaded Landsat 8 Operational Land Imager (OLI) Analysis Ready 30-meter resolution data to determine the burn severity of the Woolsey Fire. To create the Relativized Burn Ratio (RBR) burn severity map, we downloaded Landsat 8 OLI multispectral imagery via the United States Geological Survey (USGS) Earth Explorer portal for dates prior to and after the Woolsey Fire. Imagery acquired pre-fire was collected on 11/03/2018 and paired with the post-fire imagery collected on 01/22/2019. The team used Band 5 Near Infrared (NIR) and Band 7 Short Wave Infrared 2 (SWIR) which contain wavelengths of .845 - .885µm and 2.100 - 2.300µm respectively.

We used two sets of RapidEye Ortho Tile 5-meter imagery acquired from Planet Team (2019) to identify surviving vegetation following the Woolsey Fire. The initial set contained 13 Ortho Tiles ranging from January 22 - January 25, 2019. We used this initial set of imagery to create the Normalized Difference Red Edge Index (NDRE) to locate remaining vegetation post-fire. The second set of RapidEye imagery consisted of 9 Ortho Tiles taken on June 30, 2019, and only depicted 95% of our study area. After combining both sets of imagery, we used the five-band, multispectral imagery to create a land cover classification that showed current vegetation health conditions. Additionally, field investigation was conducted on July 3rd by our project partners, coincident with our second set RapidEye acquisition date. We used the results of this investigation to refine and ground truth our map of vegetation health conditions.

We acquired climate data for species distribution models from the NASA Earth Exchange (NEX) Downscaled Climate Projections (NEX-DCP30) dataset (Thrasher et al., 2013). The NEX-DCP30 comprises downscaled outputs of 33 general circulation models for the conterminous United States as part of the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor, Stouffer, & Meehl, 2012). NEX-DCP30 outputs were generated for the representative concentration pathways (RCP) scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) for the Fifth Assessment Report (IPCC, 2014; Meinshausen et al., 2011). We used monthly averages of precipitation flux (kg m-2 y-1) maximum near-surface air temperature (K), and minimum near-surface air temperature (K) for historical, RCP 4.5, and RCP 8.5 scenarios.

Our partners at the National Park Service (NPS) provided us with a detailed vegetation classification of the Santa Monica Mountains National Recreation Area and surrounding areas. The classification was created by the NPS in conjunction with the Biological Resources Division (BRD), the U.S. Geological Survey (USGS), Aerial Information Services (AIS), Environmental Systems Research Institute (ESRI), NatureServe, and the California Department of Fish and Game. The classification constituted of repeated rounds of ecological reconnaissance, aerial photography, and image interpretation, coupled with extensive ground-truth verification over many years.

To incorporate topography into our species distribution model, the team downloaded a 30-meter resolution digital elevation model (DEM) from the Shuttle Radar Topography Mission (SRTM) using USGS EarthExplorer. SRTM data was acquired globally over an 11 day period in February of 2000. The mission created a DEM of much of the world, spanning from 60° N to 56° S. The DEM from SRTM was processed to create topographic data for the study.

3.2 Data Processing

3.2.1 AVIRIS

The team pre-processed and mosaicked the AVIRIS images to the study area using Harris Corporation ENVI (Exelis Visual Information Solutions, 2019). Pre-processing included rotating the images to the correct angle specified in the metadata, which ENVI automatically reads in the rotate tool. We changed values representing missing data to be uniform throughout each image, as the downloaded AVIRIS data had multiple values for areas with no data.

Species Mapping

VIPER Tools, an ENVI package created by the VIPER Lab at the University of California, Santa Barbara, was used to classify land cover for the study area prior to the Woolsey Fire event. VIPER Tools simplifies the process of multiple endmember spectral mixing analysis (MESMA), a method of using pure representations of a spectral class, called endmembers, to classify an image. MESMA has been used to successfully map vegetation species with high accuracy (Roberts et al., 1998). MESMA can be used as a classifier with a two-endmember model. In this method, the classification algorithm is based upon picking two endmember models that fit each pixel spectrum with the lowest RMSE. For this term, the team used the spectral library created by the fall 2017 Santa

Monica Mountains Ecological Forecasting II team to classify 2018 AVIRIS imagery into 7 classes. The vegetation classes are: annual grass, chaparral (*Adenostoma fasciculatum, Ceanothus megacarpus, Ceanothus spinosus, Cercocarpus betuloides, Malosma laurina, Quercus berberidifolia)*, coastal sage scrub (*Artemisia spp., Eriogonum cinereum, Eriognum fasciculatum, Cercocarpus fasciculatum, Salvia spp.,)*, Oak Woodland (*Quercus agrifolia*), and riparian (*Alnus rhombifolia, Juglans californica, Platnaus racemosa, Salix spp.)*. We also included substrate (including urban areas) and water classes to prevent misclassification, as our image contained large areas of these classes. This term used the same constraints as the previous term; we ran MESMA with 2-endmember models, fractional constraints limited from values 0 to 1, and RMSE and residuals maxima raised to 0.15. We chose these constraints due to computational limitations and in order to fully classify every pixel within the image. Outputs consisted of a non-shade fraction and shade-fraction for each class. The shade-normalization tool in VIPER tools was used to create a classification showing class dominance within each pixel for the entire Santa Monica Mountains recreation area.

3.2.2 Landsat 8 OLI

All Landsat 8 OLI imagery was processed using QGIS Raster Calculator Tool (QGIS Development Team, 2019). To determine the Relativized Burn Ratio (RBR), multiple preliminary indices needed to be calculated. The initial index used within RBR was the Normalized Burn Ratio (NBR) (*Equation 1*), a common index used for burn analysis. The NBR was then implemented within a more advanced burn severity index, the difference Normalized Burn Ratio (dNBR) (*Equation 2*). This index takes the pre- and post-fire NBR and calculates the difference between them, indicating the burn severity of the fire. Finally, the RBR was produced using the dNBR and the pre-fire NBR (*Equation 3*). The dNBR is relativized using the pre-fire NBR, which gives a more accurate result of burn severity (Parks, Dillon, & Miller, 2014).

$$NBR = \frac{NIR - SWIR}{NIR + SWIR} \tag{1}$$

$$dNBR = (NBR\,prefire - NBR\,postfire) \times 100 \tag{2}$$

$$RBR = \frac{dNBR}{NBR\,prefire + 1.001} \tag{3}$$

$$NDRE = \frac{NIR - RE}{NIR + RE} \tag{4}$$

3.2.3 Rapid Eye

To create a single raster that included the entirety of the study area, we mosaicked the imagery together. Next, using the raster calculator tool, we calculated the Normalized Difference Red Edge (NDRE) index as defined in *Equation 4*. RapidEye Imagery from 06/30/2019 was also classified to highlight vegetation health. A MESMA two-endmember model classification algorithm was chosen as a classifier because of its ability to account for brightness of pixel spectra (Roberts et al, 2019) This feature was of interest due to the topographic variations in the Santa Monica Mountains that result in a large amount of shaded areas. Endmembers were selected to represent 5 classes: thriving vegetation, healthy vegetation, vegetative presence, non-photosynthetic areas, and water.

Initially, 200 endmembers were selected to represent these classes. Non-photosynthetic areas were also broken up into separate classes (burned area, dirt/substrate, and urban) because of the difference in spectra which would cause the model to not run due to high RMSE. Using VIPER Tools, endmembers were pruned based on endmember average RMSE (EAR) and the resulting spectral library consisted of 28 endmembers. Spectra of these endmembers are depicted in Figure J1 in Appendix J. Non-photosynthetic classes (burnt, dirt, and urban) were combined into one class prior to spectral unmixing. No constraints on the two-endmember model were in place due to the high RMSE caused by the non-photosynthetic class spectra variability. A dominant class pixel classification was output in identical style to the AVIRIS MESMA classification. The classification was passed through a 3x3 pixel majority/minority analysis in ENVI to reduce speckles.

3.2.4 Climate Data

Monthly values of precipitation rate, minimum near-surface air temperature, and maximum near-surface air temperature from NEX-DCP30 (30-arcsecond grain size) were averaged over four time periods to reflect the life stages of trees: 1950-1979; 1980-2005; 2020-2060; and 2061-2099 (Appendix B Figure B1). The targeted time periods are necessary to reflect the different climatic conditions which are optimal for seedling vs. mature trees. The time period 1950-1979, covers the end of a recruitment pulse of many tree species in the SMM (R. Dagit, personal communication, July 8, 2019) through their seedling and sapling life stages. We assumed that the same cohort matured during the 1980-2005 time period. The current distribution of this cohort is assumed to be reflected in the NPS vegetation polygons used to determine species presence. The 2020-2060 time period reflects recruitment and the seedling stage for the cohort to be planted by the RCDSMM and other partners as part of their effort to restore the Santa Monica Mountains; models run for this time period will be referred to as seedling models. The 2061-2099 time period will be the period when the restoration cohort will mature; models run for this time period will be referred to as mature models. The purpose of using targeted time periods was to project the future distributions of seedlings when they are seedlings and mature trees when they are mature trees. By projecting the distributions separately and combining them in ArcMap, we generated a map of the most suitable habitat throughout the life of the trees (ESRI 2019). All climate data file manipulation was done using R package ‘ncdf4’ (Pierce, 2019; R Core Team, 2019).

3.2.5 Topographical Data

Slope and aspect rasters were derived from the SRTM 30-meter DEM using the 3D Analyst toolbox, Raster toolset with the Slope and Aspect tools in ArcMap. A flow accumulation raster was generated using the Raster Analysis toolbox, Hydrology toolset. The Fill tool was used to remove all small imperfections in the DEM. The Flow Direction tool identified the path of flow by finding each individual downslope neighbor and used the D8 flow method to find the steepest of these neighbors. Lastly, the Flow Accumulation tool was used to create the final raster of flow into each individual cell, providing us with the full hydrologic network to base our model on.

3.2.6 Guild Occurrence Records

We generated occurrence records from vegetation polygons provided by the NPS by placing one presence point in the center of each polygon. When appropriate, species of interest were grouped into guilds based on temperature and precipitation requirements, water source, and topography. The guilds we used for our analysis were a subset of the USGS & NPS (2007) report on vegetation types in the SMMs. We used Oak Woodland (Coast Live Oak Woodland and Valley Oak Woodland combined), Riparian Woodland (Willow Woodland, Red Willow Woodland, Arroyo Willow Woodland, White Alder Woodland, and California Sycamore Woodland combined), California Bay Woodland, and California Walnut Woodland. Descriptions of vegetation types can be found in USGS & NPS (2007). Occurrence records were not spatially rarefied, as is common practice in species distribution models, because we assumed our records to be an unbiased sampling of the study area that covers the full range of environmental conditions.

3.3 Data Analysis

3.3.1 Maxent

The guilds we identified were Oak Woodland, Riparian Woodland, California Bay Woodland and California Walnut Woodland. Guild distributions were projected for 2020-2060 and 2061-2099 based on climate variables of precipitation rate, minimum near-surface air temperature, and maximum near-surface air temperature from the NEX-DCP30 dataset (Thrasher et al., 2013) and topographical variables of slope, aspect, and flow accumulation using Maxent software (Phillips, Anderson, & Schapire, 2006). Climate and topographical variables were used to build separate species distribution models due to differing spatial resolutions among the two datasets as follows. We changed the default settings in Maxent by selecting linear, quadratic, and “hinge only” features (Raes & ter Steege, 2007). We divided and sub-sampled our occurrence data using 60% for training and 40% for testing for each of 10 replicate runs and set the regularization multiplier to 2.5 to reduce overfitting (James, 2014). We did not include a biased background file to Maxent because we assumed our records to be an unbiased sampling of the study area that covers the full range of environmental conditions.

3.3.2 Combined Suitability Models

Vegetation in the study area is sensitive to climate and topography, and these variables interact to create microclimate refugia for different vegetation types. The 30-meter spatial resolution of topographical variables was small enough to capture differences relevant to vegetation; however, we were unable to find a fine-scale climate dataset that covered the time periods of interest and was capable of identifying microclimates on a relevant scale. Rather than upscale the topographical variables to match the resolution of the climate variables, we created SDMs separately for climate and topographical variables. Additionally, separate species distribution models were built based on climate variables for seedling and mature life stages. This was done to account for the different climate conditions that are most suitable in each life stage (Collins & Carson, 2004; McLaughlin & Zavaleta, 2012). We assumed that topographical requirements would not vary by life stage and would not change drastically over the study period. We combined the occurrence probability raster based on topography with the occurrence probability rasters for each of the two life stages per guild using Raster Calculator (ArcMap tool) by taking an AUC-weighted average. The combined climate-topography rasters for seedling and mature life stages were then averaged to identify suitability throughout the lifespan of trees regenerating after the Woolsey Fire.

3.3.3 Distributional Shifts

To predict distributional changes between current and forecasted occurrence probability under RCP 4.5 as well between forecasted RCP 4.5 and 8.5 occurrence probability, we utilized the SDMtoolbox 2.4 in ArcMap 10.6 (Brown, Bennett, & French, 2017; Environmental Systems Research Institute (ESRI), 2019). First, we used the "Quick Reclassify to Binary" tool to convert each continuous raster to a binary raster. We then executed the "Raster to ASCII" tool and specified an ".asc" output to satisfy the requirements of the tools that calculate distribution changes. After obtaining the ASCII files, we defined the projection as WGS 1984 using the "Define Projection" tool and utilized the "Centroid Changes (Lines)' and "Distribution Changes Between Binary SDMs" tools to obtain metrics of change. The outputs of these tools were a vector file showing the magnitude and direction of change and a raster and .csv file depicting range contraction and expansion. This process yielded results that allowed us to quantify how, where, and what amount of range shifted between current to forecasted occurrence probabilities and between forecasted RCP 4.5 to 8.5 occurrence probabilities

4. Results & Discussion

4.1 Existing Conditions

4.1.2 Burn Severity

We used RBR to determine the burn severity and extent of the Woolsey Fire. Studies assessing burn severity indices have shown that RBR provides both a higher classification accuracy and correspondence to field-based burn severity measurements than common alternatives such as dNBR and RdNBR, especially in arid areas of the Western U.S., such as the continually drying SMM (Parks, Dillon, & Miller, 2014). Additionally, RBR is shown to determine high-severity burn effects across a wide range of pre-fire vegetation cover, making it an ideal index for the requirements of our study area, specifically with the high severity of the Woolsey Fire and level of floristic biodiversity characteristic of the area. *Figure 4* displays the composited RBR image with urban, agriculture, and water polygons excluded. The dark red areas of the map were most heavily affected by the Woolsey Fire and when overlaid with the Woolsey Fire polygon provided by our partners at the RCDSMM, the areas with high levels of RBR visually align with the fire burn area, further validating the accuracy and use of RBR as a proper metric for burn severity in this context. This kind of burn severity mapping is critical for land managers who need to identify highly impacted areas post-fire to prioritize replanting and restoration efforts.

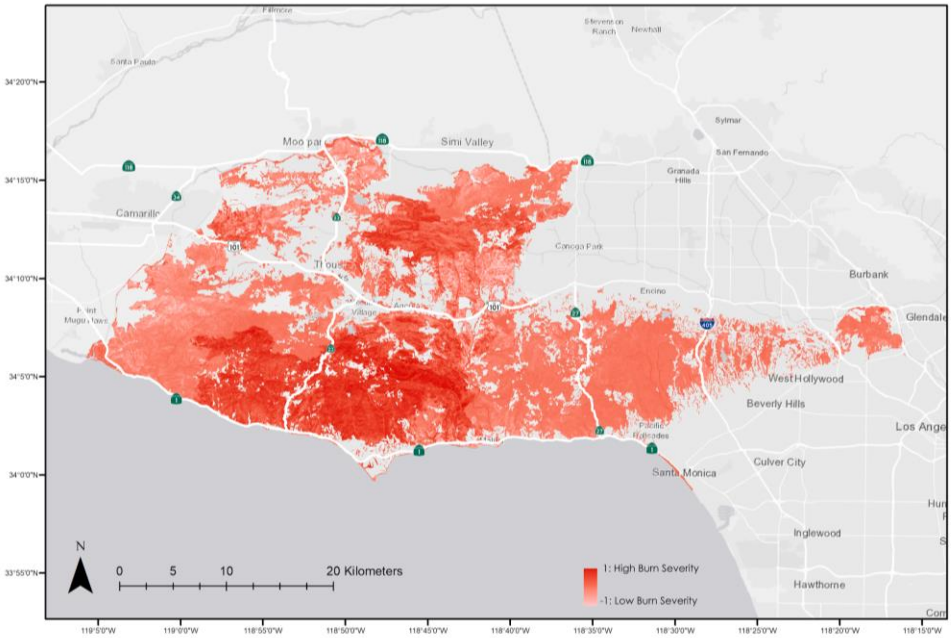

Figure 4. A composited RBR image over the SMM displaying burn severity from the Woolsey Fire (from Landsat 8 OLI, 2018 to 2019). Darker red indicates areas with higher burn severity.

4.1.3 Vegetation Health

A spectral based vegetation health classification was created for imagery acquired 6/30/2019 (Appendix L Figure L1). A confusion matrix was created comparing in-situ observations acquired 7/3/2019 (Appendix K Figure K2). A comparison of green vegetation and non-photosynthetic areas were made due to the absence of vegetation health observations, as in-situ data only specified green vegetation or dead vegetation. Thriving vegetation, healthy vegetation, and vegetative presences classes were combined to form green vegetation, while water was combined with the existing non-photosynthetic area class to create the final non-photosynthetic area class, resulting in a binary classification. Field vegetation aliveness observations were turned into point features, then into a binary raster to be used as ground control observations in a confusion matrix; a total of 41 pixels were compared. An overall agreement of 94.63% was found between the in-situ observations, and the classification produced. High agreement is expected due to the large spectral difference between green vegetation and non-photosynthetic areas and due to the coincidence of observation data and satellite imagery. Lack of ground observations for observations could be also attributed to high accuracy, since the majority of the study area is omitted from comparison.

We also mapped NDRE in the SMM to determine the vegetation condition within the study area following the Woolsey Fire. NDRE has been shown to provide the highest vegetation classification accuracy of any commonly used vegetation index such as the Normalized Difference Vegetation Index (NDVI) or Green Normalized Difference Vegetation Index (GNDVI) due to its use of the red-edge band included in RapidEye imagery, which is sensitive to the chlorophyll content found in healthy vegetation (Ustuner, Sanli, Abdikan, Esetlili, & Kurucu, 2014). *Figure 5* displays NDRE of the study area with urban, agriculture, and water polygons excluded. The light green areas of the map contained the least healthy vegetation due to burning from the Woolsey Fire. Mapping NDRE at a 5-meter spatial resolution allows land managers to better assess vegetation health conditions, specifically where vegetation survived following the Woolsey Fire. The NDRE was used to create the current vegetation conditions map by clipping the extent of the alive vegetation extent to the MESMA AVIRIS vegetation classification. The cutoff value for alive versus dead vegetation based off of NDRE was identified using a combination of the ground-truthed data provided by the RCDSMM, the RapidEye MESMA vegetation classification, and indications of vegetation health thresholds identified through post-fire vegetation analysis (Key & Benson, 2006). This revealed the current vegetation conditions for the SMM as of June 2019.

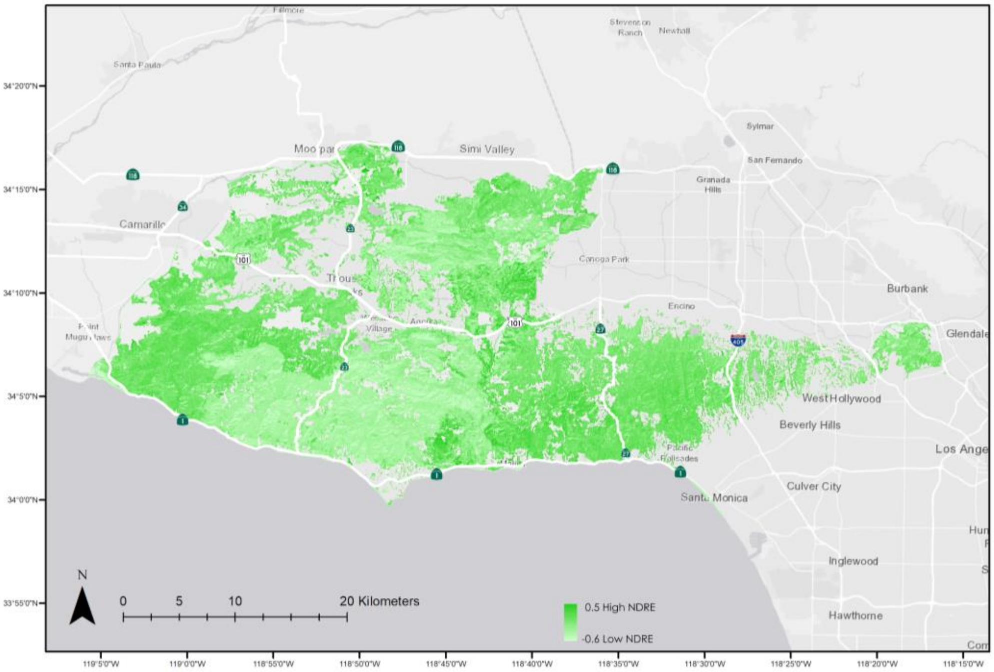

Figure 5. This is a composited NDRE Index image over the Santa Monica Mountains displaying vegetation health following the Woolsey Fire (from RapidEye, 2019). Lighter colors represent non-photosynthetic vegetation and darker green colors indicate thriving vegetation.

4.1.4 Vegetation Community Classification

We created a spectral based vegetation community classification using MESMA for the Santa Monica Mountains Recreation Area (Appendix I Figure I1). A confusion matrix were created to assess accuracy (Appendix K Figure K1). The classification was compared to NPS polygon data from 2007. NPS polygon data was randomly selected throughout the study area for each class and rasterized. An average of ~200 pixels from each class were created out of the polygon data to be used as an . An overall agreement of 90.54% was found in the comparison between the sampled NPS polygon data and AVIRIS classification. Water, urban areas, and annual grasses resulted in an accuracy of 100% which was expected as these classes had very distinct spectra compared to the other vegetation classes. Oak woodlands and riparian classes had lower agreement percentages, with the classification showing primarily chaparral where the NPS data shown Oak and riparian areas. This disagreement could be attributed to the increase in chaparral and coastal sage scrub and decrease in riparian woodlands due to recent drought. Since the NPS polygon data was created in 2007, it would not show the land cover change after the drought, and omit the decrease in riparian woodland land cover.

4.2 Species Distribution Models

4.2.1 Model Performance

We used AUC to quantify predictive power of climate and topography SDMs. AUC varied among guilds; however, AUC scores among life stages and climate scenarios within a guild did not exhibit any clear patterns. For the climate SDMs, predictive power was highest for California Bay Woodland (AUC = 0.811–0.823), followed by Riparian Woodland (AUC = 0.679–0.699), California Walnut Woodland (AUC = 0.652–0.673), and Oak Woodland (AUC = 0.592–0.598). Appendix C Table C1 includes AUC plus or minus standard deviation for all climate SDMs. Topography SDMs had higher AUC in guilds when compared to climate SDMs. For the topography SDMs, AUC was greatest in California Bay Woodland (0.852 ±0.014), followed by California Walnut Woodland (0.777 ±0.006), Riparian Woodland (0.732 ±0.015), and Oak Woodland (0.675 ±0.003) (Appendix D Table D1).

Our results suggest that slope, aspect, and flow accumulation may be better predictors of California Walnut Woodland, California Bay Woodland, Oak Woodland, and Riparian Woodland distributions than precipitation rate, minimum temperature, and maximum temperature. Although, the possible influence of grain size of the topographical (30-meter) and climate (~250m) variables should not be ignored. Khosravi et al. (2016) found that AUC had a significant negative correlation with grain size when testing model performance of environmental variables that were downscaled to seven different resolutions between three kilometers and 250 meters. Similar declines in AUC with increasing grain size were reported by Seo et al. (2008), Gottschalk et al. (2011), and Song et al. (2013). Conversely, Guisan et al. (2007) found that AUC did not necessarily decline significantly at differing grain sizes across modeling techniques, geographic regions, and species. Because nearly all studies examining the effect of grain size on model performance were using the same set of variables at different scales, it is impossible to determine whether the decrease in AUC that we observed between topographical and climate SDMs is an artefact of the larger spatial scale of the climate variables or whether it is ecologically meaningful.

Increasing grain size results in fewer habitat types being found on the landscape because rare habitat types are lost (Turner et al., 1989). The large grain for climatic variables used in our study may have caused microclimates to disappear. Microclimate refugia are becoming increasingly important as the regional climate becomes warmer and drier (McLaughlin et al., 2017). Loss of microclimates on the map due to a coarse resolution may have caused the poor model performance we observed in climate SDMs.

4.2.2 Variable Importance

We used permutation importance to determine the most important variable in projecting species distributions for climate and topography SDMs. Precipitation rate was the most important variable in climate SDMs for all species and climate scenarios. Appendix E

Table E1 contains the permutation importance of precipitation rate for RCP 4.5 and RCP 8.5 scenarios averaged across lifestage. Permutation importance or precipitation rate ranged from 83.3% to 89.05% for California Walnut Woodland, Riparian Woodland, and California Bay Woodland; however, precipitation rate had a permutation importance of 48.3% for Oak Woodland. Within guilds, the permutation importance of precipitation rate was slightly larger in the RCP 8.5 scenario for California Bay Woodland, Oak Woodland, and Riparian Woodland. California Walnut Woodland, however, decreased from 83.3% to 53.05% between RCP 4.5 and RCP 8.5.

The most important variable in topography SDMs differed among guilds. Slope was most important for California Walnut Woodland and California Bay Woodland, aspect was most important for Oak Woodlands, and flow accumulation was most important for Riparian Woodland. Permutation importance for the most important variable by guild are shown in Appendix F Table F1. The importance of slope for California Walnut Woodland and California Bay Woodland is evident when comparing their projected distribution maps with maps of slope. Both species appeared to prefer steep slopes. We are unsure if this is accurate or an artefact of sampling bias in the occurrence data. It is intuitive that flow accumulation is the most important variable for Riparian Woodland as these plants generally grow in valleys, canyons, and other low-lying areas where run-off tends to collect. Our finding that Oak Woodland distribution is most affected by aspect is supported by the literature. Brooks and Merenlender (2001) found that natural regeneration of several oak species was greater on north-facing slopes than south-facing slopes.

4.2.3 Guild Distributions

We projected guild distributions using climate and topographical variables as inputs to Maxent. The probabilities of occurrence in the study area are shown in Figure 6. We found that Oak Woodlands had a moderate probability of occurrence throughout most of the landscape, with a slight preference for north-facing slopes. Natural regeneration of oaks was found to be greater on north-facing slopes in a study investigating species distributions and regeneration in a cleared Oak Woodland in Mendocino County, CA. The cool, moist climates found on north-facing slopes in the Santa Monica Mountains are the most likely habitat to support natural regeneration of Oak Woodlands in the future. Because of this, it may be important to focus restoration efforts on marginal areas where oaks are predicted to occur, but where they may not regenerate naturally.

California Walnut Woodland was projected to have a high probability of occurrence in most areas except the northeast corner of the study area. Steep slopes generally lead to the highest occurrence probabilities. The distribution of California Bay Woodland was similar to California Walnut Woodland, but was restricted to steep slopes in the southern and western portion of the study area. Occurrence probability was low in the northwest for both California Walnut Woodland and California Bay Woodland likely due to the extensive development in that area. Riparian Woodland has a high probability of occurrence in the southern part of the study area, specifically in valleys or canyons. The cooler climate near the coast and the high accumulation of precipitation in valleys and canyons contribute to the clustered distribution of Riparian vegetation.

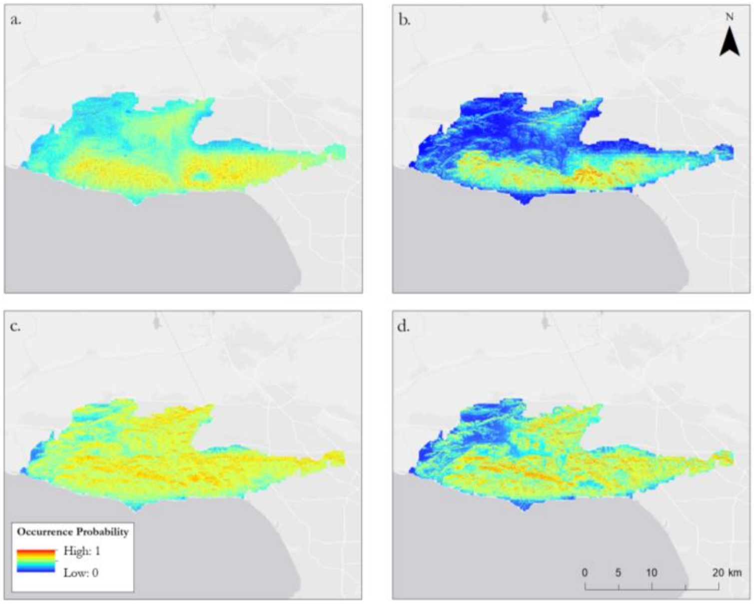

Figure 6. A map depicting projected probability of occurrence of a.) Riparian Woodland, b.) California Bay Woodland, c.) Oak Woodland, and d.) California Walnut Woodland in the SMM given RCP 4.5. Areas with low probability of occurrence are dark blue, and areas of high probability of occurrence are red. The maps are averages of occurrence probabilities of topography and climate SDMs, weighted by model AUC. The seedling and mature life stages in each guild were also averaged with equal weight given to each life stage.

4.2.4 Distributional Shifts

To quantify how the changing climate affected the probability of occurrence for each vegetation guild we calculated area of expansion, contraction, no change, and no occupancy. These metrics of change between the current and forecasted time periods under RCP 4.5 are shown in Appendix G Table G1. All vegetation guilds exhibited a higher degree of expansion than contraction, though Oak Woodland, Riparian Woodland, and California Walnut Woodland shifted approximately northwest while California Bay Woodland shifted southeast. The average amount of expansion was 79.54 km^2 and the average amount of contraction was 56.14 km^2, with Riparian Woodland exhibiting the most expansion and California Walnut Woodland exhibiting the most contraction.

The same metrics were calculated between the forecasted RCP 4.5 and RCP 8.5 scenarios and are shown in Appendix H Table H1. As expected, the amount of contraction and expansion between RCP 4.5 and 8.5 is lower than that of the current and forecasted time periods. The average amount of expansion was 7.00 km^2 and the average amount of contraction was 5.44 km^2, with Riparian Woodland exhibiting the most expansion and California Walnut Woodland exhibiting the most contraction.

4.3 Future Work

Continuing work on this project would allow us to better predict suitable replanting habitat, as well as creating a more accurate assessment of the current conditions in the SMM. Further work could comprise of adding more climate variables to the SDM. The incorporation of additional climate variables such as the maximum temperature of the warmest month, evapotranspiration, solar insolation, and water capacity; among others, would increase the confidence of the SDM in predicting suitable habitat for these tree species for the remainder of the century. These climate variables would increase the confidence of the SDM due to their ecological impacts on these species's ability to recruit, mature, and thrive. As well, to increase the confidence in the SDM the use of climate data with a finer spatial resolution that accounts for microclimate refugia would allow for a more accurate prediction of these variable areas. Additionally, the use of the most recent AVIRIS data from the June 2019 acquisition would allow us to more accurately classify vegetation health and species post Woolsey Fire. This data is not yet available and thus, we are using the June 2018 data for our study.

5. Conclusions

As the climate in Southern California continues to become hotter and drier, species will respond by shifting their distribution or evolving to persist under the new conditions. However, many species, particularly those with limited dispersal and longer generation times, will rely on climatic microrefugia for protection and stability (Mclaughlin et al., 2017). Although the resolution of our analysis was too coarse to accurately assess where climatic microrefugia could occur under future climate scenarios, we were able to assess broad trends in species occurrence probability for Riparian Woodland, Oak Woodland, California Bay Woodland, and California Walnut Woodland species.
Through a species distribution modeling approach in Maxent we found that precipitation had the highest permutation importance across all vegetation guilds for RCP 4.5 and 8.5 scenarios. Although our selection of climatic input variables was limited, this finding suggests that water availability is a more important distribution determinant than minimum and maximum temperature in this ecosystem. However, while precipitation rate still had the highest permutation importance for California Walnut Woodland in the RCP 8.5 scenario, it was only marginally more important than maximum temperature. This increase in the importance of maximum temperature in determining California Walnut Woodland distribution suggests that under the hotter, drier RCP 8.5 scenario, rising temperatures will be a limiting factor for California Walnut Woodland survival in the future.

Our analysis of distributional change of occurrence probability showed that all vegetation guilds expanded rather than contracted, when comparing current to future probabilities. Similarly, the distribution change between the forecasted RCP 4.5 and 8.5 scenarios showed greater expansion than contraction, but only marginally. This expansion across both distributions and into potentially novel climatic conditions, may indicate that these particular vegetation guilds are adapting to the changing climate. However, the effects of Maxent parameter selection on model performance should not be ignored when considering these results. When dealing with a small number of presence points, such as in our study, a combination of parameters should be evaluated to avoid creating a non-optimal model (Morales, Fernández, & Baca-González, 2017; Warren & Seiffert, 2011). We selected our parameters based on recommendations of related literature, but it would be judicious to further investigate how they affect model performance.

Successful conservation and managed relocation of key species by land managers in the Santa Monica Mountains relies on the identification of areas that will remain suitable under future climate conditions. Although most species in the area are influenced by myriad environmental factors, our inclusion of only climate and topography in the SDM still offers insight into these persisting suitable areas. The fine spatial scale of the topographic variables allowed us to identify topographic refugia which shape microclimate refugia. Furthermore, by separating and then recombining models for both the seedling and mature life stages of each vegetation guild, our resultant maps of species occurrence probabilities include climatic conditions that are suitable for both life stages. Nevertheless, we suggest the inclusion of more environmental variables into the SDM for a more robust model.

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7. Glossary

AVIRIS (Airborne Visible / Infrared Imaging Spectrometer)
An airborne optical hyperspectral sensor.

dNBR (difference Normalized Burn Ratio)
An element of the RBR equation which identifies change in burn severity.

Earth observations
Satellites and sensors that collect information about the Earth’s physical, chemical, and biological systems over space and time.

ENVI (Environment for Visualizing Images)
Image Analysis Software used to extract data.

IPCC (Intergovernmental Panel on Climate Change)
Governing body that oversees the creation of climate Assessment Reports.

Maxent
A maximum entropy modeling software used for projecting species distributions.

MESMA (Multiple Endmember Spectral Mixture Analysis)
A spectral mixing technique. Used as a classifier in this analysis

NBR (Normalized Burn Ratio)
An element of the RBR equation which identifies burn severity.

NDRE (Normalized Difference Red Edge)
A quantified index of vegetation health.

NIR (Near Infrared)
The electromagnetic radiation range with wavelengths larger than visible light used to calculate NDRE.

RBR (Relativized Burn Ratio)
A quantified ratio of burn severity.

RCDSMM (Resource Conservation District of the Santa Monica Mountains)
The primary partner organization of the project.

RCP (Representative Concentration Pathway)
A trajectory of greenhouse gas concentrations used by the IPCC in the fifth Assessment Report (AR5).

Red Edge
The electromagnetic radiation range with wavelengths smaller than NIR used to calculate NDRE.

RSME
Root mean square error, the standard deviation of residuals

SDM (Species Distribution Modeling)
A broad term encompassing various methods of predicting species distributions based on environmental variables using computer algorithms.

SMM (Santa Monica Mountains)
The area of interest for this project. A small mountain range north of Los Angeles, CA.

SMMNRA (Santa Monica Mountains National Recreation Area)
A protected area designated by the federal government encompassing the Santa Monica Mountains.

SRTM (Shuttle Radar Topography Mission)
A mission flown February 2000 that acquired global digital elevation model data.

SWIR (Short Wave Infrared)
The electromagnetic radiation range with wavelengths larger than NIR used to calculate RBR.

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Appendix A

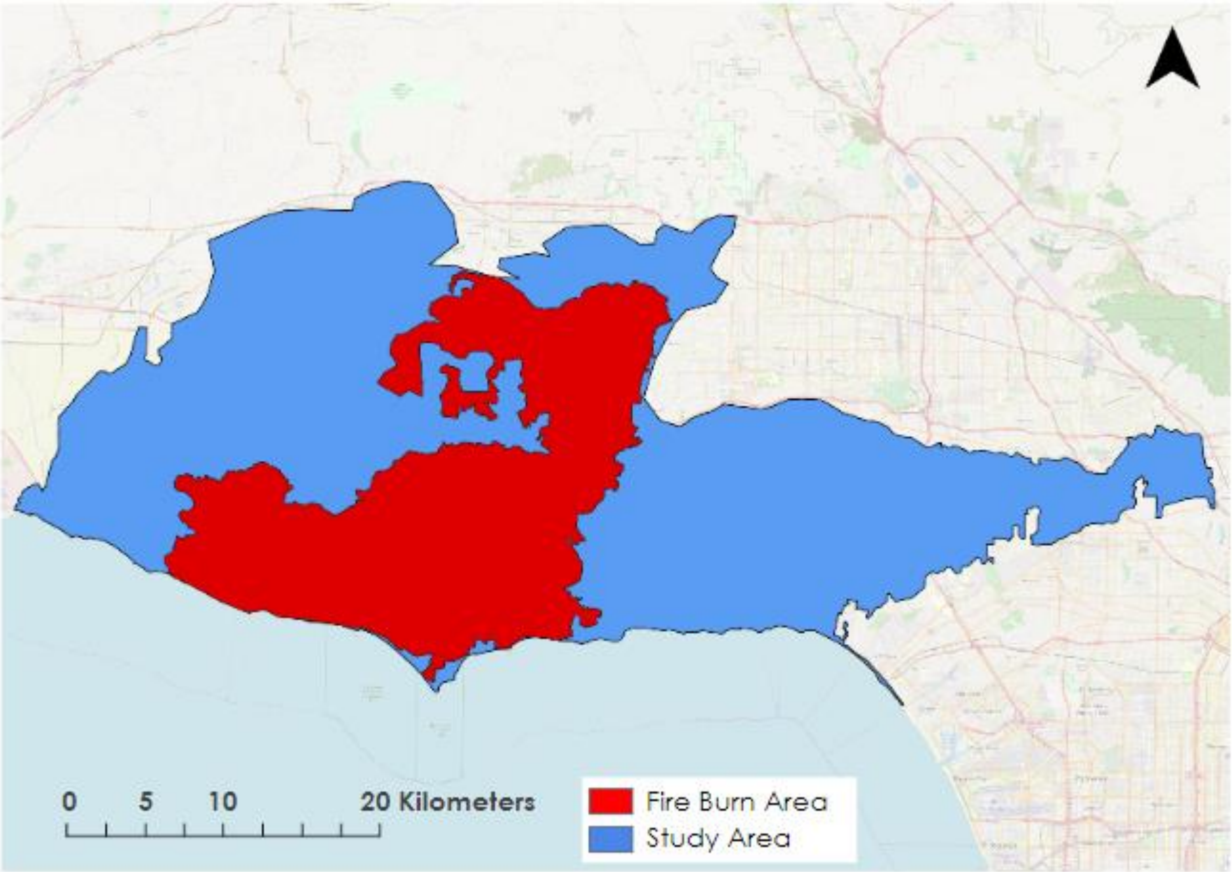


Figure A1. Map of study area depicted in blue and the Woolsey Fire burn area in red.

Appendix B

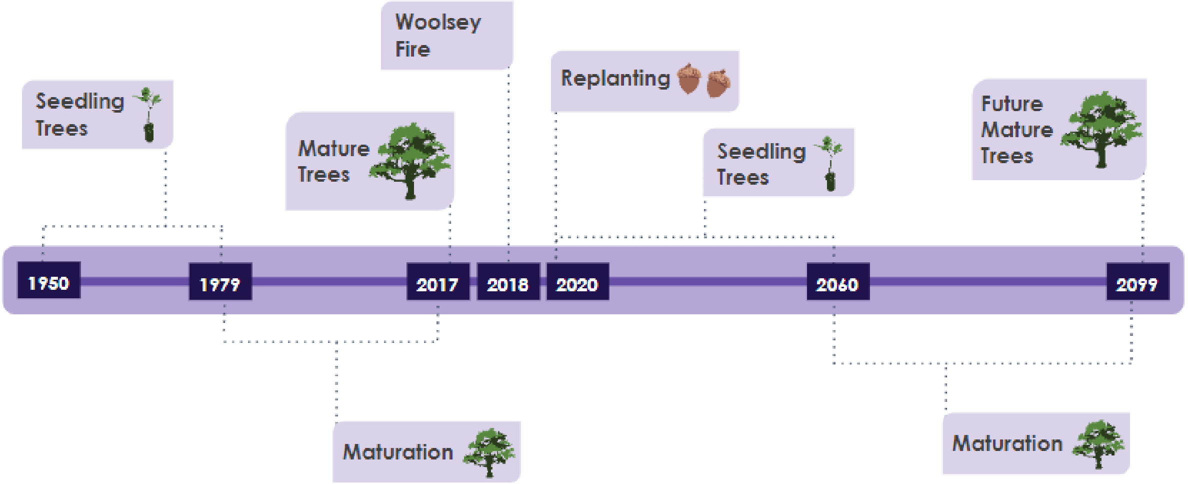


Figure B1. A timeline of important events in the study area. The time period 1950-1979, covers the end of a recruitment pulse of many tree species in the SMM (R. Dagit, personal communication, July 8, 2019) through their seedling and sapling life stages. We assumed that the same cohort matured during the 1980-2005 time period. The 2020-2060 time period reflects recruitment and the seedling stage for the cohort to be planted by the RCDSMM and other partners as part of their effort to restore the Santa Monica Mountains. The 2061-2099 time period will be the period when the restoration cohort will mature.

Appendix C

Table C1

Climate SDM performance. Area under the [receiver operating characteristic] curve (AUC) is reported plus or minus standard deviation. Habitat suitability was assumed to change across life stages and climate scenarios; therefore, SDMs were generated for each guild, targeted life stage, and climate scenario combination.

Guild	Life Stage	Climate Scenario	AUC (±SD)
California Walnut Woodland	Seedling	RCP 4.5	0.673 ±0.017
		RCP 8.5	0.662 ±0.018
	Mature	RCP 4.5	0.664 ±0.015
		RCP 8.5	0.652 ±0.014
Oak Woodland	Seedling	RCP 4.5	0.598 ±0.010
		RCP 8.5	0.592 ±0.011
	Mature	RCP 4.5	0.595 ±0.008
		RCP 8.5	0.596 ±0.010
Riparian Woodland	Seedling	RCP 4.5	0.685 ±0.020
		RCP 8.5	0.699 ±0.014
	Mature	RCP 4.5	0.679 ±0.017
		RCP 8.5	0.686 ±0.019
California Bay Woodland	Seedling	RCP 4.5	0.819 ±0.011
		RCP 8.5	0.823 ±0.012
	Mature	RCP 4.5	0.811 ±0.013
		RCP 8.5	0.817 ±0.015

Appendix D

Table D1

Topography SDM performance. Area under the (receiver operating characteristic) curve (AUC) is reported plus or minus standard deviation. Topographical requirements of species was assumed to be constant across climate scenarios and life stages; therefore, one SDM was generated per guild.

Guild	AUC (±SD)	
California Walnut Woodland	0.777	±0.006
Oak Woodland	0.675	±0.003
Riparian Woodland	0.732	±0.015
California Bay Woodland	0.852	±0.014

Appendix E

Table E1.

Permutation importance of precipitation rate in climate distribution models for RCP 4.5 and RCP 8.5 averaged across mature and seedling life stages.

	RCP 4.5	RCP 8.5
Juglans californica	83.3%	53.05%
Oak Woodland	48.3%	49.9%
Riparian Woodland	84.3%	91.95%
California Bay Woodland	89.05%	90.0%

Appendix F

Table F1.

Permutation importance of the most important variable identified in topography species distribution models by species.

	Most Important Variable	Permutation Importance
California Walnut Woodland	Slope	52.1%
Oak Woodland	Aspect	70.0%
Riparian Woodland	Flow accumulation	82.1%
California Bay Woodland	Slope	59.4%

Appendix G

Table G1

Changes in guild range in current and forecasted species occurrence probability for each vegetation guild in km^2.

	Expansion	Contraction	No Change	No Occupancy
California Walnut Woodland	99.93	67.45	424.04	596.14
Oak Woodland	83.08	61.62	741.21	301.66
Riparian Woodland	101.01	65.63	348.80	672.12
California Bay Woodland	34.15	29.87	148.08	978.70

Appendix H

Table H1

Changes in guild range in forecasted RCP 4.5 and forecasted RCP 8.5 species occurrence probability for each vegetation guild in km^2.

	Expansion	Contraction	No Change	No Occupancy
California Walnut Woodland	.95	11.41	513.00	665.50
Oak Woodland	3.50	6.86	818.49	362.022
Riparian Woodland	20.91	1.76	449.01	719.18
California Bay Woodland	2.61	1.74	180.34	1006.20

Appendix I

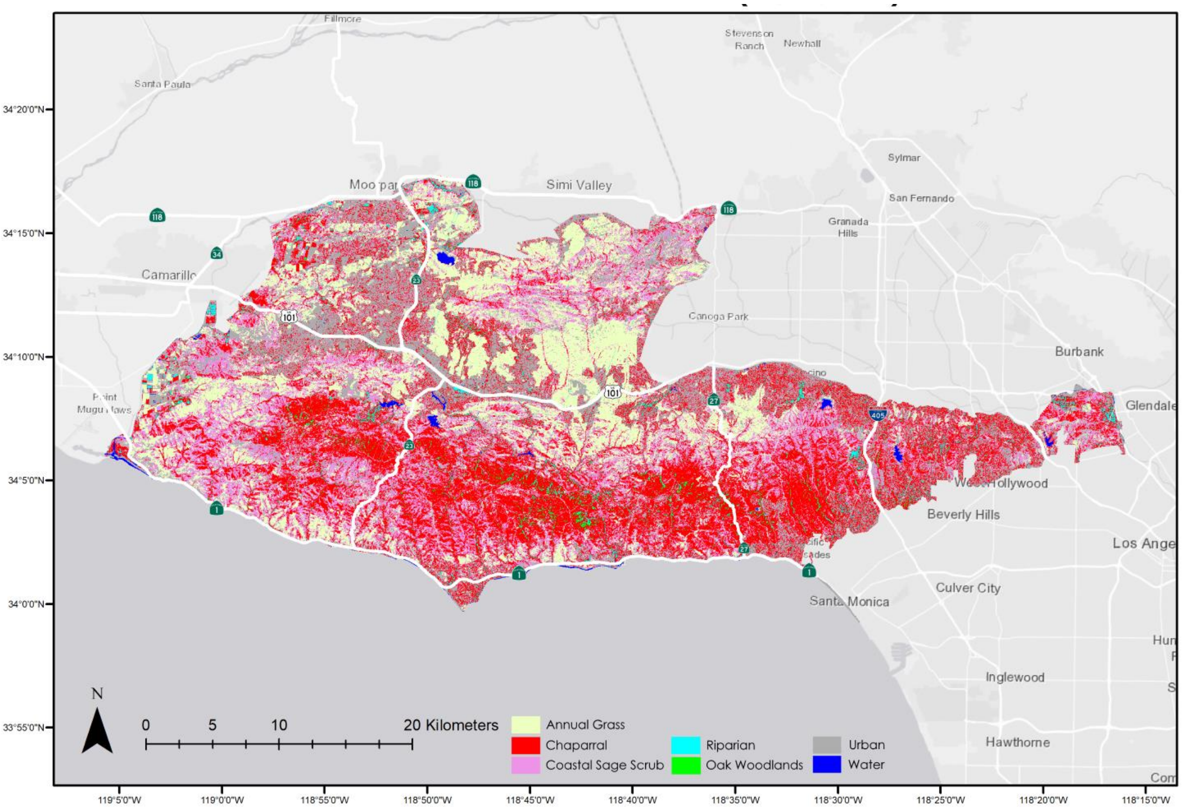


Figure I1. AVIRIS MESMA Classification of imagery acquired 06/25/2018

Appendix J

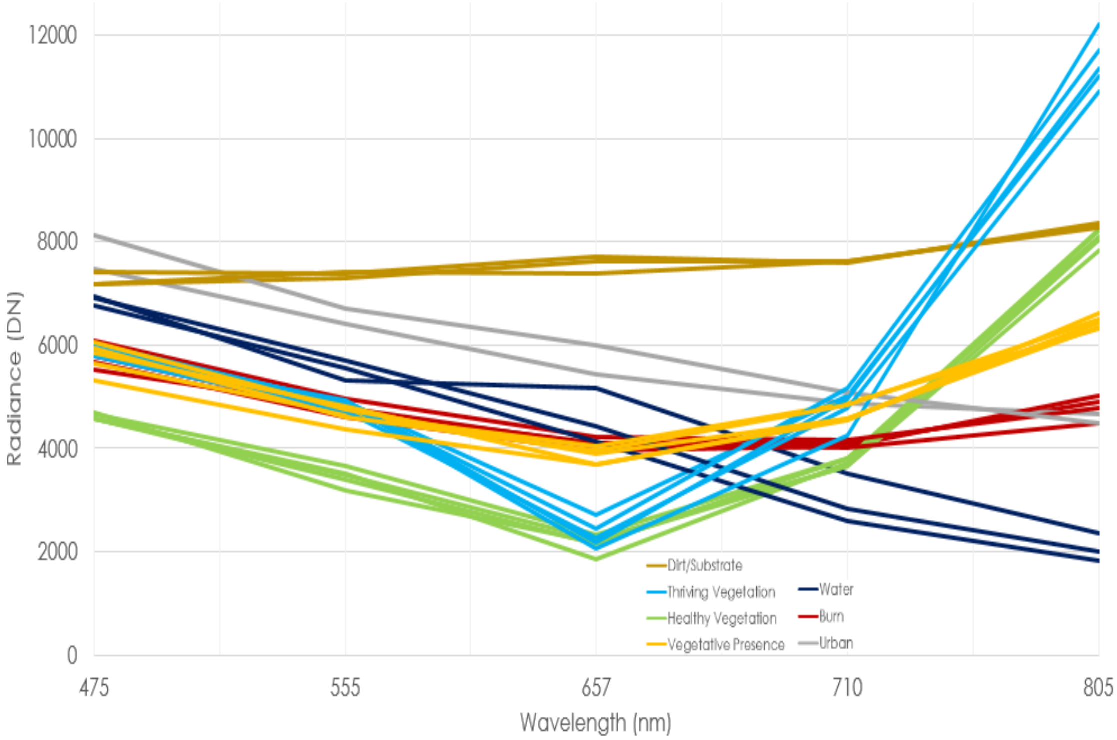
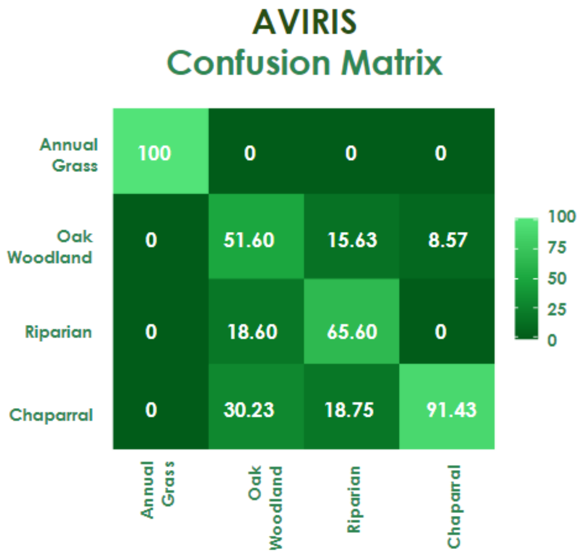


Figure J1. RapidEye imagery endmember spectra is depicted. Final spectral library used for classification included 28 endmember models. Water, burn, urban, and dirt were aggregated into one non-photosynthetic area class prior to spectral mixing.

Appendix K



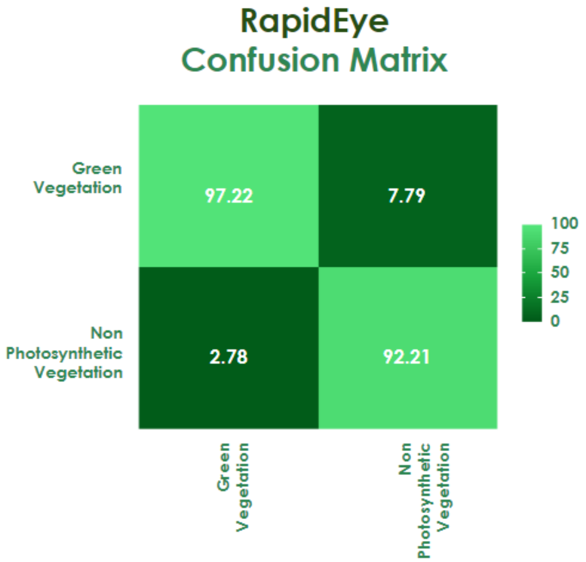
	Annual Grass	Oak Woodland	Riparian	Chaparral
Annual Grass	100	0	0	0
Oak Woodland	0	51.60	15.63	8.57
Riparian	0	18.60	65.60	0
Chaparral	0	30.23	18.75	91.43

Overall Accuracy: 90.54%

Kappa Coefficient: .845

	User's Accuracy	Producer's Accuracy
Annual Grass	100	100
Oak Woodland	84.62	51.16
Riparian	56.76	65.63
Chaparral	50	92.43

Figure K1. A confusion matrix and table of user's and producer's accuracy of the AVIRIS MESMA classification



	Green Vegetation	Non Photosynthetic Vegetation
Green Vegetation	97.22	7.79
Non Photosynthetic Vegetation	2.78	92.21

Overall Accuracy: 94.63%

Kappa Coefficient: .893

	User's Accuracy	Producer's Accuracy
Green Vegetation	92.11	97.33
Non Photosynthetic Vegetation	97.26	92.21

Figure K2. A confusion matrix and table of user's and producer's accuracy of the RapidEye MESMA classification

Appendix L

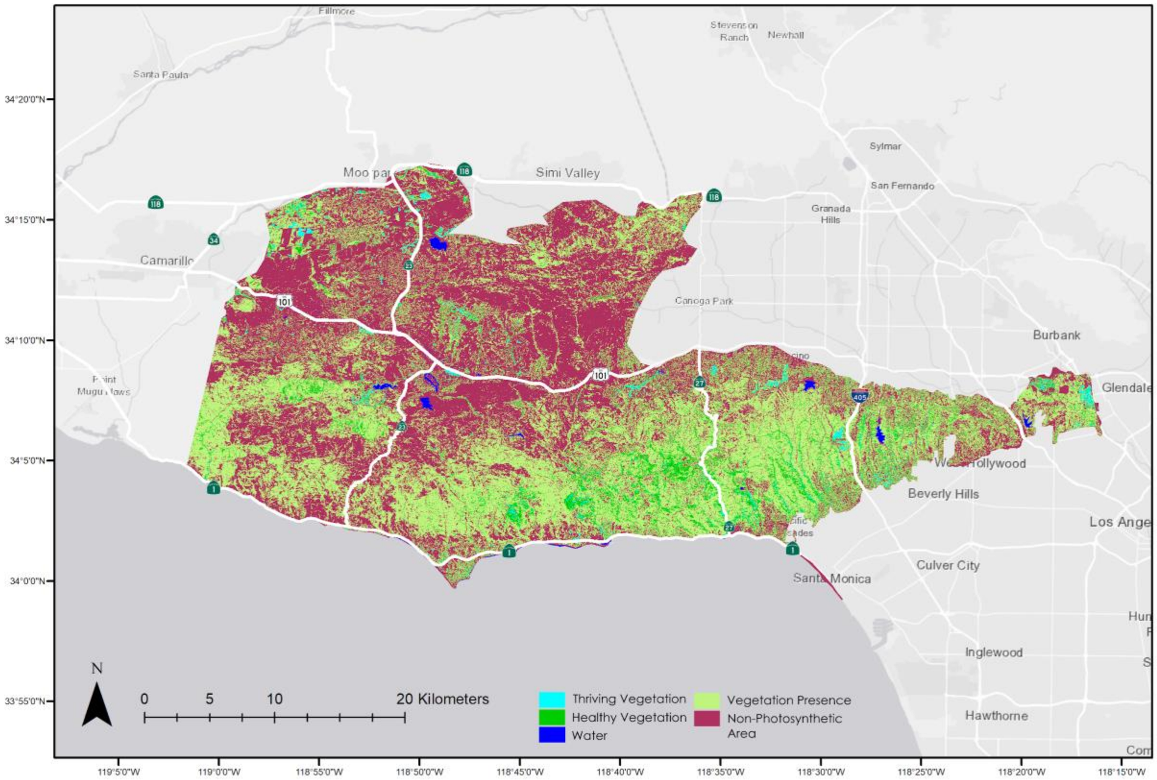


Figure L1. RapidEye MESMA classification on imagery acquired 06/30/2019