April 20, 2021

PUBLIC EXCHANGE

Maximizing the benefits of increased urban canopy on the eastside of Los Angeles

Authors

Rachel Ablondi
Dulce Acosta
Marianna Babboni
Will Berelson
Jackson FitzGerald
David Galaviz
Erik Huisman
Yuliang Jiang
Beau MacDonald
Esther Margulies
Melinda Ramos-Alatorre
Seher Randhawa
Coleman Reardon
Kate Weber
John Wilson

USC Dornsife Spatial Sciences Institute
USC School of Architecture
CARBON CENSUS at USC

Acknowledgements

This report was prepared in coordination with the Los Angeles Department of Public Works as part of a strategic partnership on urban trees between the City of Los Angeles and the University of Southern California. We are grateful for the expert advice and collaboration from our City of Los Angeles partners. Thanks to Rachel Malarich, Melinda Gejer, Irene Burga, Amy Schulenberg and Rachel O'Leary for working hand-in-hand with us since the beginning of the project.

We would also like to acknowledge the many community members and organizations that took the time to meet with our project team and voice their opinions. A special thanks to Joe Laskin and Aaron Thomas from North East Trees for sharing their deep expertise with us.

This project was made possible with the generous facilitation of funding support from USC President Dr. Carol L. Folt and funding from the USC Dornsife College of Letters, Arts and Sciences. Our project team would like to express deep appreciation to President Folt for her continued support of the Urban Trees Initiative and her leadership on sustainability.

Additionally, we would like to thank USC University Relations, including Senior Vice President Samuel Garrison and Vice President for Civic Engagement and Economic Partnerships Effie Turnbull Sanders. The entire University Relations team provided invaluable support throughout the course of this project and we are deeply grateful for their partnership.

Finally, thank you to USC University Communications and USC Dornsife Communications for supporting this initiative, especially Gary Polakovic, Lance Ignon and Dennis Lan who made the production of this report possible.

Disclaimer

The views expressed herein are those of the authors and not necessarily those of the City of Los Angeles or the University of Southern California as a whole. For more information, please contact: publicexchange@usc.edu

Authors

Rachel Ablondi, Undergraduate Research Assistant, Spatial Sciences Institute, Dornsife College of Letters, Arts and Sciences, University of Southern California

Dulce Acosta, Senior Principle Director, Community & Local Government Partnerships, University Relations, University of Southern California

Marianna Babboni, Project Administrator, Dornsife Public Exchange, University of Southern California

Will Berelson, Professor, Department of Earth Sciences and Environmental Studies Program, Dornsife College of Letters, Arts and Sciences, University of Southern California

Jackson FitzGerald, Undergraduate Research Assistant, Spatial Sciences Institute, Dornsife College of Letters, Arts and Sciences, University of Southern California

David Galaviz, Associate Vice President, Community & Local Government Partnerships, University Relations, University of Southern California

Erik Huisman, Undergraduate Research Assistant, Spatial Sciences Institute, Dornsife College of Letters, Arts and Sciences, University of Southern California

Yuliang Jiang, Research Assistant, Master of Landscape Architecture + Urbanism, School of Architecture, University of Southern California

Beau MacDonald, GIS Project Specialist, Spatial Sciences Institute, Dornsife College of Letters, Arts and Sciences, University of Southern California

Esther Margulies, Associate Professor of Practice and Assistant Director, Master of Landscape Architecture + Urbanism, School of Architecture, University of Southern California

Melinda Ramos-Alatorre, Senior Managing Director, Community & Local Government Partnerships, University Relations, University of Southern California

Seher Randhawa, Undergraduate Research Assistant, Spatial Sciences Institute, Dornsife College of Letters, Arts and Sciences, University of Southern California

Coleman Reardon, Program Assistant, Community & Local Government Partnerships, University Relations, University of Southern California

Kate Weber, Director, Dornsife Public Exchange, University of Southern California

John Wilson, Professor and Founding Director, Spatial Sciences Institute, Professor of Sociology, Dornsife College of Letters, Arts and Sciences, Preventive Medicine, Keck School of Medicine, Civil & Environmental Engineering, Viterbi School of Engineering, and the School of Architecture, University of Southern California

Table of Contents

List of Figures

List of Tables

1. Executive Summary

Extreme heat from climate change is a growing concern in Los Angeles. Current predictions suggest that by 2060 the city will see temperatures of 95 degrees Fahrenheit or higher 40 days per year.

With higher temperatures come greater risks to human health, including life-threatening conditions such as heat stroke and heart attacks. High temperatures also lead to increases in harmful air pollution that can trigger health issues for residents.

Unfortunately, communities of color and those with low incomes are disproportionately more likely to live in areas with less shade and worse air quality. For the University of Southern California and the City of Los Angeles, this inequity is an important issue of environmental justice.

In April 2019, Mayor Eric Garcetti announced Los Angeles' Green New Deal in response to the global climate emergency. The Green New Deal includes ambitious goals to address shade inequity; the city aims to plant 90,000 new trees and the plan calls for a 50 percent increase in land area covered by tree canopies in neighborhoods with the greatest need.

Increasing the urban tree canopy reduces risks caused by heat and pollution, improves health outcomes and general well-being, and makes urban neighborhoods more walkable, more enjoyable, more livable environments.

The Urban Trees Initiative is a collaboration between USC and the City of L.A. to guide the growth of an urban forest on the Eastside. This is part of a growing partnership between the city and USC as envisioned by Mayor Garcetti and President Carol L. Folt. Under this partnership, USC developed a strategic vision that recommends where the city and others could plant trees, as well as how many and what types of trees, to achieve the greatest benefit to the health and well-being of local residents. The initiative presents a vision for climate justice that is driven both by data and meaningful engagement with the people who live in the area.

USC Health Sciences Campus Community

79% Hispanic, **14%** Asian

34.7yrs median age, **21%** 0-15 yrs, **12%** > 65 yrs

15,544 households, **3.6** people per household

$48,700 median household income

71% of households **< 300%** of Federal Poverty Line

62% are renters, **38%** homeowners

28% spend **>50%** of income on housing

15% lack a vehicle

66% of residents have lived in area **>10yrs**

The multidisciplinary research team is composed of USC faculty and students with expertise in advanced mapping techniques, earth sciences and landscape architecture. The team studied a 5-square-mile area surrounding USC's Health Sciences Campus that is home to underserved communities, including much of Lincoln Heights, El Sereno and Ramona Gardens.

The project team spent time in the area and held several meetings with community members to understand their needs and preferences for green space. A total of 28 individuals attended these meetings, including representatives from pertinent nonprofits, local businesses, and L.A. City Council district offices. Combining social priorities with scientific data, the project team created a series of scenarios for the City of L.A. outlining where, how many and what kinds of trees could be added to these Eastside neighborhoods.

Where Could Trees Be Added

The study used a variety of computer analyses and maps to describe conditions as they exist in the study area today: the natural environment; the built environment, including land use, homes, parks, schools and transportation; and the residents, including elements of race, ethnicity, age, income, vehicle access and housing costs relative to people's ability to pay.

Based on these assessments, the researchers created a set of criteria to find the areas of greatest need for new trees. The criteria prioritized areas with:

- a high percentage of young children and elderly,
- low median household incomes,
- high population density and
- large numbers of households with no vehicles, indicating that people rely on walking or public transport to get around.

The research team developed five separate scenarios laying out the most effective places for planting new trees within or next to the selected priority locations. These scenarios include opportunities for planting additional trees:

- on streets with narrow parkways,
- on streets with wide parkways,
- in existing parks,
- at elementary schools and
- in specific settings such as the Ramona Gardens public housing community.

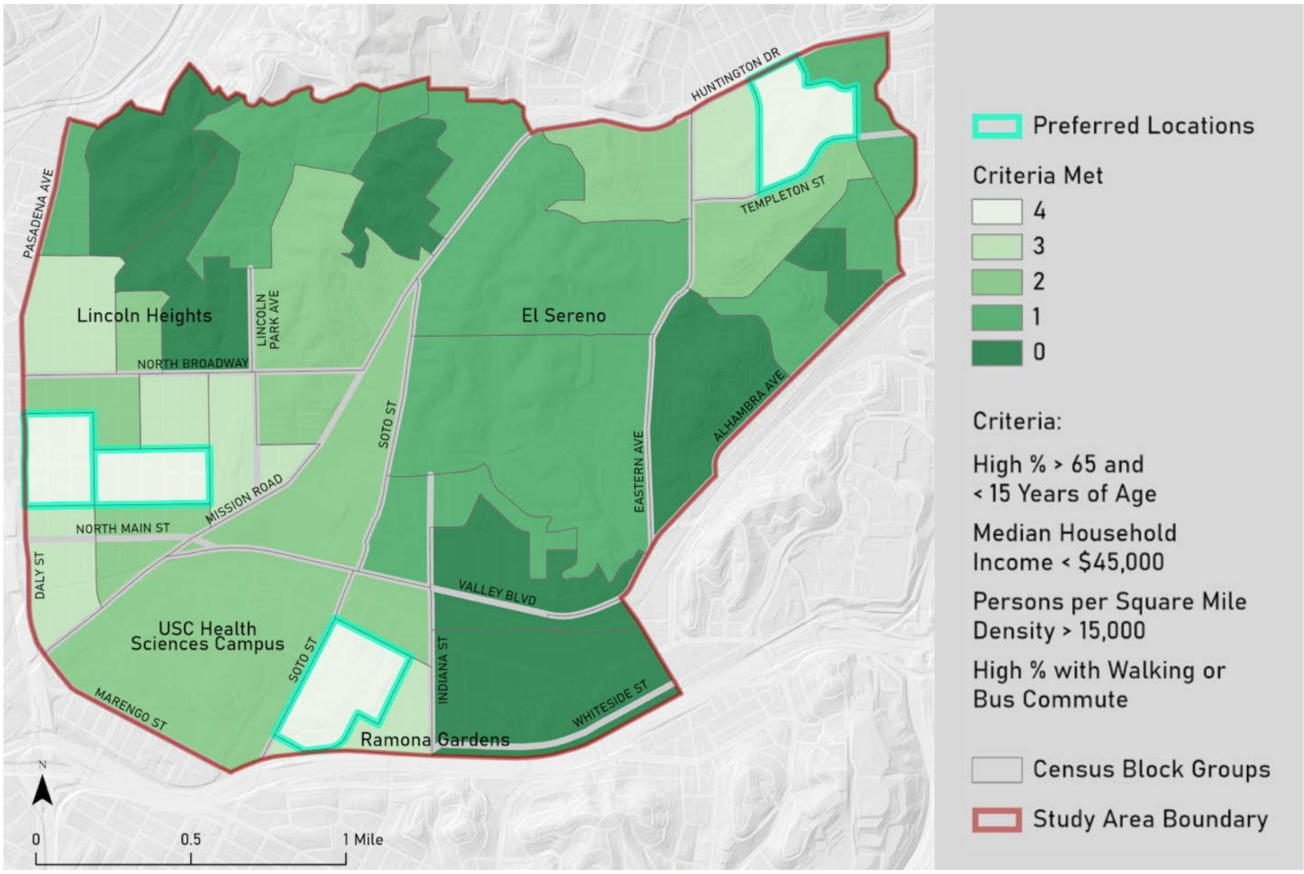
How Many Trees Could Be Added

The researchers selected two streets, Axtell and Barbee, as examples of what could be achieved on a variety of the parkways found in these neighborhoods. Barbee Street, for instance, could experience an 800% increase in shade coverage through a combination of small and large tree plantings. Adding these trees would require planting on both public and private property, as well as construction on some roads and curbs. Nonetheless, this eightfold increase in shade is just one example of what could be done in an area where there are no trees alongside nearly one-third of the 1,157 streets.

Similarly, parks in these neighborhoods have about six trees per acre — half the average number of trees at parks city-wide. The potential to add new trees to parks is particularly significant. In Hazard Park, for instance, the researchers estimate there is the potential to add 97 trees to the existing 193 trees. The two largest parks — Ascot Hills and Rose Hills — have more modest tree canopies today and could, like all of the parks, support more tree cover. While planting that many trees at once would be ill-advised because a healthy urban forest needs to have trees of various ages, the project's findings show that significant increases could be achieved at these sites over time.

The next scenario focused on providing shade covering outdoor areas to reduce surface temperatures at two elementary schools — Murchison and Hillside. Murchison was selected as an example of a relatively large elementary school campus with little tree cover on expansive asphalt playgrounds. Hillside is a smaller campus with less paved area, but pavement still covers a majority of the outdoor space. At Hillside Elementary there is potential to add 50% more trees than the site currently has. On Murchison's campus the existing number of trees could be doubled.

Lastly, the researchers studied the Ramona Gardens public housing complex, adjacent to Interstate 10, and found that there is room to add 183 trees, a 66% increase. The recommendations target the south and west sides of the buildings



and paved areas, to provide cooling for the two-story apartment buildings that lack air conditioning and to remove more pollution from the air. These proposed additions would complement the ongoing work of many local nonprofits focused on adding plants in and around Ramona Gardens.

Each scenario illustrates a different opportunity for tree planting. Collectively, the researchers found that tree canopy could be doubled across much of Lincoln Heights, El Sereno and Ramona Gardens using land available on both public and private property.

What Kind of Trees Should Be Added

Based on predictions that days with extreme heat will increase in the next 40 years, the USC team recommended planting large, dense shade trees that will tolerate hotter, drier conditions.

The team also built a series of mobile sensors to measure air quality in the community. The data they gathered measured the air quality within a tree canopy, among clusters of trees and across neighborhood blocks. While much more of this work is needed, early findings suggest that individual tree species do affect local air quality.

Two evergreen varieties, Cypress and pine trees, show evidence that they remove tiny particles, such as dust and microbes, from the air. Another evergreen species, Deodara cedar, did not demonstrate any significant ability to trap those particles. Thus, even among evergreens, individual species of trees may affect air quality differently.

Ultimately, these findings provide a springboard for further work. The priority locations and recommended scenarios for planting trees identified by this project help the City of L.A. pinpoint where they should focus such efforts to meet their goal of increasing tree canopy, beginning in low-income heat zones. The City of L.A. and its partners can use the methods developed through the Urban Trees initiative to launch further urban forestry efforts that meaningfully benefit the people of the Eastside, and perhaps other parts of the city, in the immediate future.

The USC team is made up of faculty experts, students and staff from multiple parts of the university:

- the USC Dornsife Public Exchange, which connects researchers with public and private partners to help solve problems;
- the USC Dornsife Spatial Sciences Institute, which uses spatial analytics, models, and maps to show how we can support sustainable commuinties;
- the USC Dornsife Carbon Census network, an initiative measuring air quality on the neighborhood scale;
- USC's Landscape Architecture program at the School of Architecture, a graduate program focusing on how landscape design can help address social issues, and
- USC's Office of Community and Local Government Partnerships, which works to build stronger communities for the people who live nearby USC campuses.

The City of Los Angeles team includes:

- Rachel Malarich, City lead, City Forest Officer, Department of Public Works
- Irene Burga, Air Quality Advisor, Mayor's Office of Sustainability
- Melinda Gejer, Service Coordinator, Bureau of Street Services (StreetsLA), Department of Public Works
- Amy Schulenberg, Project Coordinator, LA Sanitation and Environment, Department of Public Works
- Rachel O'Leary, Program Director, City Plants, the City's non-profit tree planting partner

For more information, visit the
USC Urban Trees Initiative website

2. Introduction

Extreme heat due to climate change is a growing concern in Los Angeles. By 2060, predictions suggest the number of extreme heat days, defined as temperatures of 95°F or higher, could rise to 40 days per year (Hulley et al., 2019, 2020). Higher temperatures and greater numbers of extreme heat days pose greater risks to human health, such as heat strokes and heart attacks. Exacerbating this risk is the "urban heat island" effect, which occurs when asphalt and concrete for roads, buildings, and other structures replace vegetation (Hulley, 2012). These surfaces absorb the sun's heat, causing surface temperatures and emissions to rise, making air pollution more hazardous for people.

Unfortunately, the risk of exposure to extreme heat and air pollution varies inequitably across the neighborhoods in the City of Los Angeles. Communities of color and those with low income levels are disproportionately more likely to live in areas with less shade and worse air quality. A study by the U.S. Forest Service found that the city's poorest areas often have the barest tree canopies, with as little as 5% coverage (McPherson et al., 2008). Another study by one of the authors of this report (Wilson) found similar results when documenting tree cover on single family lots during the period 2000-2010 (Lee et al., 2017). A similar analysis of tree canopy in Los Angeles County found the blocks with the most significant tree coverage were in the city's most affluent neighborhoods, including Pacific Palisades, Brentwood, Los Feliz, and Shadow Hills (TreePeople, 2018).

In April 2019, Mayor Eric Garcetti announced the City of Los Angeles' Green New Deal with plans to address shade as an equity issue in Los Angeles (City of Los Angeles Mayor's Office, 2019). The plan sets ambitious targets for climate action, including a goal of planting 90,000 urban trees citywide. The Green New Deal cites the numerous environmental and health benefits to society that would accrue from this increase in canopy, including an additional 61.3 million square feet of shade and a reduction in the urban/rural temperature differential of 1.7°F. The city also hopes to increase canopy by 50% in the areas of greatest need—low-canopy areas of the city like the study site. The City of Los Angeles appointed the first-ever City Forest Officer, Rachel Malarich, to help with the implementation of these goals (Cormie, 2020).

The Urban Trees Initiative is a collaboration between the University of Southern California and the City of Los Angeles to guide the growth of an urban forest of shade trees on the Eastside of Los Angeles. This is part of a growing partnership between the City and USC as envisioned by President Carol L. Folt and Mayor Garcetti. Within USC, the Urban Trees Initiative is a collaborative effort coordinated by the USC Dornsife Public Exchange and including the USC Dornsife Spatial Sciences Institute, the USC Dornsife Carbon Census Network, USC's Landscape Architecture Program at the School of Architecture, and USC's Office of Community and Local Government Partnerships. The goal of this collaborative is to present a data-driven vision for climate justice that combines advanced geospatial analyses, novel scientific study of air quality and trees, and landscape architecture expertise.

The purpose of the research presented in this report is to provide a guide for where the City and other stakeholders could plant trees in a way that maximizes the benefits of green infrastructure for the health and wellbeing of local residents. In particular, this report models the potential to add to the urban forest in the underserved communities around USC's Health Sciences Campus. The study area spans 4.93 square miles and encompasses much of Lincoln Heights, El Sereno, and Ramona Gardens. Locations of greatest need were identified within the study area based on demographic characteristics as well as climate and pollution impact factors. The project team also engaged local community organizations and leaders to understand the needs and preferences for green space in the study area. Based on a combination of these scientific and social priorities, the USC researchers developed five separate greening scenarios that recommend the most effective locations for trees whereby the Eastside can get the most out of L.A.'s tree-planting efforts.

The report also includes a novel scientific analysis conducted on a selection of California native tree species and other tree species commonly planted in southern California to understand which species reduce particulate matter concentrations. The study presents recommendations for tree species that would be likely to act as "pollution sponges" by extracting significant quantities of particulate matter from the atmosphere in areas with high concentrations of $PM_{2.5}$. This is of particular importance to the communities in the study area located close to the US 5, 10 and 110 Freeways that suffer from poor air quality. A 2018 USC analysis found that Lincoln Heights had the third poorest air quality of any neighborhood in Los Angeles and air quality is likely to worsen as temperatures rise (Mackovich, 2018).

The remainder of this report builds on the executive summary (Section 1) and introduction (Section 2) and has five parts. Section 3 delineates the study site and describes the people of the place and land uses in more detail. Section 4 summarizes the related work with a focus on the ecosystem services contributed by the urban forest, the threats posed by green gentrification, the need for climate-ready interventions, and current and recent greening projects in the study site. Section 5 describes the methods and data used to document the current state of the urban forest that led to the development of five scenarios for greening this study site. Section 6 describes the results, including the baseline conditions, air quality monitoring, community engagement, and greening scenarios. Section 7 offers some conclusions and suggestions for future work.

3. Study Site

The study site is located immediately north and east of the US 10 and 5 Freeways, respectively and covers parts of the El Sereno, Lincoln Heights and Boyle Heights neighborhoods in the City of Los Angeles and an unincorporated area that is part of Los Angeles County immediately to the east of Ramona Gardens. Parts of Daly Street and Pasadena Avenue mark the western boundary of the study site. The northern boundary starts at the intersection of Pasadena Avenue and East Avenue 35 and then travels along the latter and part of Griffin Avenue before heading more or less due east until it meets and follows Huntington Drive from the junction with North Mission Road to the junction with Lifur Avenue. The latter marks the northeastern corner of the study site and from there, the eastern boundary heads south along parts of Lifur, Farnsworth, and Warwick Avenues before meeting up with Alhambra Avenue, which along with Whiteside and Marengo Streets, marks the study site's southern boundary.

The study site today includes USC's Health Sciences Campus, Ramona Gardens, a public housing community operated by the Housing Authority of the City Los Angeles (HACLA), and numerous parks and schools as well as light industrial and single- and multi-family residential areas. The locations of the El Sereno and Lincoln Heights neighborhoods, the USC Health Sciences Campus, Ramona Gardens, the seven prominent streets that traverse the study site—Broadway, Eastern, Huntington, Main, Mission, Soto, and Valley—are shown in Figure 1.

The study site spans 4.93 square miles, the surface comprises flat areas, portions of the Repetto Hills, typical urbanization, transportation infrastructure, urban recreation facilities, and protected habitat and natural areas. The earliest maps show ephemeral streams in many of the valleys and that the current artificial lake in Lincoln Park was likely an ephemeral wetland prior to European settlement.

The topographic surface reproduced in Figure 2 is important to the work at hand, because the south facing slopes will receive more sunlight than other aspects, and because the hydrology is a key part of the ecosystem services in semi-arid landscapes like this one. The local surface and subsurface hydrologic conditions have a large impact on the species selection of trees and other vegetation that will prosper on various sites, and whether or not supplemental water will be required to establish the trees or support their long-term survival as temperatures increase. The hydrologic and topographic information visualized in Figure 2 should inform the development and refinement of future planting plans.

Turning next to land use, single- and multi-family housing covers nearly 50% of the land surface (Table 1). Substantial areas are also devoted to parks, open space, school campuses and a variety of industrial, institutional, and transportation uses in this study site.

Table 1: Study site land uses

Metrics	Area (acres)	Area (%)
Residential	1472	47.0
Commercial and industrial	366	11.6
Parks	216	6.8
School campuses	145	4.6
LAC+USC Medical Center	41	1.3
USC Health Sciences Campus	86	2.7
Transportation	607	19.2
Other	222	7.0
Totals	3,155	100.0

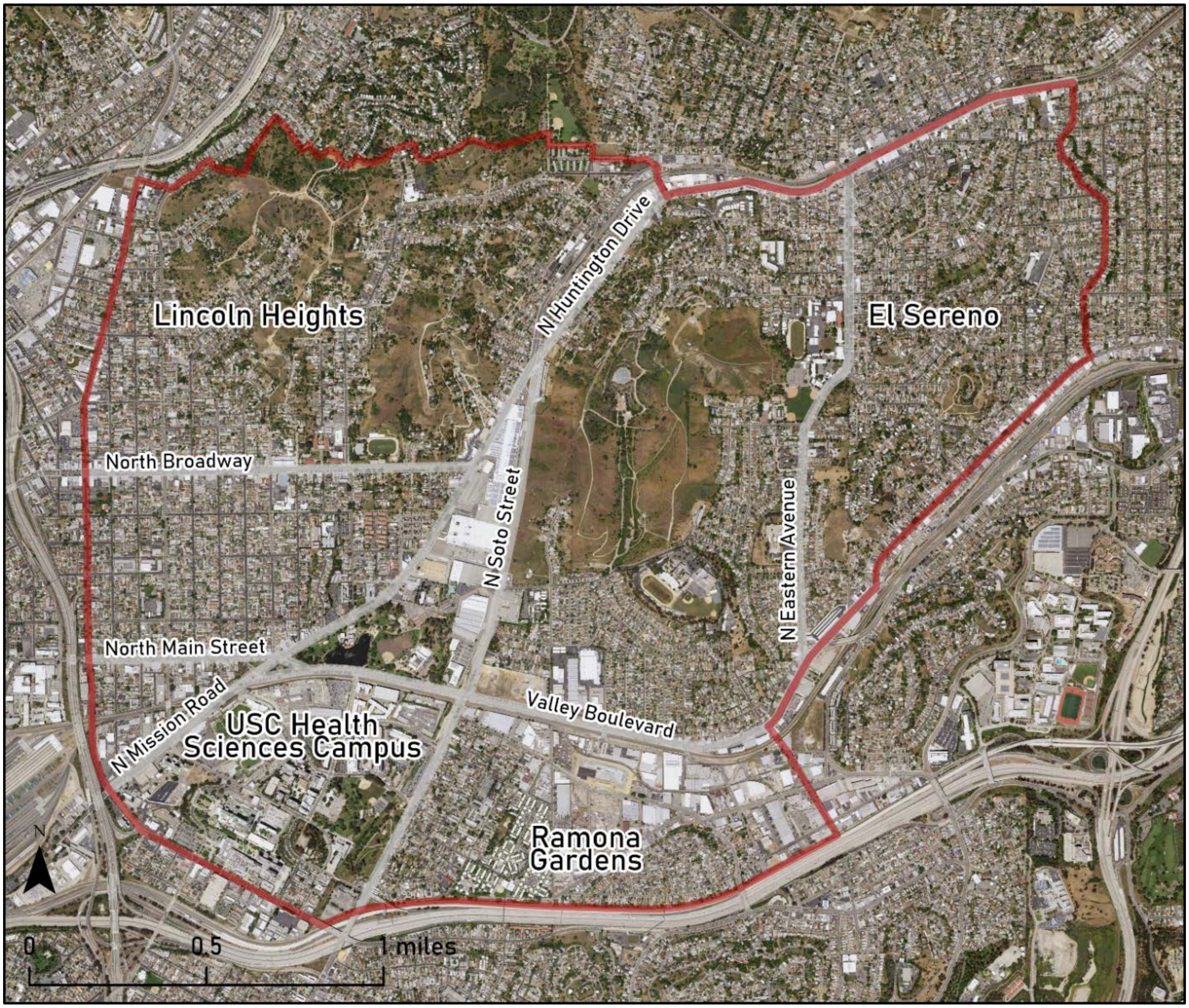


Figure 1: Map showing prominent features of study site within Los Angeles Metropolitan Area

The map reproduced in Figure 3 shows the spatial pattern of the various land uses and the distinctive residential uses that occur to the west and east of North Mission Road and North Soto Street. This pair of streets separate Lincoln Heights to the west and El Sereno and Ramona Gardens to the east and the pattern shows a transition from multi- to single-family units from south to north in Lincoln Heights and the reverse pattern in El Sereno. The map also shows distinctive clusters of multi- and single-family housing in each of these communities and the Ramona Gardens public housing complex immediately adjacent to the US 10 Freeway in the southeast corner of the study site (Figure 3). The housing stock also varies in size and age with 63% of the units built before 1950, 21% built from 1950 to 1980, and 16% built since 1980. The Ramona Gardens housing complex, for example, with 610 apartments spread across 100 buildings on 32 acres, opened in 1940 and today is home to approximately 1,700 Angelenos.

Figure 4 shows the permeable and impermeable areas of the study site and in particular, the large impermeable areas that dominate many of the residential lots as well as the commercial, industrial and institutional land uses, and the streets and parking lots. The state-of-affairs has important implications for greening and stormwater recharge because impermeable surfaces consist of water-resistant materials like asphalt and concrete that dramatically reduce rainwater infiltration and natural groundwater recharge. The permeability information used to generate the map reproduced in Figure 4 was from the U.S. Environmental Protection Agency's EnviroAtlas Meter Scale Urban Land Cover dataset for Los Angeles County. This dataset uses a square grid 1 meter on a side for the permeability and other environmental layers (U.S. Environmental Protection Agency, 2019).

The 14 parks plus 15 public and 11 private school campuses

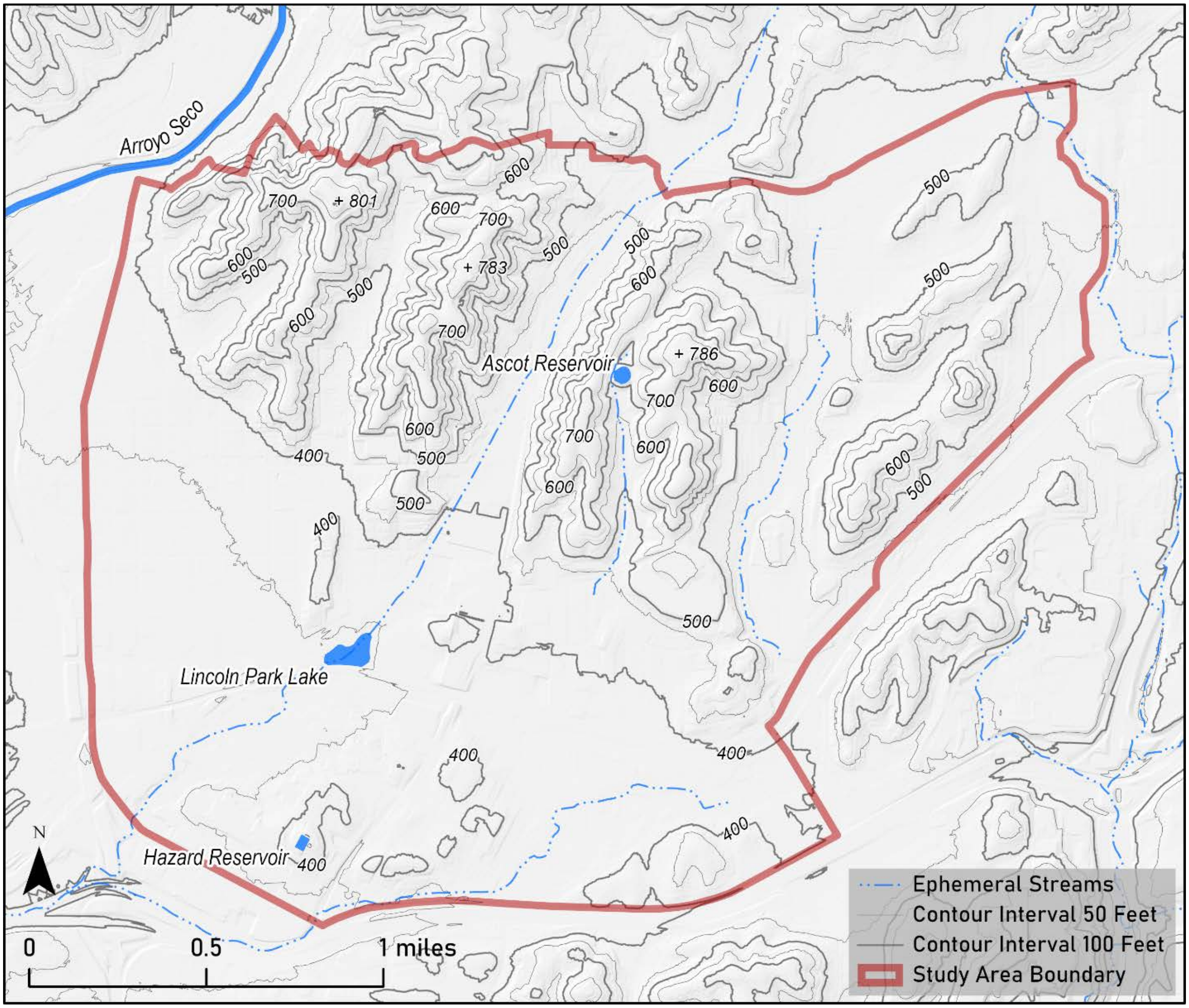


Figure 2: Map showing major topographic and water features of study site

scattered throughout the study site constitute important landmarks and destinations for local residents (Figure 5). These land uses provide numerous opportunities for greening the study site, as illustrated in Section 4.

It is also worth noting that the USC Health Sciences Campus and LAC+USC Medical Center in the southwest corner coupled with the commercial and industrial land uses that follow Alhambra Avenue in the southeast corner of the study site provide a large and diverse set of employment opportunities for local residents as well as those from further afar. However, these employment opportunities coupled with the large numbers of local residents, narrow streets, and lack of parking lots means that parking is a challenging proposition throughout the study site. The street parking demands are pervasive throughout the study site and these may limit the opportunities for planting and maintaining an urban forest that makes extensive use of street trees. These parking challenges are particularly severe near the USC Health Sciences Campus and LAC+USC Medical Center, notwithstanding the construction of several new parking structures and surface parking lots during the past 3-5 years.

Turning next to demographics, the study site has 57,015 residents with equal numbers of males and females, and substantial numbers ≤ 15 years (12,209, 21.4%) and ≥ 65 years (6,577, 11.5%) (Figure 6 and Table 2). The presence of twice as many children compared to the elderly points to a relatively young population, and the median age for males (31.8 years) is nearly three years lower than that for females (34.7 years).

Nearly four of every five residents in the study site are Hispanic (78.7%) with slightly higher percentages in Ramona Gardens and El Sereno and lower percentages in Lincoln

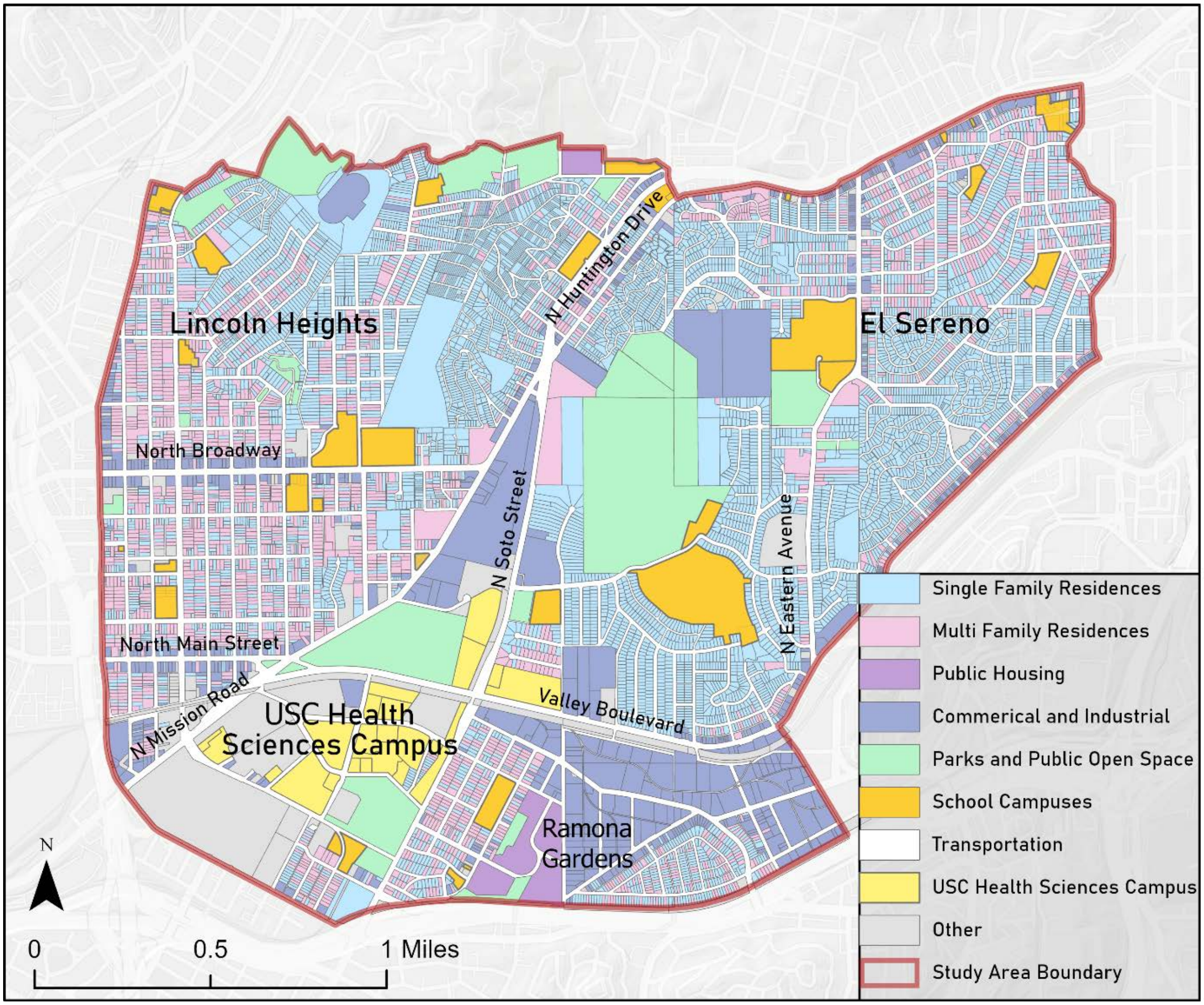


Figure 3: Map showing major land uses of study site

Table 2: Study site population metrics

Metrics	Females	Males	Totals
Population, 0-15 years	5,913	6,296	12,209
Population, 16-64 years	19,004	19,225	38,229
Population, ≥ 65 years	3,770	2,807	6,577
Total population	28,687	28,328	57,015
Median age, years	34.7	31.8	33.3

Heights (Table 3). Asians make up the second largest group and are more prevalent in Lincoln Heights. Non-Hispanic whites comprise just 5% of the residents overall. The numbers of Hispanic and Asian residents in the three neighborhoods also vary in terms of their origins but Mexican dominates among Hispanics followed by those of Salvadoran and Guatemalan origin and Chinese dominates among Asians followed by those of Vietnamese origin (Table 4). Approximately one-half of the Hispanics are of Mexican descent and two out of every three Asians are of Chinese descent.

The latest census data also shows that homeowners comprise only about four of every 10 households indicating a high percentage of renters in the area (Table 5). Most of the homeowners (83.6%) and approximately half of the renters (54.9%) have lived in the study site for 10 year or longer. However, these data also show that one of every four homeowners and renters allocate ≥ 50% of their total household income to mortgage or rent payments and that approximately one in seven households (14.4%) has no vehicle, which is nearly 20% higher than the ratio for the City of Los Angeles as a whole (12.2%). The renters are the most transit dependent, with nearly one in five (19.1%) of these households lacking access to a vehicle. Several Los Angeles Department of Transportation (DASH) and Metropolitan Transit Authority (Metro) bus routes traverse the study site and connect residents with Downtown Los Angeles and places further afield.

The population of the study site is also quite dense—there are 11,565 residents per square mile in the study site, and 23,959 residents per square mile if we only use residential lots to calculate density. There are also four large parks—Ascot Hills, Hazard, Lincoln and Rose Hills—and 10 smaller parks scattered across the study site (Figure 5). These parks cover 216 acres and provide just 3.79 park acres per 1,000 residents, which is approximately one-third of the citywide park acreage to resident ratio of 9.23 park acres per 1,000 resident (City of Los Angeles Department of Recreation and Parks, 2009).

Finally, there is an average of 3.6 residents in each of the 15,544 households and the median household income across the whole study site is $48,706, compared to $62,142 for the City of Los Angeles as a whole. There is some variability from one census block group to the next in the study site but overall, 71.3% of the households have incomes below 300% of the federal poverty line and nearly one out of every five households receives Supplemental Nutrition Assistance Program (SNAP) benefits (Table 6). A map of the census block groups that make up the study site is included in the Appendices (see Figure A1).

Table 3: Study site race and ethnicity by neighborhood as a percent of total population

Neighborhoods	Hispanic	Non-Hispanic			
	All races	Asian	White	Black	Other
El Sereno	80.7	10.2	6.2	0.9	2.0
Lincoln Heights	73.2	20.3	5.2	0.7	0.6
Ramona Gardens	92.6	2.7	1.4	2.2	1.1
Totals	78.7	14.0	5.1	1.0	1.2

Table 4: Asian and Hispanic populations by neighborhood and origin as a percent of total population

Neighborhoods	Hispanic origin				Asian origin		
	Mexican	Salvadoran	Guatemalan	Other	Chinese	Vietnamese	Other
El Sereno	54.9	4.9	2.0	18.8	6.4	0.4	3.4
Lincoln Heights	47.3	2.4	1.6	22.0	12.2	3.5	4.7
Ramona Gardens	61.4	3.6	3.6	24.0	1.0	0.1	1.6
Totals	52.1	3.6	2.0	21.0	8.4	1.8	3.7

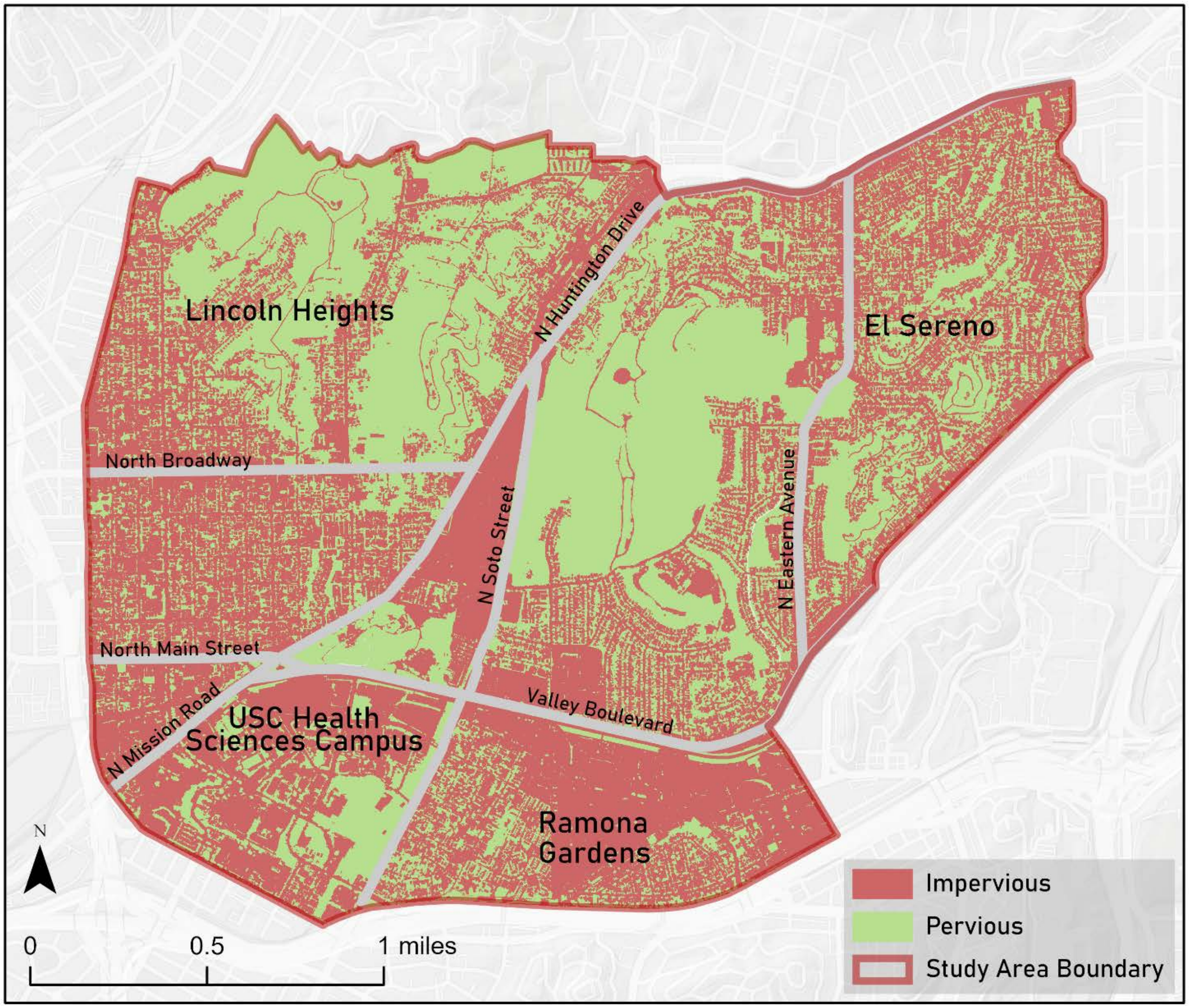


Figure 4: Map showing the impermeable and permeable surfaces of the study site

Table 5: Demographic and socio-economic household profiles

Metrics	Homeowners	Renters	Totals
No. of households	5,983	9,571	15,544
Percent of households who moved in before 2010	83.6	54.9	66.0
Percent of households whose mortgage payment is ≥ 50% of total income	28.6	--	--
Percent of households whose rent is ≥ 50% of total income	--	27.8	--
Percent of households with no vehicle	7.0	19.1	14.4

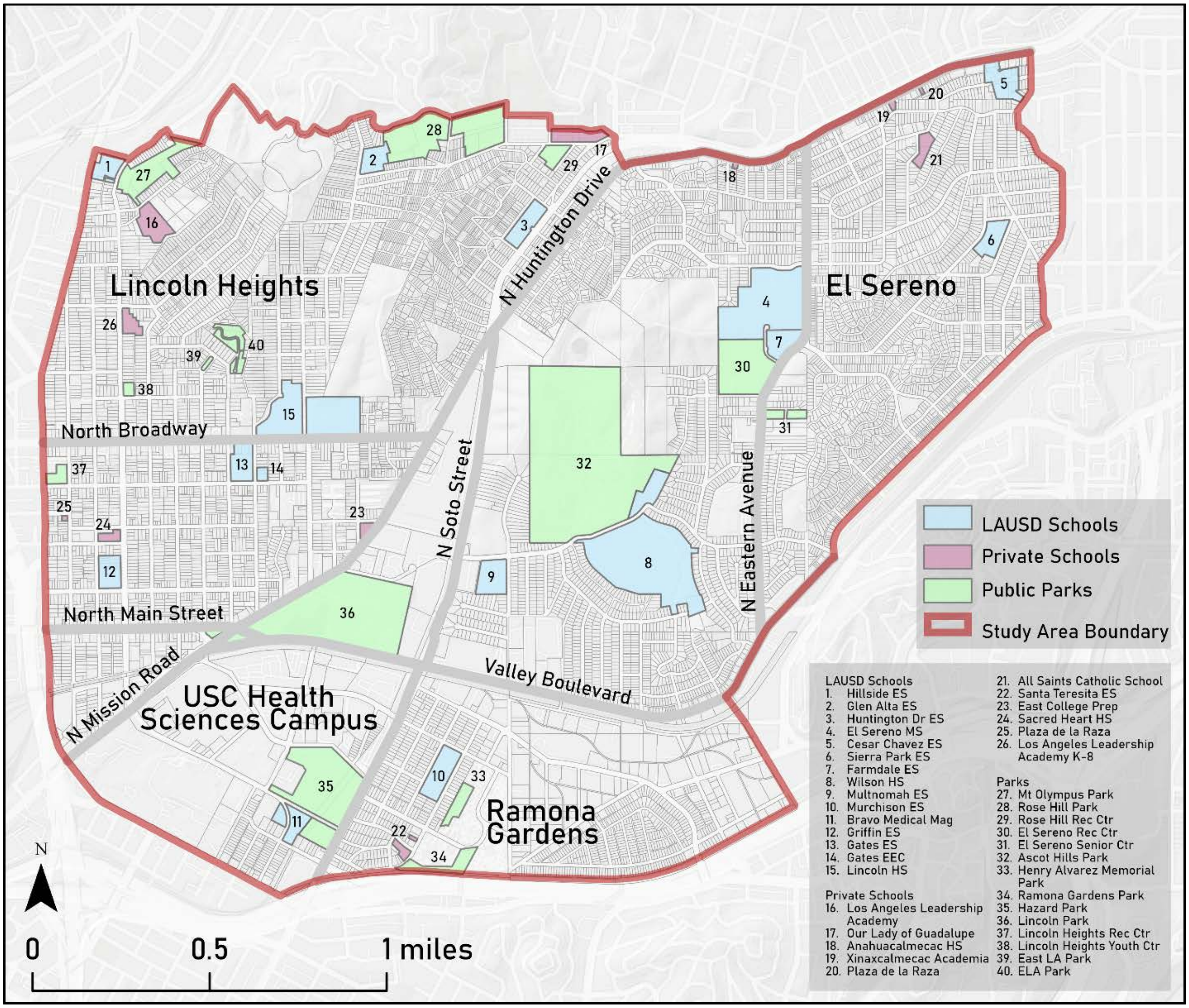


Figure 5: Map showing parks and school campuses of study site

Table 6: Demographic and socio-economic household profiles by census block group

Metrics	Mean	Range
Household size	3.6	2.6 – 4.3
Median household income	83.6	17,417 – 105,211
Percent of households < 300% of the federal poverty line	71.3	54.7 – 84.7
Percent of households receiving Supplemental Nutrition Assistance Program (SNAP) benefits	17.0	1.5 – 53.3

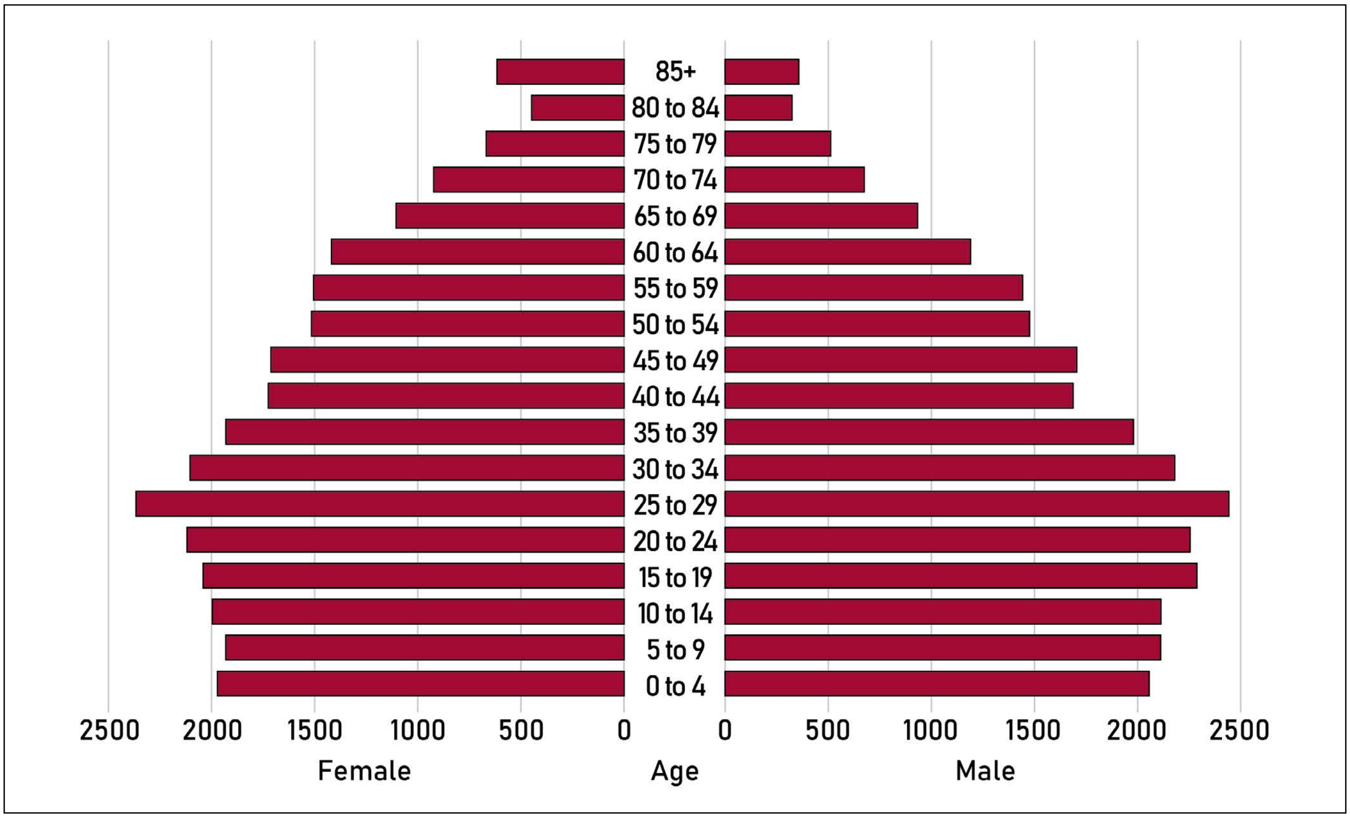


Figure 6: Age-sex pyramid showing numbers of females and males using 5-year age intervals

4. Related Work

Urban forests provide ecological and environmental services that contribute to enhanced human wellbeing and advance an array of local, state, national, and global goals (e.g., Endreny 2018; City of Los Angeles Mayor's Office, 2019; United Nations 2019). Urban forests include all of the trees in an urban area—street trees, trees in pocket parks or on hillsides or in riparian corridors, and those on private property—and they are more relevant than ever before because cities are home to a rising majority of the global population (Edgar et al., 2021). Residential neighborhoods in many cities across the Los Angeles Metropolitan Region have lost trees as infill redevelopment replaces buildings with smaller footprints (Lee et al., 2017). The aforementioned metrics support the urgency to increase green infrastructure and reverse the losses on residential lots as well as other locations noted in 'L.A.'s Green New Deal Sustainable City pLAn' (City of Los Angeles Mayor's Office, 2019).

The three sections that follow describe some of the ecosystem services that would follow the expansion of the urban forest, the rise of green gentrification and ways to combat this threat, and the need for climate-ready interventions in southern California to successfully plant and nurture trees over the long-term. The latter is required to retrieve the full value from these investments since many of the ecosystem services provided by an urban forest will vary over the lifespan of the forest itself. A number of recent publications have called out the urban forest as a key component of nearly all of the urban- and transport-planning innovations proposed for achieving carbon neutral, liveable and healthy cities (e.g., Carrus et al., 2015; Samson et al., 2015; Endreny et al., 2017; Endreny, 2018; Nieuwenhuijsen, 2020).

4.1. The urban forest and ecosystem services

The general argument for a healthy and robust urban forest is relatively straightforward and easily captured using infographics like the one reproduced in Figure 7. This figure argues that a large and healthy urban forest captures and infiltrates rainwater, promotes groundwater recharge, improves soil quality, reduces energy consumption, cools cities, reduces air pollution, sequesters carbon, decreases rates of asthma, cardiac disease and strokes, increases physical activity, reduces stress, and improves mental health.

This general argument, however, glosses over many of the subtleties that would be important if one wanted to increase the urban forest to achieve one or more of the aforementioned outcomes in specific locations like the study site at hand. These include the available soil volume and maintenance required to achieve a large and healthy urban forest.

Anderson et al. (2013), for example, recently reviewed the methods used to calculate the heat index as an exposure metric in environmental health research. Similarly, Yao et al. (2018) explored the influence of different methods and data on the estimation of the urban heat island intensity. Deilami et al. (2018), on the other hand, provide a systematic review of the spatiotemporal factors and accompanying methods, data, and mitigation measures used to combat the urban heat island effect. Finally, Livesley et al. (2016) examined the effects of urban forest on urban water, heat, and pollution cycles at the tree, street, and city scale.

These subtleties also speak to the need to capture the spatiotemporal variability of the opportunities or problems at

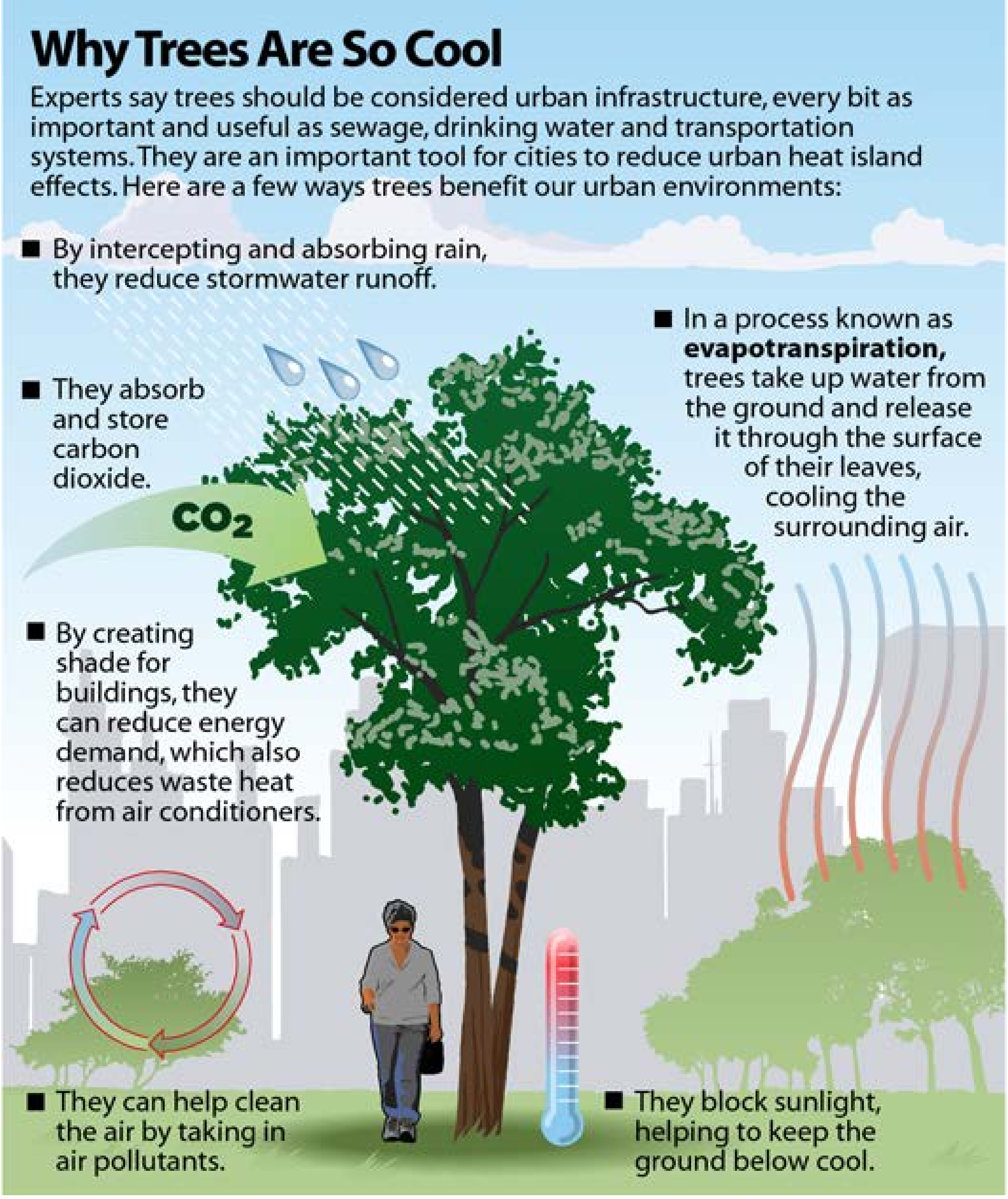


Figure 7: Schematic summarizing some of the benefits of trees (Source: Paul Horn, Inside Climate News, using materials published by North Carolina State University, the U.S. Environmental Protection Agency, and the U.S. Forest Service)

hand. Anniballe et al. (2014), for example, recently documented the spatial and temporal trends of the surface and air heat island over Milan in Italy using MODIS satellite data. Przybysz et al. (2014) examined the effect of pollution level, rainfall and the passage of time on the accumulation of particulate matter and trace elements on vegetation. Mori et al. (2015) measured the particulate matter and element accumulation on coniferous trees at varying distances from a highway. Tong et al. (2015) and Ozdemir (2019) examined the efficacy of using roadside trees to mitigate particulate pollution. Sæbø et al. (2012) examined plant species differences in particulate matter accumulation on leaf surfaces. Muhammad et al. (2019) quantified the atmospheric net particle accumulation on 96 plant species with varying morphological and anatomical leaf characteristics. He et al. (2020) estimated the particulate matter captured by roadside evergreen vegetation during the winter season in Hanover, Germany. Pallozzi et al. (2020) examined the particulate matter concentrations and fluxes within an urban park in Naples, Italy. Blanusa et al. (2015) evaluated the leaf trapping and retention of particulate matter by *Quercus ilex* (Holm oak) and other common trees in Mediterranean urban climates (i.e., that mirror the climate in southern California). Xu et al. (2019) measured the accumulation of particulate matter by boles, branches and leaves.

This last collection of papers focused on the ability of trees to mitigate air pollution is important for the work at hand given the proximity of the study site to the US 5 and 10 Freeways (Figure 1) and the difficulty and expense of collecting data to support these kinds of validation studies. Many of the studies at the tree, street, neighborhood, and city scale in the U.S. rely on i-Tree (https://www.itreetools.org). Hirabayashi et al. (2015) described the tree dry deposition models used in i-Tree to predict these relationships. This, and the aforementioned papers, point to the importance of local conditions and the need to use site-specific data to inform assessments of trees' ability to mitigate air pollution [see Traverso (2020) and the discussion of our own work in Section 4.3 for additional details].

A series of papers focuses on the need to validate the efficacy of one or more benefits of a large and healthy urban forest. Some of these papers focus on heat mitigation and we will focus on this outcome because it helped to motivate and shape the scenarios proposed later in this report. McPherson and Simpson (2003), for example, examined the potential energy savings in buildings following an urban tree-planting program. A few years later, McPherson et al. (2005) estimated the benefits and costs associated with municipal forests in five U.S. cities and more recently, McPherson et al. (2016) examined the structure, function, and value of street trees in California. Bosch et al. (2020) documented the need for spatially explicit approaches to evaluate urban greening scenarios for urban heat mitigation. Rahman et al. (2020) reviewed the importance of different traits of trees for cooling urban heat islands. Zhou et al. (2017) examined the effects of the spatial configuration of trees on urban heat mitigation and Wujeska-Klause and Pfautsch (2020) showed how the best trees for daytime cooling might leave nights slightly warmer in Sydney, Australia. Sailor et al. (2020) estimated the reduction that might accompany increases in vegetative cover and surface solar reflectance (albedo) to reduce total indoor and outdoor exposure to dangerously hot conditions in Los Angeles (cf. Wu and Chen, 2017).

This last paper by Sailor et al. (2020) also noted some of the tradeoffs associated with the various management options. Many of these focus on water supply and impacts in Mediterranean climates like that found in southern California. Bijoor et al. (2014), for example, modeled the water budgets of lawns under three different management scenarios. Litvak and Pataki have co-authored a series of papers that have examined the evapotranspiration (i.e., water use) associated with the watering options for urban forests in the Los Angeles Metropolitan Region (Pataki et al., 2011; Litvak et al., 2016, 2017a, 2017b). Porse et al. (2018), on the other hand, estimated the economic value of local water supplies in Los Angeles and the desirability of finding ways to retain and infiltrate local precipitation. The expansion of the urban forest could help with retention and infiltration of local precipitation.

The choice of tree species will weigh heavily on our ability to achieve these kinds of outcomes. The wet and cool winters and long and hot summers that dominate southern California's climate, for example, means that most of the rainfall events occur in the winter months when deciduous tree species are defoliated. Evergreen species offer consistent performance throughout the year while deciduous species have minimal value for rainfall interception, land surface temperature reduction, and air pollution interception when they are leafless.

Hence, leaf area, surface roughness and hydrophobicity or attraction are characteristics that significantly affect the potential of specific species to intercept precipitation and cool the atmosphere by way of evapotranspiration. Deciduous species with smooth flexible leaves like *Fraxinus* (Ash), *Pyrus calleryana* (Callery pear), *Lagerstroemia* (Crape myrtle) and *Ginkgo biloba* (Gingko) have the lowest rainfall interception volume. Species with rough and hydrophilic surfaces like *Pinus pinea* (Italian stone pine), *Quercus ilex* (Holly or Holm oak) and *Pinus canariensis* (Canary Island pine) with additional interception potential on stems, branches and other surfaces, offer the highest rates of interception among drought tolerant species appropriate for planting in southern California (Xiao and McPherson, 2016).

Similarly, tree species with large crown volumes and a high leaf area index (LAI) are more effective than small and more open trees in providing shade and reducing land surface temperatures. Large dense canopies reflect more light, provide more shade and transpire more water resulting in cooler surface temperatures (Wujeska-Klause and Pfautsch, 2020). In addition, Litvak et al. (2014) have shown that the reductions in irrigated grass evapotranspiration (ET) caused by the shading effects of open-grown trees were more important in influencing total landscape ET than the addition of tree transpiration. This means that the low-density planting of trees that partially shade irrigated urban lawns may be a water-saving measure in southern California. Trees planted in irrigated lawn areas also have higher transpiration rates, which leads to increased cooling (Pataki et al., 2011). Tree canopies reduce solar radiation between 60-90% and surface temperatures under tree canopies are up to 55°F cooler than adjacent exposed asphalt paving (see Figure 8 for an example from the study site). Cooling specifically from transpiration has been found to be between 1 and 8°C. The effectiveness of individual tree species depends on tree size, canopy density and leaf shape, size, thickness and color. Pyramidal and round shaped tree canopies are more effective in surface cooling than horizontal spreading tree canopies. Species with the highest cooling potential include pines and species with high LAI. Species with simple thin leaves typically have higher transpiration rates and cooling than species with compound leaves or thick and waxy leaves typical in dry climates where plants must conserve water. Spacing and arrangement of trees can have positive effects on surface temperature cooling. For example, planting trees with overlapping canopies and in multiple rows will reduce surface temperatures more than single rows of trees at spacing greater than the canopy radius (Rahman et al., 2020). These kinds of considerations helped to motivate and shape the greening scenarios proposed in Section 5.4 below.

There is a need for more work to quantify the downstream impacts of the urban forest on human health and wellbeing. Bikomeye et al. (2021), for example, recently documented the impact of schoolyard greening on children's physical activity and socioemotional health and Wolf et al. (2020)

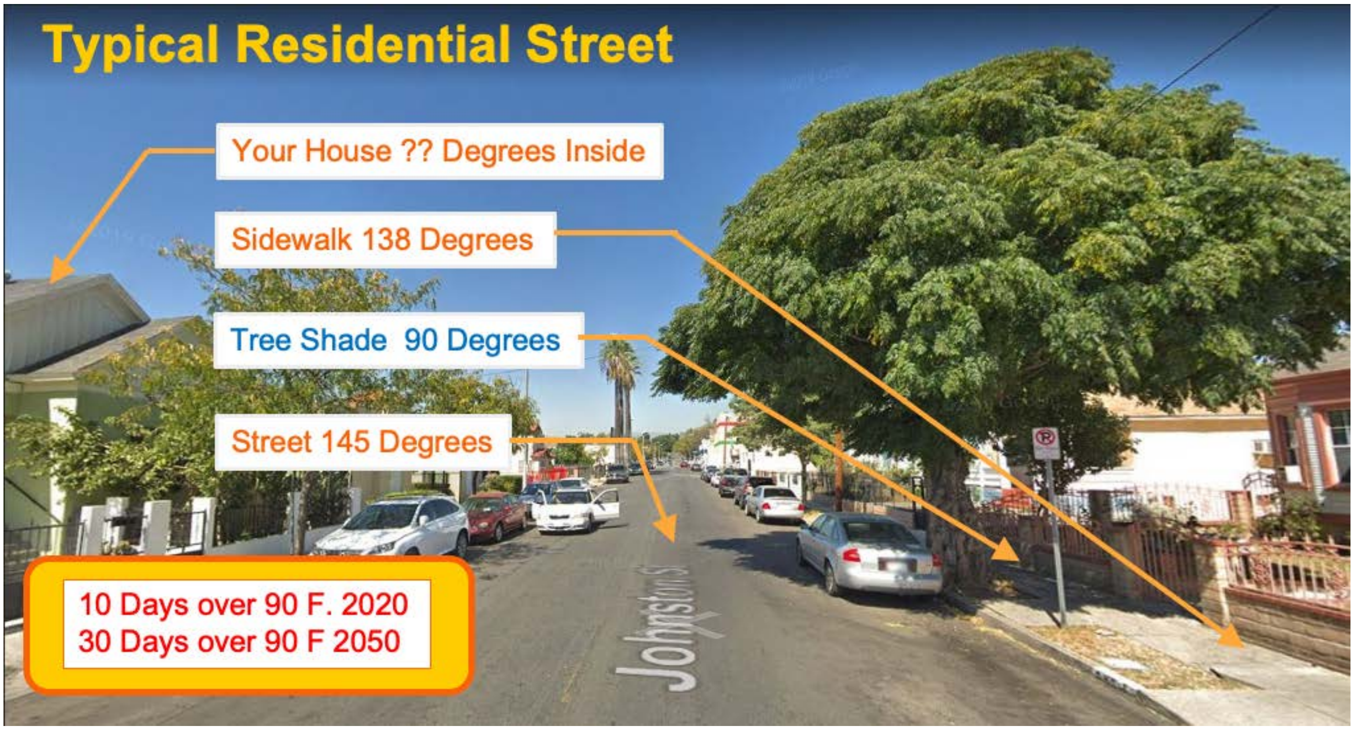


Figure 8: Surface temperature measurements recorded in various settings on a typical residential street (Johnston) in Lincoln Heights on September 15, 2020

in a recent scoping review classified these downstream impacts in three groups as follows:

1. Reducing Harm, which considers the role of vegetation in mitigating the conditions that can compromise health, and includes concerns connected with exposure to air pollution, noise, and heat.
2. Restoring Capacities, which describes how nature experiences are a resource that promotes improved psychological and physiological functioning, including cognitive attention restoration, and stress recovery.
3. Building Capacities, which describes nature experience pathways that facilitate multiple conditions of wellness for both individuals and communities, such as encouraging physical activity and providing settings for social interaction.

However, these benefits will only accrue if the people whose neighborhoods are greened stay in place and we turn our attention next to the rise of green gentrification and ways to combat this threat.

4.2. Green gentrification

The term “green gentrification” refers to the displacement of low income residents and neighborhood businesses caused by increases in housing prices and influxes of wealthy and often white residents that often accompanies greening projects implemented to serve longtime residents in low-income neighborhoods (Rigolon and Christensen, 2000; Rigolon and Németh, 2018; Chen et al., 2021). Greening projects contribute to a broader environmental agenda (i.e., densification, mixed uses, green infrastructure and walkability) focused on sustainable urban forms and human wellbeing (Haase et al. 2017). However, they may produce or exacerbate environmental inequities that Anguelovski et al. (2018a, 2018b) and others have referred to as the green space or green gentrification paradox.

Numerous studies have also examined existing greening projects to learn more about ways to combat green gentrification. Rigolon and Christensen (2000), for example, described 26 types of parks-related anti-displacement strategies (PRADS) implemented in 13 park projects before noting that it was too early to assess their effectiveness in limiting displacement. Chen et al. (2021), on the other hand, have suggested using a ‘just green enough’ approach using distributed smaller green spaces with less stringent maintenance to solve the green gentrification paradox.

Rigolon and Németh (2020) recently tested this hypothesis using multilevel logistic regression to decipher whether the location (i.e., distance to downtown), size and function (i.e. active transportation) of new parks built in 10 U.S. cities during the periods 2000-2008 and 2008-2015 predict whether the nearby census tracts gentrified. The results showed that park function and location are strong predictors of gentrification (unlike park size) and that new greenway parks with an active transportation component and parks located closer to downtown triggered gentrification more than other park types and locations on a city’s margins. These results call into question the ‘just green enough’ claim, and the better route might be to focus on strategies that park and recreation professionals can use to achieve environmentally equitable outcomes.

Rigolon et al. (2020) recently proposed using four complementary strategies to combat green gentrification. The first entails park proponents joining with urban planners to establish or preserve affordable housing near greening projects. The second entails building park agencies in which the race and ethnicity of the leadership and workforce mirror those of the communities they serve. The third is the need for the community outreach activities to engage all of the community and with the goal of preparing the most marginalized people to participate. The fourth is the need for the new and renovated parks and streets and accompanying recreation programs to welcome and engage long-term residents as well as newcomers and visitors. The intent is to create social environments in which marginalized populations gain just as much access to quality green space and to protect the ability of long-term residents to stay in place as the environment around them is greened. These strategies point to the need to preserve and expand safe and affordable housing opportunities and local workforce development in conjunction with neighborhood greening initiatives.

The aforementioned line of reasoning suggests that meaningful engagement in the planning and design of parks, open space, and green infrastructure is essential for green equity. A recent scoping review conducted by Jelks et al. (2021) to explore the connections between green gentrification and health reaffirms that a big shift is required to achieve the desired outcomes with urban greening initiatives like those envisaged in LA’s Green New Deal Sustainable City pLAn (City of Los Angeles Mayor’s Office, 2019). Using 15 studies focusing on green space use, physical activity, sense of community, safety, and self-reported health, Jelks et al. (2021) found that green gentrification negatively affects long-term, marginalized residents. These residents experienced a lower sense of community, felt that they do not belong in green space, and used green space less often than new residents and visitors.

The COVID-19 pandemic may have made matters worse. Mell and Whitten (2021), for example, using work in the United Kingdom have argued that the series of lockdowns that accompanied COVID-19 has cast green infrastructure as an essential infrastructure and noted how communities with higher ethnic diversity, lower income, and great health inequality suffered from insufficient access, perhaps heightening the need to solve this green gentrification paradox. Tomasso et al. (2021) offers a very similar commentary on COVID-19, nature deprivation, and human wellbeing. Anguelovski et al. (2019), on the other hand, have argued why green 'climate gentrification' may threaten poor and vulnerable populations even more in the next few decades. These authors note first how these populations have contributed the least to climate change, have had the least access to environmental amenities such as green space, are the most exposed to climate hazards and effects, and have the fewest resources to mitigate or adapt to rising temperatures. They then argue that a fifth type of climate injustice is about to envelop these populations, because they are among the social groups most likely to experience residential and social displacement from the green climate infrastructure described in Section 4.3 below.

4.3. Climate-ready interventions

The changing climate also means that one needs to choose greening strategies that can prosper in a warming climate (e.g. McPherson et al., 2019). The current predictions point to increasing numbers of hot days with temperatures exceeding 95°F and for these conditions to persist over longer periods of time (Hulley et al., 2019, 2020). These effects will vary tremendously over short distances, and they generally increase with distance from the coast. Figure 9 shows predictions prepared by Alex Hall and colleagues in the University of California Los Angeles Center for Climate Science, which suggest that the number of days with temperatures exceeding 95°F in the study site during the period 1981-2000 will be three times higher by 2060.

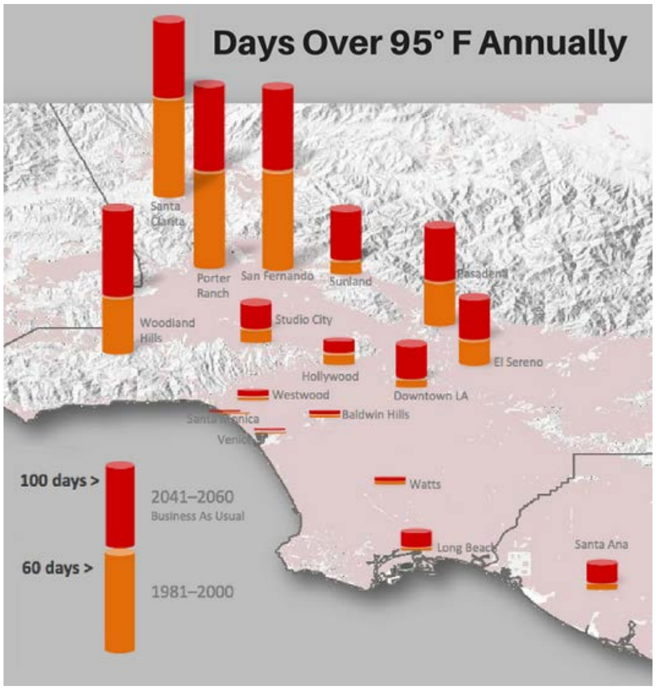


Figure 9: Map showing days over 950F annually in select locations, including El Sereno, for the periods 1981-2000 and 2041-2060, respectively (Source: Los Angeles County Department of Public Health)

Southern California is also highly dependent on imported water to support urban landscape vegetation and urban forest canopy. Large scale tree planting programs like those envisaged in LA's Green New Deal Sustainable City pLAn (City of Los Angeles Mayor's Office, 2019) might have significant impacts on urban water use and cause further stress if high water use species such as plane trees (*Platanus* sp.) and even southern California native *Plananus racemosa* (Sycamore) trees are selected for inappropriate locations. Transpiration rates vary widely between tree species typically planted in Los Angeles with low levels in unirrigated *Pinus canariensis* (Canary Island pine) and much higher levels in irrigated landscapes (Pataki et al., 2011). Low water use species, locations with moister soil such as ephemeral waterways (see Figure 2 for likely locations in the study area) and bioswales or sources of recycled water will reduce potential water resources stress. Trees use far less water than other irrigated landscapes, especially natural turf. Tree planting to shade lawns could reduce irrigation needs by lawns and other planting (Litvak et al., 2014).

The City of Los Angeles is currently working to revise the list of recommended tree species with a focus on species that will thrive in the increasingly warming climate, provide valuable shading, and minimize the damage to sidewalks and water use. The preparation of this list has included calculations and discussion about the water used to generate biomass and carbon sequestration and the waste that occurs when poor or excessive pruning occurs. The water used to grow plant material is thrown away (i.e., wasted) through the improper or excessive pruning. This list will help communities to build new and sustainable urban forest in the years ahead so long as appropriate maintenance practices are used for mature trees to ensure the best possible return on investment for an urban forest.

4.4. Local greening projects

Our goal is to propose scenarios that would complement the work of other agencies and organizations working to improve the green infrastructure of the study site. Here we describe a series of recent or ongoing projects that will help to green parts of one or more neighborhoods in the study site.

The first project is the recent habitat restoration work led by North East Trees in Ascot Hills Park. This work to help restore the native flora, attract native fauna back to the park, capture stormwater runoff and allow for natural infiltration, and improve air quality started several years ago. The latest grant funded projects have focused on about 40 acres in the center of this 88-acre park north of the Multnomah Street entrance and included the restoration of 14 acres of native habitat and two natural stormwater infiltration areas, the planting of 950 trees and 5,000 shrubs, and the addition of two vista points and interpretative signage.

The second project is the Lincoln Park Neighborhood Green Street Network Project submitted by Los Angeles Sanitation and Environment in partnership with the City of Los Angeles Recreation and Parks Department to the State of California Safe Clean Water Program Stormwater Investment Plan for funding a few months ago. This project would restore the public lake, enhance and beautify the community and improve water quality and sustainability practices by building a three-mile "Green Street" network that would capture stormwater and connect Lincoln Park with surrounding neighborhoods.

The third project is a work in progress by North East Trees to plant hundreds of trees at and around Ramona Gardens. The current plans for the Ramona Gardens Green Connections Project include planting 65 trees to help improve air quality, shade buildings and provide natural beauty at Ramona Gardens. Another 250 trees will be planted along nearby resident paths of travel to create safe green walking connections to local schools, transportation centers, and nearby amenities. The development of an open space park in Henry Alvarez Park (la loma) is also included in the project plans and was selected by the Ramona Gardens Resident Advisory Committee during community outreach. North East Trees will be installing three rain gardens to help capture and clean stormwater and a new ADA ramp will more easily connect the community to this park.

The fourth and final series of projects focus on USC and their efforts to enhance the sustainability measures used on the Health Sciences Campus and to connect the campus and services with the community. The campus and accompanying medical enterprise have grown in size and stature over the past 10 years via a series of new buildings, including new clinical, teaching and research spaces, two new multi-story student residences, a new hotel and parking structure, and three new surface parking lots. The university has worked in close collaboration with the Lincoln Heights and Ramona Gardens communities to develop a campus and community beautification process that included installing wider sidewalks for more accessible public space, new vegetation including drought tolerant flora, 200 new street trees, the installation of bioswales to infiltrate water from surface parking lots, and the undergrounding of overhead utilities.

5. Methods and Data

The study site characteristics described in Section 3 and opportunities and constraints described as part of the related work in Section 4 guided the choice of methods and data used for this project. The first two work tasks focused on the baseline conditions—how many and what kinds of trees exist today and what kinds of opportunities and constraints the natural and built environments afford for improving the green infrastructure to help combat extreme heat and mitigate air pollution. The third task focused on the need to learn more about how the placement and choice of tree species affects the removal of particulate matter and sequestration of carbon. The fourth task focused on engaging the community so we could learn more about their experience with extreme heat, where they go to cool off, and their insights and feedback about existing green space in their neighborhoods. The fifth and final task involved the selection of candidate sites, the preparation of several greening scenarios, and some preliminary estimates of what these would contribute to the everyday life and wellbeing of the residents of the study site.

5.1. Identifying, locating, and characterizing the existing tree cover

We used two existing data sources and various imagery products to identify, locate, and describe the existing tree cover.

The first data source was the street tree inventory prepared by the Davey Resource Group for the Urban Forestry Division of the City of Los Angeles Bureau of Street Services as part of the effort to develop an urban forestry plan for the City.

We used this to locate and describe the street trees. Their data covered most of the streets in Lincoln Heights when the project kicked off and initially we gathered information about street trees in other parts of the study site using various imagery products ourselves. The city’s street tree inventory has expanded over time, and it now includes most of the streets in El Sereno as well. This afforded us an opportunity to evaluate the efficacy of our own data collection methods and the results of the comparison of our own and the city’s street counts in El Sereno. The results show that our counts from various imagery sources mirrored those gathered in the field by city staff (see Table A1 in the Appendix for additional details).

The City of Los Angeles provided the street tree inventory data from the TreeKeeper application (https://laparksca.treekeepersoftware.com). We used these data to locate 7,229 trees on 750 of the 1,032 street segments that the City of Los Angeles has surveyed across the study site, after deleting 2,240 locations labeled as stumps, vacant or obsolete sites. The latter number points to lack of municipal funding over the past two or more decades, the low priority afforded green infrastructure generally, and lack of public education regarding the benefits of the urban forest.

The second data source was the information on trees in public parks gathered by the Forestry Division of the City of Los Angeles Department of Recreation and Parks. We downloaded the city parks tree inventory data from the Navigate LA application (https://navigatela.lacity.org/navigatela/). We used this inventory to locate and characterize some of the trees in four of the 14 public parks scattered across the study site because the majority of the trees in parks were not included in the City of Los Angeles Department of Recreation and Parks counts (see Table 9 for final counts). The full city parks tree inventory dataset is now completed.

The two aforementioned inventories left some of the trees in public right-of-ways in El Sereno and Ramona Gardens, as well as the trees associated with commercial, institutional and residential spaces, unaccounted for. We used a combination of Google Maps 3D View, Google Maps and NAIP imagery, and Google Maps Street View and occasional in person observation to locate and identify trees in these parts of the study site. The heavy reliance on virtual tours using multiple imagery sources was due to the limitations posed by the COVID-19 pandemic.

We used Google Maps 3D View to verify that a tree-like spot on the 2D NAIP satellite imagery was a tree and not a shrub. The Google Maps 3D View imagery was helpful with this task but the graphic distortion of the images significantly compromised our ability to estimate the height of deciduous trees and palm trees. Additionally, we used Google Maps Street View to ‘walk’ each of the streets in the study area virtually to differentiate trees on private versus public property. We used this product in the identification process as well by noting which trees were deciduous, semi-deciduous, or evergreen when virtually ‘walking’ each of the streets. The ability to look at archived street views was crucial in identifying the species providing multi-season images over time including flowering, fall color, and time of seasonal leaf out and leaf drop for deciduous species.

We applied this workflow with some slight variations on all 10,135 parcels and 125 of the 1,157 street segments in the study site and used the same imagery sources with additional help from a series of websites that described various tree species

Table 7: The workflow used to locate and characterize trees in the study site

Trees located on public right-of-ways (i.e. street trees):

1. Identify address of parcel, and then copy and paste this address to the point features used to record specific street trees
2. Examine the tree in Google Maps Street View, zooming in to look at the bark and the leaves, and using the time slider to determine if the tree is deciduous or evergreen
3. Use the available sources to identify the tree species (if possible)—the sources included TreePeople’s “Common Trees of Los Angeles”, the Instagram site “@treesofla”, CalPoly’s “Selectree” resource, and I-Tree.
4. Refer unidentifiable trees to team landscape architect (Margulies) for identification.
5. Determine tree species, botanical name, and deciduous or evergreen
6. Rank confidence high, medium, low
7. Identify trunk diameter < 6” and > 6”

Trees located in other spaces (parks, schools and commercial, residential and related settings):

8. After identifying the street trees, use Google Maps 3D View to identify all of the trees located on individual parcels
9. Confirm the address of the parcel and paste this address to the point features used to record specific trees
10. Use Google Maps Street View to identify the tree species (if possible)

that are common in southern California (see Table 7 for additional details). Figure 10 shows examples of trees that were relatively easy to recognize and characterize, and Figure 11 shows trees that were relatively difficult to identify and characterize using the aforementioned imagery sources. The landscape architect on the team reviewed a representative sample of the research team's Google Street View images to opine on most likely species.

We used an editable feature service shared to an Esri ArcGIS Online group to collaboratively digitize tree locations and capture attribute data using domains and free text. We added this information back to ArcGIS Pro to create maps and conduct the analysis used to prepare the scenarios and this report. We recorded the following attributes for each location: (1) presence of tree or stump; (2) sidewalk presence; (3) address; (4) street name; (5) parcel side; (6) tree common name; (7) tree botanical name; (8) tree identification confidence level; (9) trunk diameter at breast height (DBH); (10) description notes; and (11) whether the tree was located on private or public property. We used the online and expert resources noted in Table 7 to guide tree species identification and input data for the common and botanical name fields. However, the trees on private property were typically not as visible with Google Maps Street View and 3D View as street trees and we sometimes lacked both the data and expertise required to be able to document the species for every tree located on private lots.

Figure 10: Examples of tree species for which specimens were relatively easy to identify and label using Google Maps 3D View, Google Maps, and NAIP imagery

Figure 11: Examples of tree for which specimens were relatively difficult to identify and label using Google Maps 3D View, Google Maps, and NAIP imagery

5.2. Generating the greening scenarios

Recent efforts like the LA County Tree Canopy Project (Los Angeles County Tree Canopy Basic Viewer; TreePeople, 2018) have identified land cover characteristics and existing and potential tree cover using LiDAR data from the Los Angeles Regional Imagery Acquisition Consortium (LARIAC). The approaches and scales used for these studies generalizes spatial data and does not synthesize the granular level of information needed by public agencies or private landowners. This granular information is required to focus on: (1) locations that reflect populations with the least resources to adapt to extreme heat; (2) locations with available open space on public and private lands; and (3) recommendations for heat and drought tolerant species with high shading potential to achieve heat reduction.

This research project has sought to investigate potential heat island and surface temperature reduction at the level of a neighborhood, individual blocks, and individual sites to provide direct benefits to residents with the fewest resources to adapt to increasing extreme heat where they spend considerable time, in their homes, walking routes and schools. To do this, we identified six typical settings in the study site to explore scenarios for strategic cooling by increasing the shade cover of large trees with dense shading capability.

We conducted site analysis and potential cooling scenario development on the following typical settings in the study site that occur throughout the City of Los Angeles and adjacent cities:

1. Residential streets with narrow parkways ≤ 3 feet;
2. Residential streets with wide parkways ≥ 6 feet;
3. Neighborhood parks;
4. School campuses with little or no green cover
5. School campuses with moderate green cover; and
6. Public housing communities.

All of the test sites in this study support dense, lower income, and transit dependent populations with high percentages of young (< 15 years) and older (≥ 65 years) people. The sites are located in or adjacent to areas zoned for multi-family housing. All of the neighborhoods in this study area have long-term Hispanic and Asian American populations.

We used the spatial analysis tools in ArcGIS Pro (Esri, Redlands, CA) with spatial information acquired from public datasets to select representative narrow and wide parkway residential blocks where people were likely to have limited household cooling and be more likely to walk to neighborhood destinations or to transit. We selected a moderate sized park within walking distance of typical residential blocks to test the potential for denser urban forest cover to provide neighborhood scale cooling facilities. We selected two elementary schools to evaluate opportunities on campuses with large proportions of paved surfaces that act as heat sinks and higher and lower levels of site building coverage. We also selected the Ramona Gardens public housing community to evaluate potential for using trees to cool larger scaled housing structures without central cooling systems and with large outdoor permeable space capable of supporting large canopy trees.

For the residential parkways, each block was visited in person and existing trees and development observed. We created maps of residential blocks including the parcels on each side illustrating street paving, curbs, sidewalks, parkways, driveways, paved areas, permeable surfaces, overhead utilities and structures. We mapped the existing street trees and trees on private property. We also estimated and mapped the legally available parking spaces by overlaying standard sized parking stalls in available areas avoiding no parking zones, driveways and areas too small for standard sized stalls on streets with narrow and wide parkways.

We next identified potential street tree locations in parkways exclusive of driveways, utility poles and other appurtenances in the parkway. To evaluate additional potential locations, we delineated opportunities to plant additional street trees on streets with narrow parkways by extending the parkway area in the vehicular portion of the street, primarily at curb returns where parking is illegal and in areas where a standard or compact space could not fit. Finally, we studied private parcels to identify potential locations on the south side of the street and structures where canopy trees would have potential to shade the asphalt street surface or a residential structure.

For the park, we conducted site visits to observe existing vegetation, park use and adjacent conditions and for the two elementary school campuses and the Ramona Gardens public housing community, we generated similar representations of the baseline conditions using a series of public datasets.

The maps of the two street blocks, Hazard Park, the two elementary schools, and Ramona Gardens were created using ArcGIS Pro (Esri, Redlands, CA) and imported into Adobe Illustrator (Adobe Systems, San Jose, CA) so that symbols for existing and proposed buildings, paving, recreation elements, and green space could be added to a series of drawings. We estimated the percentages of existing permeable and shaded space on these drawings.

We next analyzed each case study site to identify potential locations for additional trees to increase shade. Potential locations avoided parking spaces, buildings and recreation facilities, including open flat lawn areas used for informal recreation. Potential locations focused on shading street paving, sidewalks, the south and west faces of buildings, park pathways, picnic areas, the perimeter of school outdoor areas, courtyards appropriate for outdoor classes or events, playgrounds, and sloping open lawn areas.

We identified locations for large shade trees in appropriate locations and added these to site scale drawings. We also added locations for smaller trees in blocks with narrow parkways or under existing utility lines to these drawings.

We also generated three-dimensional models of the typical narrow parkway street depicting houses on both sides of the street and improvements between them, including trees, fences and vehicles. We developed this model to create a familiar image of a similar street with common characteristics in the study area. We also created a simple perspective visual to describe the existing conditions. Based on the locations identified through the site analysis, mature trees were added to the existing conditions to depict the potential additional shade and greenery in the street and park scenarios. We added people of varying ages in a variety of leisure activities that would be likely to occur when the temperatures in the shaded areas are likely to be significantly cooler than open paved areas, open lawn areas and interior spaces without air conditioning to illustrate the potential use of shaded public space.

Many studies have shown that 3D visualizations improve the understanding of urban and landscape planning projects (Hassan et al., 2014). Realistic visualizations can also convey the ‘feeling’ of a place or the emotional intent. Community members often rely on personal experience when discussing impacts and the adaptations required to combat climate change. Imagery that is familiar and local makes it easier for people to imagine the impacts and outcomes in their personal lives and as a result, we should create images specifically for the target audience as we have endeavored to in this instance (Nicholson-Cole, 2005).

5.3. Community engagement and input

The project team held two community meetings with residents and local community organizations to solicit feedback on their needs and preferences around green space. The team also met on several occasions with representatives from Council Districts 1 and 14 and with North East Trees, a local urban forestry non-profit, to receive input and share data to help them advocate for healthy neighborhoods.

In total, the project team met with 28 community members from Lincoln Heights, El Sereno, and Ramona Gardens. The following summarizes the ideas and input received during these virtual Zoom meetings.

The first community meeting occurred on December 15, 2020. The purpose of this meeting was to provide an opportunity for local leaders and organizations to learn about the Urban Trees Initiative and for the project team to understand community priorities and concerns around urban tree canopy growth.

During the open discussion, participants expressed sincere interest in seeing more greenspaces in their neighborhoods, particularly in Lincoln Heights, and referenced exemplary projects such as the revitalization of Lincoln Park. Following the meeting, the project team evaluated these comments to identify which elements the community wishes to see improved and folded these insights into the recommended scenarios.

The project team also gained invaluable insights into the concerns of several local residents and business owners. Among the most common concerns expressed were the following:

- Maintenance – For how long can the city take on maintenance of trees? When will the maintenance of trees be left to local businesses or residents?
- Renters – How can property owners be convinced to plant more trees on private property?
- Sidewalks – How can we control the damage to sidewalks caused by tree roots?
- Accessibility – How can we ensure our sidewalks remain accessible for elderly and disabled residents?
- Shade – How many years will we have to wait for the trees planted to provide shade or can we plant more mature trees?
- Safety – How will larger trees affect street lighting and thus a sense of safety at night?
- Homelessness – How can we prevent homeless encampments from developing under more shaded areas?

The aforementioned concerns were brought to the attention of our City of Los Angeles partner and subsequently informed the project team's careful selection of tree species and the proposed placement of trees. The list also speaks to the complexity of the problem because some of the maintenance concerns reflect the use of Ficus trees in these neighborhoods and the multiple city agencies that are responsible for issues highlighted in one or more of the aforementioned questions.

The second community meeting took place on March 24, 2021. This meeting was open to the public, offered live translation in Spanish, and was advertised through local channels, inlcuding The Eastsider. The goal of this meeting was to present a vision for what additional tree planting could look like in Lincoln Heights, El Sereno, and Ramona Gardens and to gather feedback on the recommended scenarios.

The participants in this second meeting expressed overwhelming support for the types of greening the project team proposed. A couple of attendees emphasized how their communities lacked access to green space and why they deserve more. Others mentioned how hot it gets in their neighborhood, and that they turn to green spaces for shade and relief. Below are a few examples of comments made:

- "En mi case trato de ir a un lugar fresco busco uno la combran de los arboles por eso la importancia de tener arboles."
- "I grew up on a hill with no trees in my front yard so in our summers we would eat in the back yard under a big tree."
- "In Boyle Heights, we had no trees, so we would take our shoes off and sit on the grass."
- "Most of the houses in these areas are also not insulated which adds to the heat inside homes. Large trees go a long way."
- "No AC at our family home in El Sereno, so we usually try to stay in a shady part of the house."

The project team also made sure to encourage community members to voice their honest opinions and concerns. The concerns mentioned were very similar to those outlined during the first community meeting and were addressed in real time by our City of Los Angeles partner on the call.

Based on the participant's feedback, the project team will consider a couple of new spaces when building out future greening scenarios. Prioritizing bus stops and senior housing, for example, are new areas that should be studied to make sure we meet the needs of the most vulnerable residents. Moreover, the project team was encouraged to consider workforce development and local hiring opportunities. These are important points of feedback that will be taken into account in future phases of this project.

6. Results

The results below paint a picture of the baseline (i.e., the green infrastructure at present) and what this could become in the future and what benefits would accrue to the residents of this study site. The discussion spans four sections. The first describes the green infrastructure, as it exists today. The second describes our initial monitoring work to connect trees and air quality. The third presents a series of greening scenarios to show what is possible, both here and in other parts of the City of Los Angeles, in terms of new green infrastructure. The fourth and final section offers some preliminary thoughts on the kinds of benefits additional greening would bring to the City of Los Angeles and its residents.

6.1. Baseline conditions

The study site contains an estimated 37,813 trees today with 7,543 street trees, an additional 2,806 trees in parks and school campuses, and another 27,464 trees scattered across commercial, industrial, institutional, residential and other land uses. The two figures below provide two views of the distribution of this green cover across the study site. The first map shows the green cover estimated with the satellite-based Normalized Difference Vegetation Index (NDVI) in which the values range from -0.826 (no green cover) to 0.721 (extensive green cover) (Figure 12). This index provides a simple measure of the green vegetation on the land surface. The green vegetation includes trees as well as other forms of vegetation (shrubs, grasses, etc.) and therefore this representation was not a perfect measure for the work at hand. However, it is still useful because it provides a general indication of the parts of the study site with more or less green infrastructure. The second map shows the locations of the 37,813 trees we mapped, which includes city trees where available in 87% of the study site. Figure 13 uses dots with

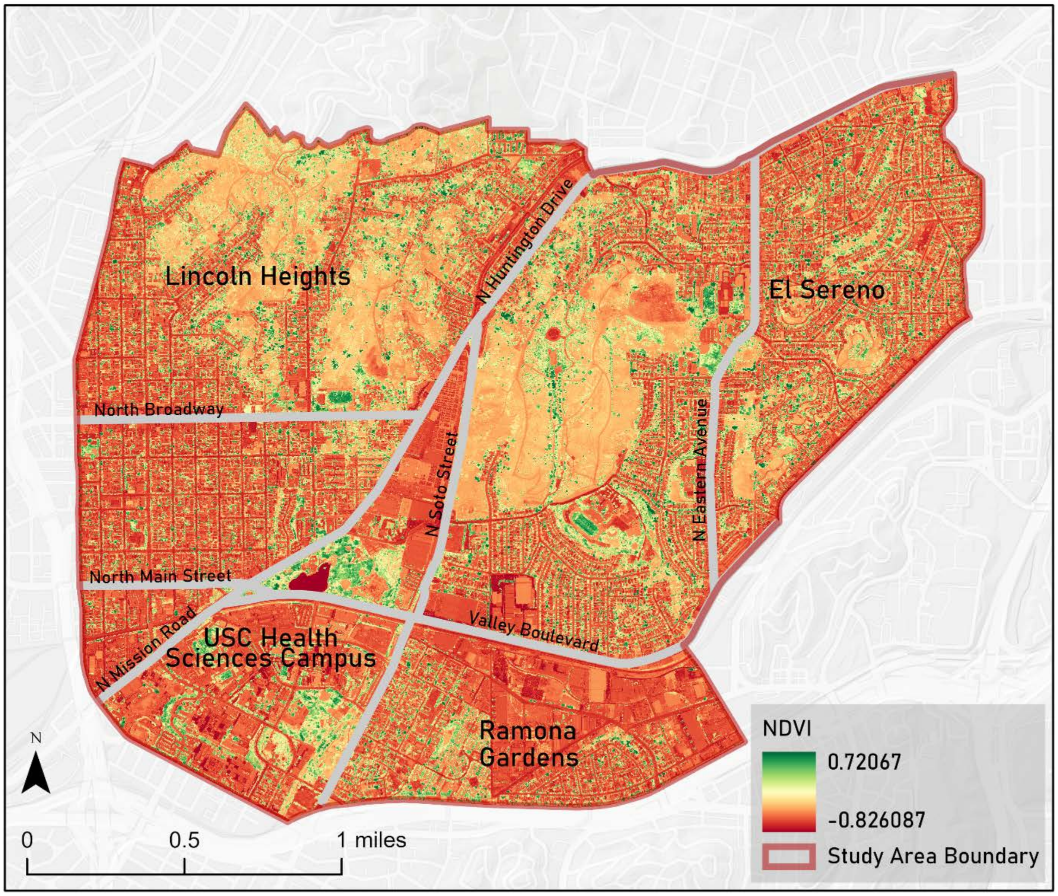


Figure 12: Map showing the existing green infrastructure for the study site based on the Normalized Difference Vegetation Index

different colors to differentiate the street trees, trees in parks and school campuses, and those in other settings. This information was far more valuable than the satellite-based NDVI for building out the greening scenarios depicted in Section 6.4 but the number of trees and scale of the map in Figure 13 make it difficult to decipher which parts of the study site has more or less green cover at present.

6.1.1. Street trees

The map reproduced in Figure 14 and the metrics reported in Table 8 show how the numbers and density of street trees vary across the study site at present. We constructed the map reproduced in Figure 14 by first identifying the street segments with no street trees (n=362) and then dividing the remainder into four categories with equal numbers of street segments (n=199) so that we could capture the number of street trees per 100 feet that marked the boundaries of each of these categories. The legend and colors used for the map itself tell this story. The streets with no street trees whatsoever occur in industrial and commercial areas and in some of the residential areas that traverse the hills in the study site. The four categories with varying colors delineate street segments with ≤ 0.92 street trees per 100 feet (purple), ≤ 1.75 street trees per 100 feet (blue), ≤ 2.82 street trees per hundred feet (orange blue), and ≤ 12.93 street trees per 100 feet (green) (Figure 14). The patterns show few if any street trees in Ramona Gardens, relatively low numbers of street trees in the western parts of El Sereno and the highest numbers in Lincoln Heights, the USC Health Sciences Campus, and in a small section of El Sereno near the eastern boundary of the study site.

The metrics reported in Table 8 summarize the number of street trees per 100 linear feet for street segments with different right-of-way widths. The numbers of trees increased from 1.43 to 1.51 and then 1.55 trees per 100 feet when we increased the right-of-way width from ≤ 24 feet to 24 to ≤ 26 feet, and 26 to ≤ 30 feet, respectively. The average across all of the street segments was 1.51 trees per 100 feet and the density on streets with the widest right-of-ways was just 8.4% higher than on the streets with the narrowest right-of-

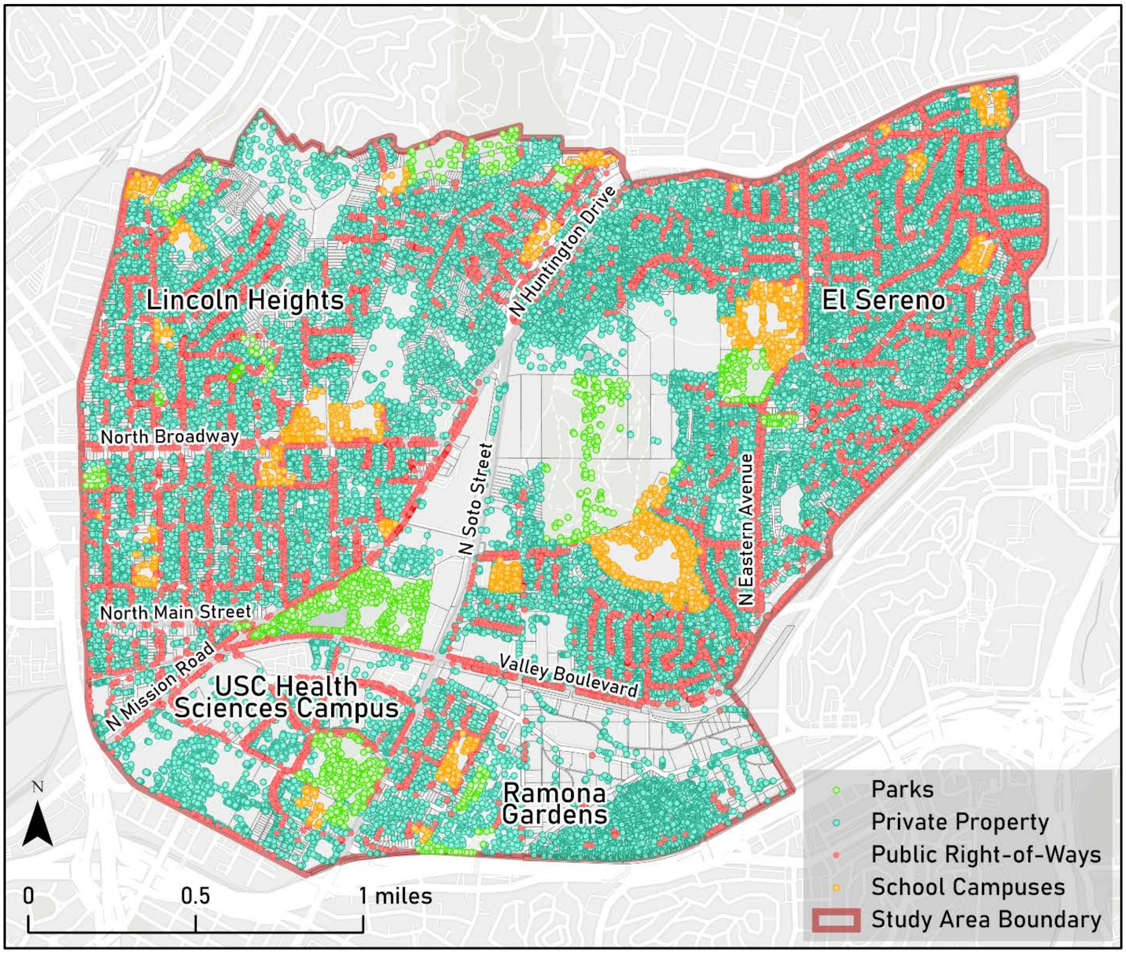


Figure 13: Map showing the existing green infrastructure for the study site based on the locations of existing trees in parks and on private property, public right-of-ways and school campuses

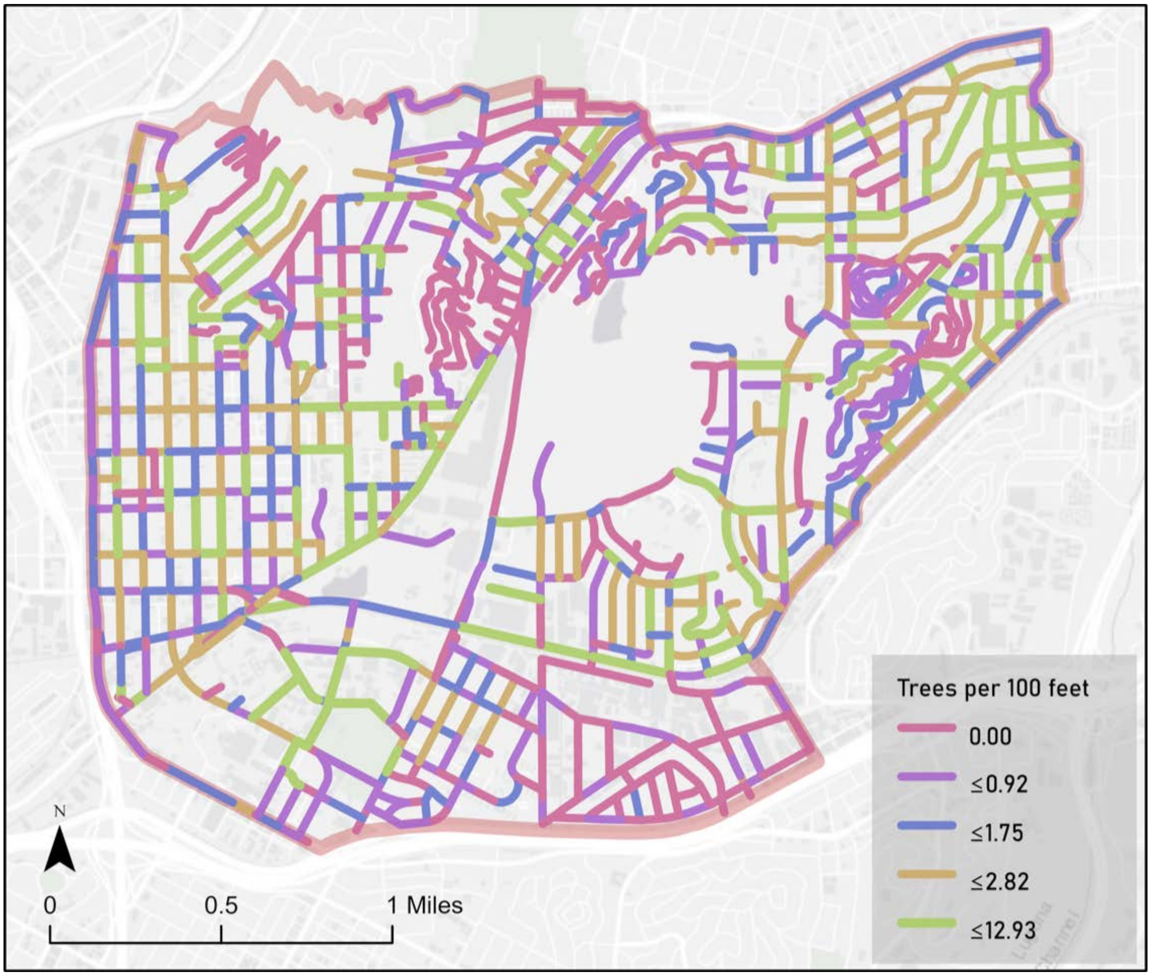


Figure 14: Map showing the number of street trees per 100 linear feet for all 1,157 street segments that comprise the street network in the study site

Table 8: Number of trees per 100 linear feet for different right-of-way widths and the leading tree species for each right-of-way width class

Right-of-way width classes	No. of street segments	No. of trees	No. of trees per 100 feet	Leading species
Wide (≤ 30 feet)	208	1,543	1.55	*Ficus microcarpa* (Indian laurel fig)
				Washingtonia robusta (Mexican fan palm)
				Cupaniopsis anacardioides (Carrotwood)
Medium (≤ 26 feet)	163	1,192	1.51	*Magnolia grandiflora* (Southern magnolia)
				Washingtonia robusta (Mexican fan palm)
				Lagerstroemia indica (Crape myrtle)
Narrow (≤ 24 feet)	786	4,808	1.43	*Washingtonia robusta* (Mexican fan palm)
				Ulmus parvifolia (Chinese elm)
				Lagerstroemia indica (Crape myrtle)
Study Site	1,157	7,543	1.51	

ways. The ranked list of common tree species was unique in each category and just one tree species, *Washingtonia robusta* (Mexican fan palm) appeared among the top three species for the narrow, medium and wide right-of-ways.

6.1.2 Trees in parks

There are 14 parks in the study site (Figure 5) with 1,220 trees. Seven out of every 10 trees in parks are found in the three largest parks—Lincoln (38.0%), Hazard (15.8%), and Ascot Hills (15.2%). Lincoln Park is also one of five parks with more than 10 trees per acre whereas Ascot Hills Park, which is twice the size of Lincoln Park, has just 2.11 trees per acre. This particular property is a Los Angeles Department of Power and Water owned site operated and maintained by the City of Los Angeles Department of Recreation and Parks with a long and storied history.

The 14 parks as a whole cover 216 acres (6.84% of the study) and currently support 5.65 trees per acre on average (Table 9). It is worth noting that nearly all of the trees in the study site were planted as part of managed landscape practices. There are few truly local tree species and the dry climate, soil, and management practices in fire prone wild areas contribute to the limited number of canopy shade trees.

6.1.3 Trees on school campuses

There are 15 Los Angeles Unified School District (LAUSD) and 11 private school campuses in the study site (Figure 6) and these currently host 1,586 trees. Two out of every three trees on school campuses are found on the four school campuses—Wilson High School (HS) (29.3%), El Sereno Middle School (MS) (17.3%), Lincoln HS (11.4%), and Multnomah Elementary School (ES) (6.6%). Fourteen of the 26 school campuses supports > 10 trees per acre—All Saints Catholic School, Anahuacalmecac HS, Cesar Chavez ES, East College Prep, El Sereno MS, Farmdale ES, Gates Early Education Center, Gates ES, Hillside ES, Multnomah ES, Our Lady of Guadalupe School, Sierra Park ES, Wilson HS, and Xinaxcalmecac Academia. Two Plaza de la Raza campuses have no trees whatsoever and one school campus—Sacred Heart HS—hosts less than one tree per acre (i.e., less than one tree for every two acres). The 26 school campuses as a whole cover 145 acres

Table 9: Number and density of trees by park

Parks	Area (acres)	No. of trees	Tree density (No. of trees / acre)
Ascot Hills Park	88.22	186	2.11
East Los Angeles Park	0.32	28	86.69
Ela Park	3.70	6	1.62
El Sereno Recreation Center	13.93	123	8.83
El Sereno Senior Center	1.80	22	12.19
Hazard Park	24.18	193	7.98
Henry Alvarez Memorial Park	2.57	34	13.24
Lincoln Heights Recreation Center	1.59	22	13.84
Lincoln Heights Youth Center	0.74	7	9.48
Lincoln Park	43.25	463	10.70
Mount Olympus Park	8.91	21	2.36
Ramona Gardens Park	3.87	30	7.76
Rose Hill Park	20.51	69	3.36
Rose Hill Recreation Center	2.26	16	7.07
Totals	**215.87**	**1,220**	**5.65**

Table 10: Number and density of trees by LAUSD (LA) and private school (PR) campuses

Schools	Type	Area (acres)	No. of trees	Tree density (No. of trees / acre)
All Saints Catholic School	PR	1.89	39	20.63
Anahuacalmecac High School	PR	0.19	3	15.79
Bravo Medical Magnet	LA	3.81	21	5.51
Cesar Chavez Elementary School	LA	5.14	86	16.73
East College Prep	PR	0.76	15	19.74
El Sereno Middle School	LA	23.85	270	11.32
Farmdale Elementary School	LA	3.90	53	13.59
Gates Early Education Center	LA	0.73	8	10.96
Gates Elementary School	LA	4.11	43	10.46
Glen Alta Elementary School	LA	3.28	17	5.18
Griffin Elementary School	LA	3.67	25	6.81
Hillside Elementary School	LA	3.03	45	14.85
Huntington Dr Elementary School	LA	4.17	38	9.11
Lincoln High School	LA	19.14	181	9.46
Los Angeles Leadership Academy	PR	4.29	29	6.76
Los Angeles Leadership Academy K-8	PR	1.88	17	9.04
Multnomah Elementary School	LA	4.93	104	21.10
Murchison Elementary School	LA	5.57	21	3.77
Our Lady of Guadalupe	PR	3.30	44	13.33
Plaza de la Raza	PR	0.16	0	0.00
Plaza de la Raza	PR	0.15	0	0.00
Sacred Heart High School	PR	1.03	1	0.97
Santa Teresita Elementary School	PR	1.01	9	8.91
Sierra Park Elementary School	LA	3.85	47	12.21
Wilson High School	LA	40.61	465	11.45
Xinaxcalmecac Academia	PR	0.30	5	16.67
Totals		**144.75**	**1,586**	**10.96**

(4.6% of the study area) and currently host 10.96 trees per acre on average (Table 10). The school campuses on average offer nearly twice as many trees compared to parks based on the numbers of trees per acre (i.e., 5.65 and 10.96 trees per acre for parks and school campuses, respectively). However, more analysis would help in this instance because this metric does not account for the species size used and a park site can usually take larger species that take up more space and provide more shade with fewer trees.

6.1.4. Trees on commercial, industrial, institutional, and residential lots

The final table in this series (Table 11) summarizes the numbers and density of trees on commercial and industrial, residential, and selected institutional land uses. The residential lots dominate in terms of geographic extent (1,472 acres, 47% of the study site) and numbers of trees (23,453, 62% of all trees counted in the study site) and density of trees (15.93 trees per acre). The metrics also show a gradient with the number and density of trees climbing sharply from the public housing (7.88 trees per acre) to the trees on multi-family units and single family homes (13.90 and 17.1 trees per acre, respectively).

The remainder of the rows in Table 11 show that the LAC+USC Medical Center has a relatively dense tree count (11.44 trees per acre) and the USC Health Sciences Campus and commercial and industrial land uses have less than half this number (5.59 and 3.73 trees per acre, respectively).

The remainder of the rows in Table 11 show that the LAC+USC Medical Center has a relatively dense tree canopy (11.40 trees per acre) and that the USC Health Sciences Campus and commercial and industrial land uses scattered across the study site have less than half this number (5.59 and 3.67 trees per acre, respectively).

6.2. Air quality and trees

The project study site suffers from high concentrations of $PM_{2.5}$ most likely exacerbated by the adjacent freeways on the south and east perimeters of the district (Reichmuth, 2019). These pollutants are associated with respiratory and cardiovascular disease, neurological disorders and cancers (Blanusa et al., 2015). A great deal of research has been conducted on the human health impacts of particulate air pollution leading to conclusions that particles with a diameter of less than 2.5 μm are potentially more harmful than larger particles (e.g., Gauderman et al., 2000, 2007; Künzli et al., 2003). They are generated almost exclusively by anthropogenic sources, mainly from industry, roadway traffic and diesel vehicles, and vary considerably over space and time (e.g. Habre et al., 2020; Lu et al. 2021).

Tree foliage may intercept these particles, leaf stomata capture gaseous pollutants, or leaf surfaces retain particulate matter and re-deposit it in rainstorms and wind. The presence of hairs and sticky substances can intercept and accumulate particulate matter (Beckett et al., 2012) These authors performed studies in the UK to measure the particulate capture by various tree species in urban areas using Leaf Area Index (LAI). They determined that aggregating groups of trees into one canopy unit would be most valuable in measuring total particulate load and potential benefits. Mature trees with larger canopies and leaves with dense hairs captured greater amounts of particulates. Wind

Table 11: Numbers and density of trees on commercial, industrial, institutional, and residential lots

Land use types	Area (acres)	No. of trees	Tree density (No. of trees / acre)
Commercial and industrial	366	1,365	3.73
Residential			
Single family homes	1,004	17,146	17.08
Multi-family units	435	6,047	13.90
Public housing	33	260	7.88
LAC+USC Medical Center	41	469	11.44
USC Health Sciences Campus	86	472	5.49
Totals	**1,965**	**25,759**	**13.11**

turbulence affected how much of the substance stayed on the leaves. Trees with sticky, rough leaves (veins, trichomes, etc.) retained more particulate matter (Beckett et al., 2012). Pines and coniferous species captured more particles than broadleaf species. Beckett et al. (2000) found that Leyland Cypress trees were the second most effective species. These authors concluded that shelterbelt and woodland plantings can facilitate air quality improvement.

In a study conducted in the heavily polluted city of Gratz, Austria, computer simulation was used to estimate the PM absorption by various tree species. The Stone Pine (*Pinus pinea*) was found to be the most effective because it has evergreen leaves that are not easily moved by winds. The results showed particulate matter concentrations exceeding the established EU limits could be reduced by half if sufficient trees were present to absorb the particulate matter. The study also found that 1 km^2 of tree canopy could achieve the reduction, and further predicted that the canopy could be distributed throughout the areas with heavy particulate matter pollution (Letter and Jäger, 2020).

Few specific species have been tested for particulate matter capture or accumulation in Mediterranean climates. One of the rare studies measured the relative effectiveness of five species, *Quercus Ilex, Quercus cerris, Platanus hispanica, Tilia cordata* and *Olea europea* in Siena, Italy (Blanusa et al., 2015). *Quercus ilex,* commonly known as Holly oak is a long lived, evergreen tree species with dense shading potential and low anticipated root damage that grows well in southern California (Urban Forest Ecosystems Institute, 2021). Although the authors found that *Quercus Ilex* was less effective at capturing aerosol and particles in the study, they concluded that the evergreen foliage made it a better choice for year round pollution capture than the more efficient deciduous species in the study (Blanusa et al., 2015).

Finally, Nowak et al. (2013) developed models to estimate the potential amount of pollutant removal by trees in various U.S. cities based on random sampling and i-Tree eco models. The amount of $PM_{2.5}$ removed by urban trees was found to have positive health impacts including reduced human mortality. However, Los Angeles had high concentrations of $PM_{2.5}$ and low removal rates. Nowak et al. (2013) concluded that more research is needed to study urban forest designs. The results for Los Angeles may have reflected the sparse urban canopy and lack of species-specific data used in their study.

The various studies described here show how the local variability in neighborhood air quality is not well quantified. The factors that will generate variability in air quality at local scales include proximity to sources, airflow patterns and the abundance and type of local vegetation. Given our focus on the urban forest, our goal was to provide preliminary data on how airflow in and among tree species may, in net, impact local air quality.

To make preliminary measurements of air quality surrounding specific trees, we developed two identical portable sensor units capable of running continuously for 2-3 days on

Figure 15: Sensor hanging from porch trellis (left) and components of portable sensor package (right)

battery power and logging temperature, pressure, humidity, and air quality parameters CO_2, CO, and $PM_{2.5}$. The two units were used to compare air quality between open air space and the air within tree canopies. The portable sensor system was packaged inside a plastic carrying case (12 x 9 x 3 inches) as shown in Figure 15, and the major components and some of their specifications are summarized in Table 12**.**

The two $PM_{2.5}$ sensors were calibrated in two ways, based first on an assessment of their accuracy, and second on the consistency between the sensors in Package A compared to Package B. The accuracy was evaluated as compared to the South Coast Air Quality Management District (SCAQMD) $PM_{2.5}$ data published for a site located on Main Street near the Southern Pacific Railroad (Wilhardt Street). The sensors were located on the street adjacent to the buildings hosting the AQMD sensors and there is agreement between readings for the same time-period to better than ±2 $\mu g/m^3$.

While the accuracy of our sensor package compared to AQMD was quite reasonable considering they were not exactly co-located, the precision and agreement between the two sensors is key to the interpretations presented in this study. To this end, the two sensor packages A and B were co-located before and after all experiments. Figure 16 summarizes the results for one of these co-location calibrations. In total, we obtain agreement between the two sensors to a value < 0.6 $\mu g/m^3$ and this value is taken as the limit of the replicate precision of these two sensors for the work at hand. Comparisons that show average values that differ by > 0.6 $\mu g/m^3$ are considered

Table 12: Major components and specifications of the portable sensor units used for this study

Components	Specifications	Descriptions
Computer	Raspberry Pi Model 3b+	Small Linux computer which collects sensor data and stores it to an SD card
Battery	RavPower 26800 mAhr Power Bank	Rechargeable 5V Li ion battery pack
CO2 sensor	CO2meter.com K-30 10,000ppm	Non-dispersive infrared (NDIR) CO2 sensor. Measurement range: 0 to 10,000 ppm (0-5,000 ppm within specifications). Repeatability: < 20 ppm or 1% of measured value within specifications. Accuracy: <30 ppm or 3% of measured value within specifications. Rate of measurement: Every 2 s. Response time: 20 s
CO sensor	Alphasense CO-AF 11211706	Electrochemical CO sensor. Range: 0-5,000 ppm carbon monoxide. Sensitivity: 55 to 90 nA/ppm in 400 ppm CO. Response time: < 25 sec. 90 (s) from zero to 400 ppm. Resolution: < 0.5 RMS noise (ppm equivalent). Linearity: +15 to +25 ppm error rate at full scale from 0-1,000 ppm
Temperature / Pressure / Relative Humidity sensor		Temperature accuracy at 200C ± 0.30C. Temperature relative humidity accuracy 20% to 80% ± 2% RH
Particulate matter sensor	Plantower A0031	Laser scatter particle matter sensor. Particle range of measurement, 0.3-1 µm, 1-2.5 µm, 2.5-10 µm. Particle counting efficiency, 50% at 0.3 µm, 98% at > 0.5 µm. Response time 10 s.

different, although the greater the difference, the greater the confidence that the two air parcels have different $PM_{2.5}$ values.

We conducted three experiments as part of this study. The first compared two sites over two days during the New Year (2020-2021). We placed one sensor on the second floor, externally located, of a USC Health Sciences Campus parking structure located on Alcazar Street between Playground and San Pablo Streets. The second sensor was located in the greenspace in Ramona Gardens, adjacent to the US 10 freeway (San Bernardino Freeway).

We conducted the final pair of experiments to develop baseline data on how air quality, particularly $PM_{2.5}$, varied between 'open space' and air within a tree canopy. The second experiment was conducted at Ramona Gardens in the parkway adjacent to the US 10 Freeway. A shade trellis over some picnic tables served as the open air control site. There was no vegetative growth on this trellis. One sensor remained at the control site while the second sensor was moved from tree to tree, spending 24 hours at each location. Four trees were tested, *Cupressus × leylandii* (Leyland cypress), *Tipuana tipu* (Tipu tree), *Quercus ilex* (Holly oak) and *Parkinsonia florida* (Blue palo verde) (Figure 17).

The third experiment was similarly designed, in this case testing tree canopies on USC's University Park Campus (UPC) near the Expo Park/USC train station. Four trees were tested, *Pinus canariensis* (Canary Island pine), *Cedrus deodara* (Deodar cedar), an unidentified tree, and *Bauhinia blakeana* (Hong Kong orchid tree) (Figure 18). Similar to the experiment conducted at Ramona Gardens, the $PM_{2.5}$ concentration within a tree canopy was compared to the values measured with a sensor located within 30 m of the tree but not within a tree canopy (Figure 19). The UPC site was chosen

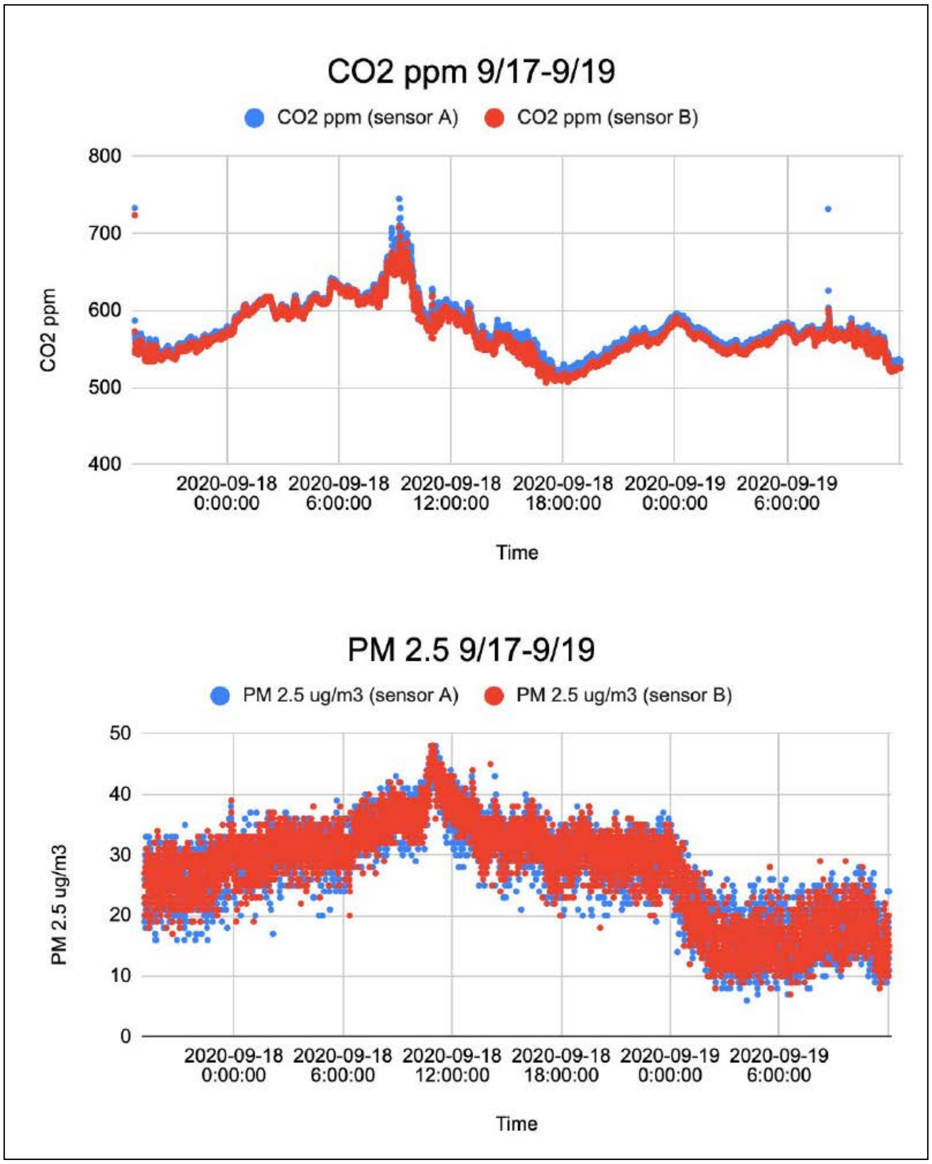


Figure 16: Co-location of sensors A and B showing 42 hours of simultaneous measurements of pCO_2 and $PM_{2.5}$. The difference between the mean $PM_{2.5}$ value between these two sensors (and other co-located sensors) is <0.6 µg/m^3. The minute-to-minute changes in PM are typically ±10 µg/m^3 and the range of PM variability over 42 hours, at this location, was almost 50 µg/m^3

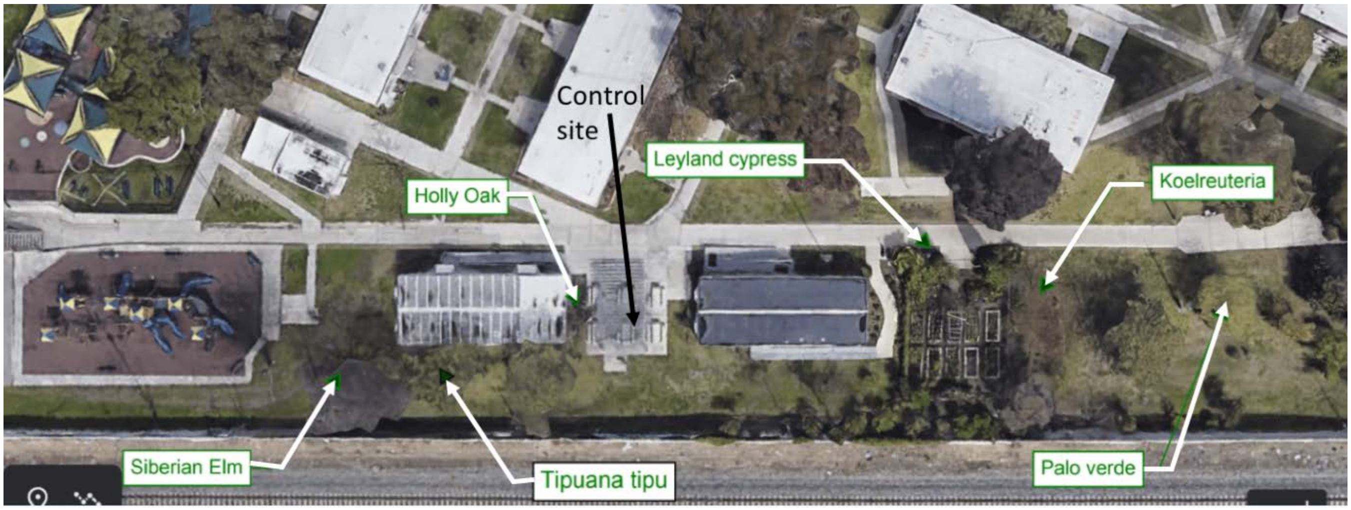


Figure 17: Map of study area in Ramona Gardens with various trees identified. The US 10 Freeway is near the bottom of this photograph, adjacent to the railroad tracks

Figure 18: Control site (star) and tree canopies tested on the USC University Park Campus. Trees identified were Pinus canariensis (A), Cedrus deodara (B), an unidentified tree (C), and Bauhinia blakeana (D)

Figure 19: Location of the control sensor (left) and the sensor in tree A (right)

in light of COVID-19 travel and work constraints and beacuase the variety of trees in the small area provided an excellent setting to conduct a replicate set of measurements.

When interpreting the results of the air quality experiments described above, it is important to note that $PM_{2.5}$ does not fluctuate in the same way that CO_2 fluctuates. $PM_{2.5}$ measurements are also not reflective, in general, of peak rush hour time-periods.

The results from the first experiment show local differences in pCO_2 and $PM_{2.5}$ even though the USC Health Sciences Campus parking structure and Ramona Gardens sites were located within 2 km of each other. On average, the Ramona Gardens site had 10 ppm higher pCO_2 concentrations and 4 µg/m^3 higher $PM_{2.5}$ concentrations (Figure 20). Both locations had a peak in $PM_{2.5}$ around midnight on New Year's Eve, which could be a reflection of fireworks and the resulting $PM_{2.5}$ generated by this activity.

These results show that local differences in air quality exist and the proximity to a large freeway, albeit during a low traffic period, may have a measurable and possibly significant influence on neighborhood-scale air quality. However, this single pair of measurements is not, itself, sufficient to define any long-term trends in air quality for these sites, this case study does serve the purpose of defining the range of variability in space and time within the study site as a whole.

The final two experiments explored the premise that air quality parameters measured a short distance apart (i.e., with 30 m), would be indistinguishable. By placing one sensor in open space and the other sensor within a tree canopy, the same distance off the ground (~4 m), we were able to test this premise. Further, by conducting these pairwise comparisons for a variety of trees, all within a 30 m radius of the control site, we were able to see if canopies of specific tree species had an influence on air qualities.

For the four trees in the parkway at Ramona Gardens adjacent to the US 10 Freeway (Figure 17), $PM_{2.5}$ values during the four days of tested ranged from 0 to 125 µg/m^3 with the lowest values recorded during the daytime. Two trees had average $PM_{2.5}$ values lower than the control sites by more

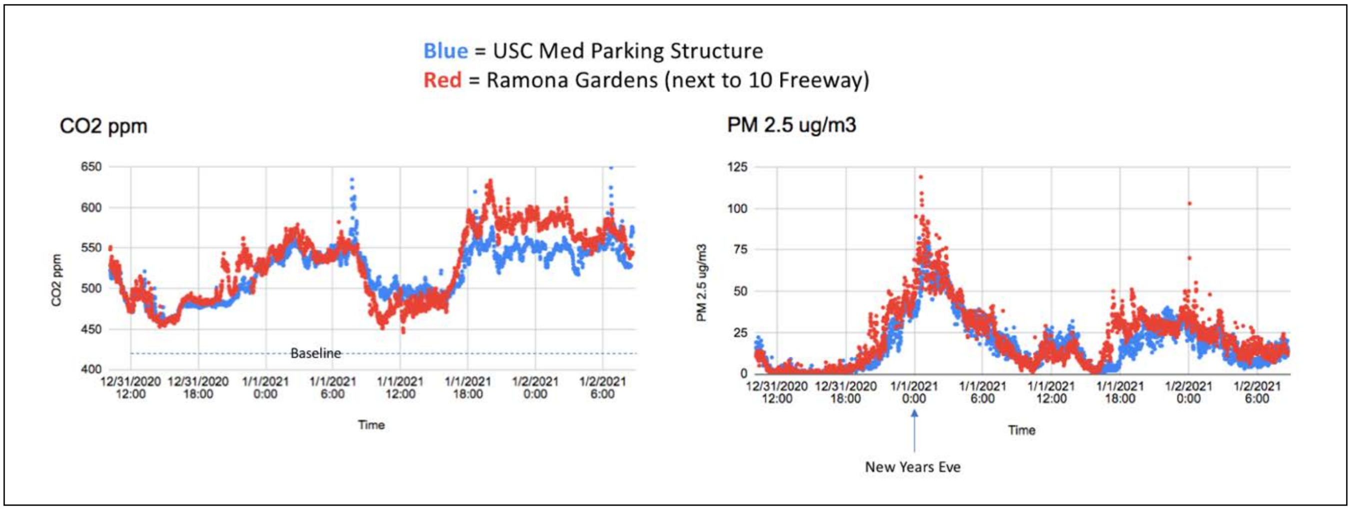


Figure 20: Comparison between two locations, CO_2 (left) and $PM_{2.5}$ (right) for a location on USC Heath Sciences Campus (blue) and in Ramona Gardens (red).

than the variability in average $PM_{2.5}$ readings when sensors were co-located, 0.6 µg/m^3. The two other trees had $PM_{2.5}$ values within 0.2 µg/m^3 of the control site. The trees with lower $PM_{2.5}$ values were the cypress and the blue palo verde trees. The difference between control PM – tree PM displayed the following trend:

> Leyland cypress (1.7) > Blue palo verde (1.0) >
> Tipu tree (<0.2) = Holly oak (<0.2)

Over the 24-hr experiment, the Leyland cypress tree canopy removed 1.7 µg/m^3 of $PM_{2.5}$ from the ambient air.

The third set of experiments on USC's University Park Campus adopted a similar design in that the $PM_{2.5}$ concentrations within the tree canopy was compared to the values measured in a sensor located within 30 m of the tree but not within a tree canopy (Figure 16). Comparing the tree canopy $PM_{2.5}$ to the control site (Control PM – Tree PM) resulted in the following differences:

> Canary Island pine (1.5) > Tree C (1.0) >
> Hong Kong orchid tree (<0.6) = Deodar cedar (<0.6)

Over the 24-hr experimental period, the Canary Island pine tree canopy removed 1.5 µg/m^3 of $PM_{2.5}$ from the ambient air (Figure 21).

The final pair of experiments quantified the efficacy of using specific tree species to mitigate air pollution. Different sets of trees, at different locations, at different times were tested using the same, calibrated instruments. By co-locating the two sensor packages for 24-hrs, we established that the $PM_{2.5}$ readings are identical within the standard deviation of the mean of ±0.6 µg/m^3. Thus, if the two sensors as deployed in this experiment had average values that deviated by < 0.6 µg/m^3, we would not claim that these two sets of readings were different. However, sensors placed in cypress and pine trees showed average $PM_{2.5}$ values 1.5-1.6 µg/m^3 lower than the control site. The palo verde tree and an unidentified tree on USC's University Park Campus also showed the capability to trap $PM_{2.5}$ as they had average values that were lower than the control average by 1.0 µg/m^3.

More work of this type is needed that includes some additional analysis around the impacts of air flow for each monitored tree and the inclusion of experiments that explore the cumulative impacts of multiple trees located in close proximity to one another. The work described here provides a good start to an area of air quality that is under studied, and the preliminary results do show how individual tree species affect local air quality. Two evergreen species (*Cupressus x leylandii* and *Pinus canariensis*) showed evidence for trapping or sequestering $PM_{2.5}$. Yet another evergreen species, *Cedrus deodara*, did not demonstrate any significant $PM_{2.5}$ mitigation. Thus, even within the evergreen group, the individual tree species does matter and the species chosen when implementing the greening scenarios described in the next section would have important implications for both cooling and air quality.

6.3. Greening scenarios

Six greening scenarios were prepared and a subset of these used to support the community engagement activities. The first two greening scenarios focused on street interventions.

The third focused on park interventions and the next two on elementary school campuses and some of the nearby streets. The sixth and final scenario looked at ways to use trees to shade the buildings in the Ramona Gardens public housing community. In addition, we would not recommend planting all of the potential trees shown in these scenarios at once because there is a need for age diversity as a component of an enduring and healthy urban forest.

The primary goal with all six of the scenarios is to provide relief for residents on warm days (i.e., days with temperatures > 95°F) that are expected to grow in number and duration in the next 30 years and with the secondary goal of mitigating air pollution whenever possible. We chose high priority areas using the four criteria—high percentages of young children and elderly; low median household incomes, high population densities; and large numbers of households with no vehicle—listed in the legend of Figure 22, and then chose street segments with wide and narrow parkways to illustrate the first two scenarios.

Figure 23 shows the current and potential conditions on a street with a 6 feet parkway. The top panel shows the existing trees and the shade cast by their canopies and the middle

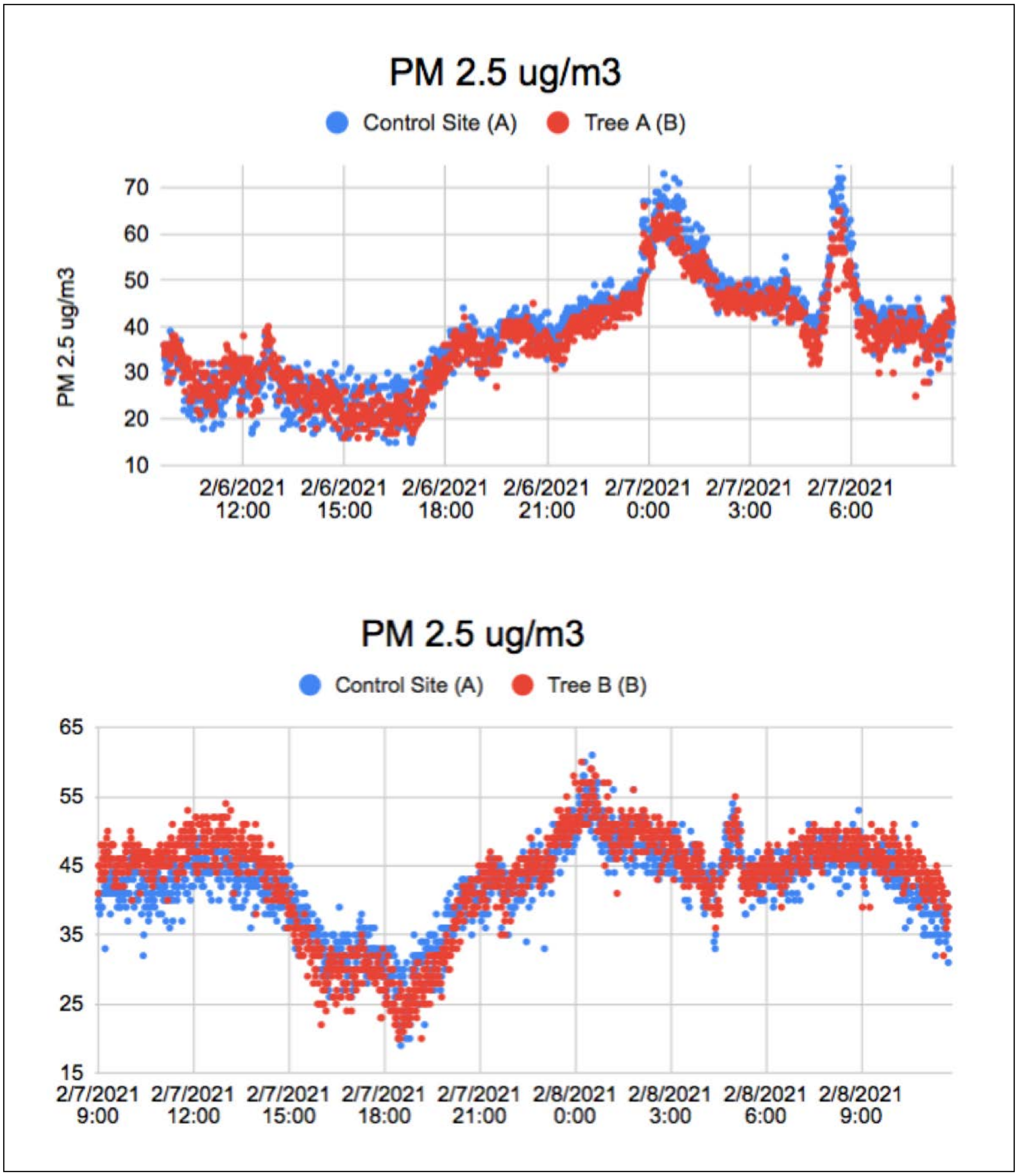


Figure 21: Top panel shows $PM_{2.5}$ sensor readings from control site (blue points) and Canary Island pine tree canopy (red points). Lower panel shows $PM_{2.5}$ in control (blue) and the Deodar cedar tree canopy (red)

panel shows what the shading effect would be with a much denser tree canopy that made full use of available planting space in the parkway. This setting shows that just 18% of the private land is permeable and that the proposed new trees would provide a 242% increase in shade cover at maturity.

Figure 24 shows the current and potential conditions using two different greening scenarios on a street with a 3 feet parkway. The top panel shows the current conditions, including the narrow parkways and the paucity of street trees. The middle panel shows the outcome when small trees are added to the narrow parkway using existing available parkway space. The bottom panel shows the outcomes that would follow the planting of large trees in areas where parking is prohibited or insufficient to fit a vehicle (i.e., those street areas near intersections with the curbs painted red or driveways). This scenario would provide additional shade from small trees planted in the existing narrow parkways and much larger trees planted in available portions of the current vehicular area in the street. Curb extensions would also create shorter street crossings for pedestrians increasing their safety. This scenario would increase the permeable areas in the streets by 2.5% (this is important for water supply) and add 2,036% more shade without any loss of parking spaces and would calm traffic as well. A third scenario (not shown here) that added trees to front yards would provide additional shade and help to cool both indoor and outdoor spaces on hot days.

Figure 25 shows a modeled perspective view of the current conditions and then a future condition with the maximum number of street trees for a street with narrow parkways. The bottom illustration envisions how residents of these streets could use the public space to escape the heat on hot days. The picture shows streets used temporarily for social gatherings with the addition of some portable chairs, tables and children's play features like wading pools on extreme heat days. Similar to the slow streets program, the current vehicular storage space can be reimagined as a vibrant community amenity and cooling resource.

The third scenario focused on the shading and cooling potential of an existing park. The Hazard Park and Recre-

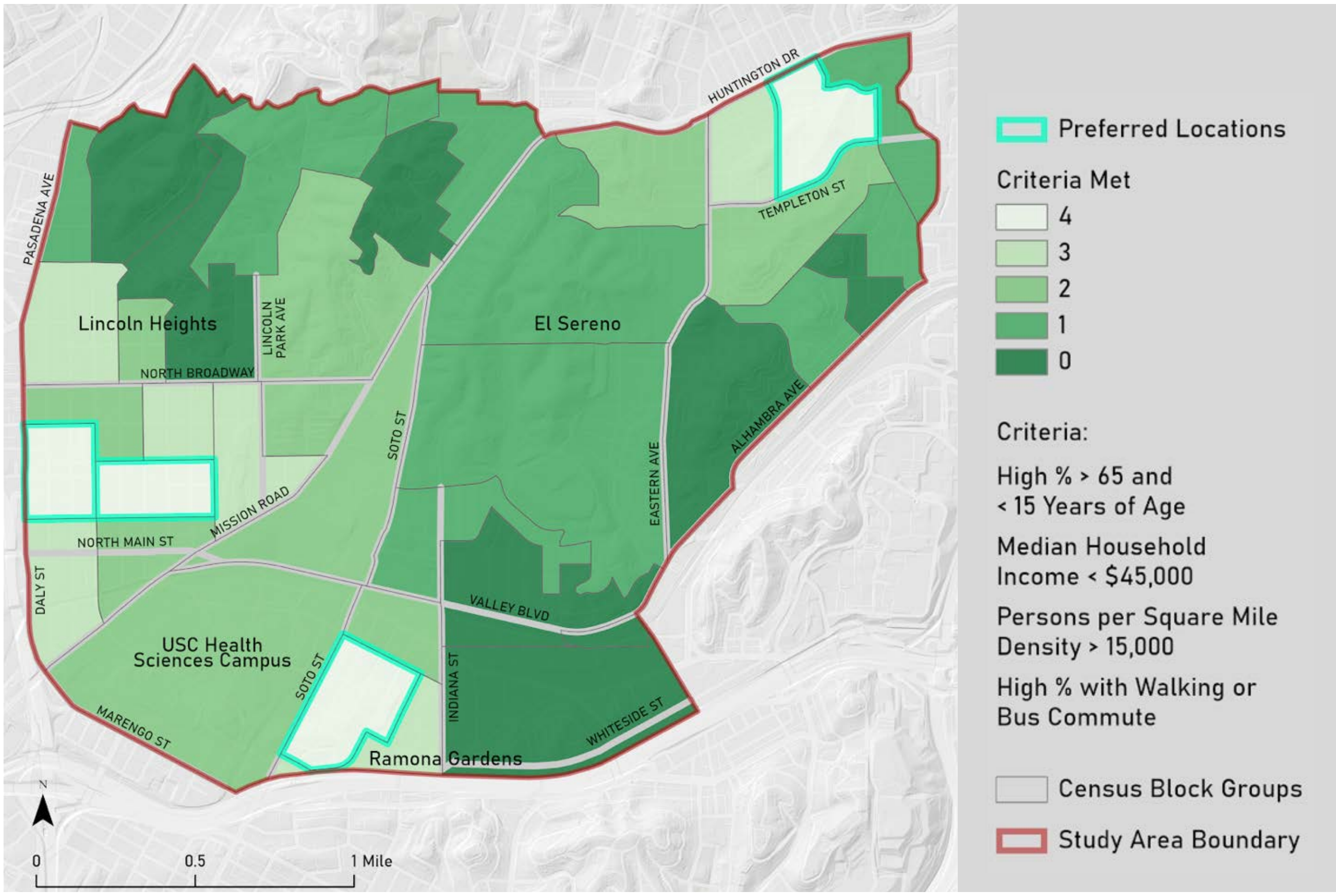


Figure 22: Map showing site suitability map for identifying the parts of the study site that satisfy one or more of the four criteria used to identify high priority greening areas

Figure 23: Potential tree planting vision for a street with a wide parkway showing the current (top panel) and potential tree cover (middle panel) and their shading potential with miscellaneous pictures and legend in lower panel

Figure 24: Potential tree planting vision for a street with a narrow parkway showing the current (top panel) and two possible greening scenarios (two lower panels) as described in the text

Figure 25: Perspective views of current and proposed street trees on a street with a narrow 3 feet parkway (similar to that shown in Figure 24)

ation Center spans 24 acres and includes a meeting room, restroom building, baseball fields, handball courts, a small skate park, a children's playground, fitness equipment, and picnic tables with benches and barbecue facilities (see Figure 26 for additional details). The map of the park and the accompanying photograph of a portion of the park reproduced in Figure 26 show that the current park includes some large trees and extensive areas that are unshaded and therefore likely unused on hot days with temperatures > 95°F. In developing additional shade scenarios, the drawing reproduced in Figure 27 adds an additional 124 trees and retains all of the recreation facilities and the tables, benches and barbecue facilities, and adds shade trees in open lawn areas to create extensive shaded areas. The numbers of trees per acre would increase from 8 to 13 and more or less match the city-wide park average of 12 trees per acre. We should note as well that the numbers of trees used for the Hazard Park, Murchison Elementary School, and Hillside Elementary School scenarios exceed those reported earlier in Tables 9 and 10 because they include trees on adjacent streets that help to shade each of these sites.

Figure 28 shows perspective views of the current and proposed conditions in the eastern part of the park that borders North Soto Street and currently includes tables, benches, and barbecue facilities. The new proposed shaded areas illustrated in Figures 27 and 28 would provide refuge from the heat on hot days and provide additional and attractive destinations for social gatherings of various kinds as well. Residents from the neighborhood east of the park will find the expansive shaded areas a convenient and affordable alternative to staying in their homes, many of which have very little unpaved open space. The 124 additional trees envisaged in this scenario would help to shade open spaces used for soccer as well other high use areas, such as the tables, benches and barbecue facilities, the fitness equipment and the skate park.

The next two scenarios focus on providing shade of outdoor areas at the Murchison and Hillside Elementary Schools (see Figure 5 for additional details about their locations). We reviewed existing trees on the campuses and adjacent streets and investigated opportunities to increase the urban canopy to provide more shade to reduce surface air temperatures and particulate air pollution.

Murchison Elementary School is located one block from the Ramona Gardens public housing community on a relatively large campus with a pre-school and elementary school. The campus includes large paved surfaces for parking, playgrounds and general recreation. Unshaded asphalt paving and treeless lawn areas occupy the majority of the site, elevating surface air temperatures on hot days, and acting as a heat sink into the evenings.

Most of the 57 existing trees on the campus are located along the site perimeter in selected courtyards with the exception of one row of trees that provides effective shading on the west side of the Murchison Early Education Center (Figure 29). The parking lot and 1.75 acre paved play area offer little effective shading from the hot afternoon sun. Our research demonstrated that even unshaded lawn areas contribute to high surface temperatures on extreme heat days. Our scenario envisages adding an additional 58 large canopy shade trees on the south and west sides of the playgrounds and in currently unshaded areas to reduce surface air temperatures and provide a neighborhood cooling resource where residents could gather to find relief from the dangerous heat. The density of the planting at this site requires additional study.

We found similar conditions at Hillside Elementary in Lincoln Heights. However, there were fewer opportunities to plant trees on a much smaller and more compact campus like Hillsdale Elementary. The scenario shows how an additional 22 trees could be planted to shade the sides of buildings most exposed to afternoon sun and provide shaded areas in the courtyards and recreation areas without any loss of useable open space (Figure 30).

The sixth and final scenario explored the potential for increased urban canopy in the Ramona Gardens public housing community. This complex provides affordable housing for some of the lowest household income families in the region in two-story apartment buildings that lack air conditioning. While the land use and building arrangements are typical for this type of housing the consolidated land control and amount of open space is atypical in this part of the city where single family or low density, multi-family units are prevalent on typical sized lots.

While there is currently 346 existing trees on this site and the adjacent streets, there are just 9 trees per acre, including park and recreation areas, within the community (Figure 31). The significant amount of open space on the site provides enormous potential for increasing the urban canopy to shade open space and when strategically located on the south and west sides of buildings, to provide interior cooling without the use of mechanical systems energy that could generate significant greenhouse gas emissions. Our scenario envisages planting an additional 183 large, high-density shade trees to reduce surface temperatures and potentially reduce $PM_{2.5}$ concentrations associated with the adjacent freeways.

Figure 26: Map showing the existing conditions in Hazard Park and on adjacent streets that includes some large trees, several sport fields and other recreational opportunities, and extensive unshaded areas

Figure 27: Map showing the proposed greening scenario for Hazard Park that includes some large trees, the same sport fields and related recreational opportunities, and extensive shaded areas

Figure 28: Perspective views of the current (top panel) and proposed large shade tree canopies (bottom panel) in the eastern part of Hazard Park that borders North Soto Street and currently hosts tables, benches and barbecue facilities

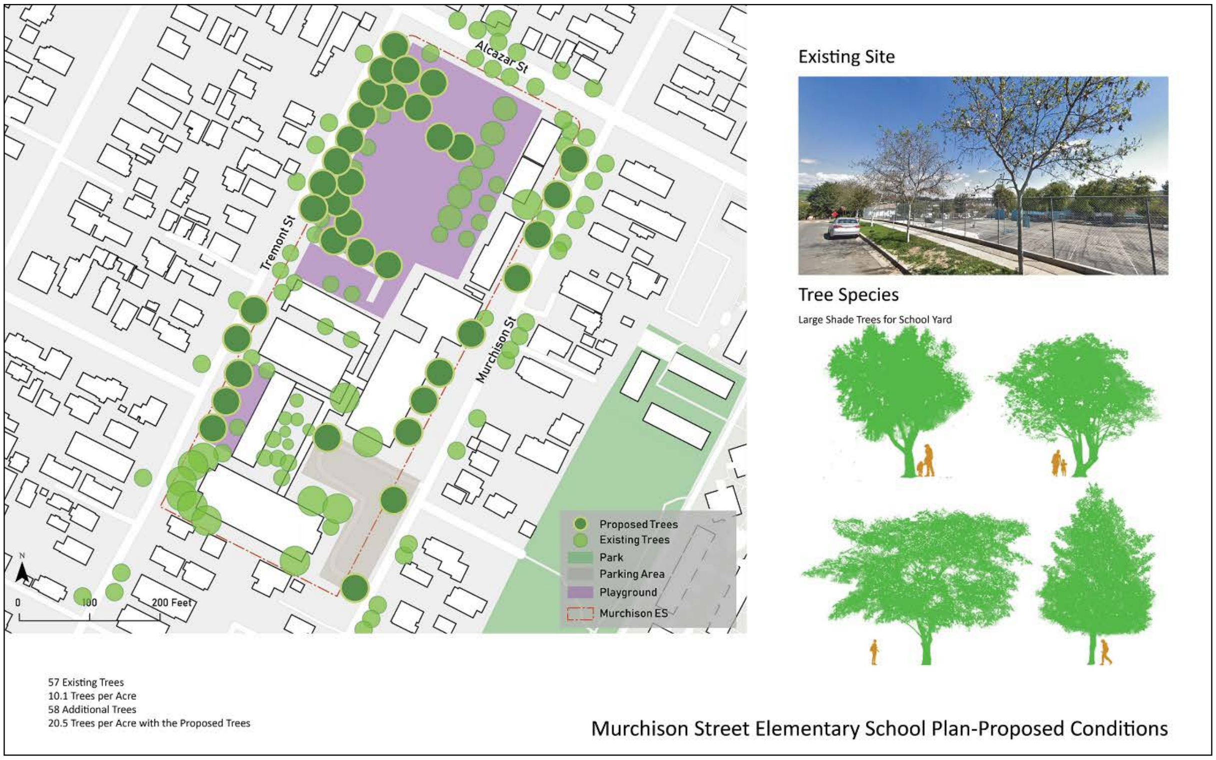


Figure 29: Potential tree planting vision for Murchison Elementary School and the adjacent streets showing the existing and proposed trees

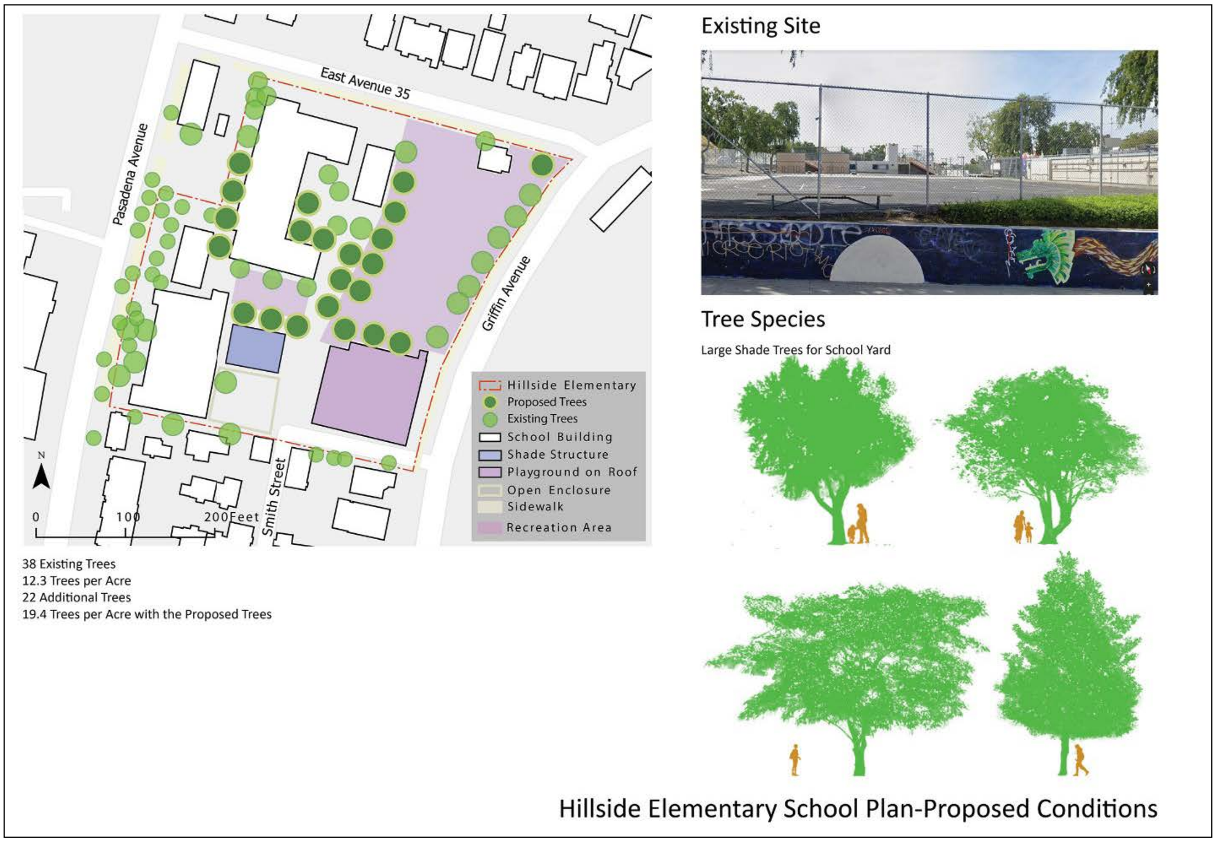


Figure 30: Potential tree planting vision for Hillside Elementary School and the adjacent streets showing the existing and proposed trees

346 Existing Trees
9.4 Trees per Acre

Ramona Gardens Plan-Existing Conditions

183 Additional Trees
14.3 Trees per Acre with the Proposed Trees

Ramona Gardens Plan-Proposed Conditions

Figure 31: Potential tree planting vision for Ramona Gardens showing the existing conditions (top panel) and proposed conditions (bottom panel)

7. Conclusions and Future Work

The fact that the study site currently hosts more residents (57,015) than trees (37,813) paints a vivid picture of conditions in the El Sereno, Lincoln Heights, and Ramona Gardens neighborhoods. The lack of air conditioning, modest homes and apartments, and poor air quality compound the impacts of the lack of green cover on human health and wellbeing. Together, these factors add up to a disturbing reality for residents in Eastside Los Angeles as they face steadily increasing number of days with temperatures above 95°F. This said, there are abundant opportunities for adding additional urban forest on streets and in the parks and school campuses scattered across these neighborhoods in the next few decades.

We applaud all those working to bring the current greening projects to fruition. However, we need additional greening projects to achieve long-term and meaningful change. The picture painted in this report suggests that we will need to take up much larger and more ambitious greening projects to combat global warming and reduce residents' exposure to extreme heat and air pollution over the next 30 years.

This project therefore had three major aims. The first was to take stock of the current conditions experienced by residents and visitors in the study site. The second was to assess the current state of the science to learn whether this could help to delineate pathways to generate more equitable, sustainable, and healthy communities. This would require the ability to measure and model the environment over multiple spatiotemporal scales—from individual trees to streets to city blocks and neighborhoods over days, months, seasons, years, and decades. The third was to build a series of greening scenarios to show how urban forest can be added to the existing environment to provide much needed relief for residents and visitors from extreme heat and particulate pollution.

The monitoring work completed to date just scratches the surface and we hope to build on this during subsequent phases of the Urban Trees Initiative. Our preliminary work with various trees as potential sinks for $PM_{2.5}$, for example, is central to the overall study effort because this information is required to know where to plant trees to mitigate air pollution, particularly for freeway-adjacent communities. We need to conduct a more thorough set of experiments across the winter, spring, summer, and fall seasons. Testing trees under a variety of airflow and ambient $PM_{2.5}$ conditions will help support the preliminary conclusions we have drawn in this work. A similar commentary applies to global warming and the opportunities to combat other exposures (heat, noise, etc.) that are pervasive in many large cities today.

This is a pivotal moment given growing concerns about sustainability, human health and wellbeing, equity and inclusion. We need to invest in people, planning, science, and technology to broker enduring and meaningful change. We also need to increase our investments in engaging the community and workforce development so the residents on the eastside of Los Angeles can help to develop the plans and interventions required to achieve the desired outcomes and simultaneously enjoy the benefits that follow these interventions.

This will likely require new forms of engagement and more nimble and flexible planning protocols tailored to the needs and aspirations of the community at hand. The narrow parkways, for example, may limit the scope of the urban forest in many parts of the city unless we are able to use public funds to promote the planting of trees on private as well as public property on a larger scale than happens at present with the City Plants Program. We will also need to make investments that span multiple domains (affordable housing, green infrastructure, workforce development, etc.) to ensure that the environmental investments benefit the long-term residents that live in these communities today. The slow streets and alfresco dining programs quickly initiated by the City of Los Angeles and many cities across southern California during the COVID-19 pandemic give hope that city governments are capable of designing and implementing creative solutions for their constituents.

The rapid convergence of science and technology and the opportunities this provides for conducting experiments over a range of spatiotemporal scales gives cause for optimism as well. The explosive growth and availability of satellite and other forms of imagery coupled with advances in geospatial analytics, machine learning and artificial intelligence, and the Internet of Things (IoT) provide new options to monitor urban tree ecosystem services and accelerate our scientific understanding of cities in the next decade [see Matasov et al. (2020) for additional details].

The two USC campuses are situated in areas of Los Angeles most vulnerable to the effects of climate change over the coming decades. We hope the Urban Trees Initiative can serve as a model for bringing together USC experts, the City of Los Angeles, and community leaders to create a shared vision for healthier, more livable neighborhoods into the 21st century and beyond. We look forward to continuing the work with our partners in the next phases of the initiative.

8. References

Anderson, G.B., Bell, M.L., Peng, R.D. 2013. Methods to calculate the heat index as an exposure metric in environmental health research. *Environmental Health Perspectives, 121,* 1111-1119.

Anguelovski, I., Brand, A. L., Chu, E., Goh, K. 2018a. Urban planning, community (re)development and environmental gentrification: Emerging challenges for green and equitable neighborhoods. In R. Holifield, J. Chakraborty, G. Walker (Eds.), *The Routledge handbook of environmental justice* (pp. 449-462). Abingdon, UK: Routledge.

Anguelovski, I., Connolly, J. J. T., Brand, A. L. 2018b. From landscapes of utopia to the margins of the green urban life: For whom is the new green city? *City: Analysis of Urban Change, Theory, Action, 22*(3), 417-436.

Anguelovski, I., Connolly, J. J. T., Pearsall, H., Shokry, G., Checker, M., Maantay, J., Gould, K., Lewis, T., Maroko, A., Roberts, J. T. 2019. Opinion: Why green "climate gentrification" threatens poor and vulnerable populations. *Proceedings of the National Academy of Sciences of the United States of America, 116*(52) 26139-26143.

Anniballe, R., Bonafoni, S., Pichierri, M. 2014. Spatial and temporal trends of the surface and air heat island over Milan using MODIS data. *Remote Sensing of Environment, 150,* 163-171.

Beckett, K.P., Freer-Smith, P.H., Taylor, G. 2000. Effective tree species for local air quality management. *Journal of Arboriculture, 26*(1), 12-19.

Beckett, K.P., Freer-Smith, P.H., Taylor, G. 2012. The capture of particulate pollution by trees at five contrasting urban sites. *Arboricultural Journal,* 24(2-3), 209-230.

Bijoor, N.S., Pataki, D.E., Haver, D., Famiglietti, J.S. 2014. A comparative study of the water budgets of lawns under three management scenarios. *Urban Ecosystems, 17*(4), 1095-1117.

Bikomeye, J.C., Balza, J., Beyer, K.M. 2021. The impact of schoolyard greening on children's physical activity and socioemotional health: A systematic review of experimental studies. *International Journal of Environmental Research and Public Health, 18*(2), 535.

Blanusa, T., Fantozzi, F., Monaci, F., Bargagli, R. 2015. Leaf trapping and retention of particles by holm oak and other common tree species in Mediterranean urban environments. *Urban Forestry and Urban Greening 14,* 1095-1101.

Bosch, M., Locatelli, M., Hamel, P., Jaligot, R., Chenal, J., Joost, S. 2020. Evaluating urban greening scenarios for urban heat mitigation: A spatially-explicit approach. Preprint, bioRχiv

Carrus, G., Scopelliti, M., Lafortezza, R., Colangelo, G., Ferrini, F., Salbitano, F., Agrimi, M., Portoghesi, L., Semenzato, P., Sanesi, G. 2015. Go greener, feel better? The positive effects of biodiversity on the well-being of individuals visiting urban and peri-urban green areas. *Landscape and Urban Planning, 134,* 221-228.

Chen, Y., Xu, Z., Byrne, J., Xu, T., Wang, S., Wu, J. (2021). Can smaller parks limit green gentrification? Insights from Hangzhou, China. *Urban Forestry and Urban Greening, 20,* 127009.

City of Los Angeles Department of Recreation and Parks. 2009. *2009 citywide community needs assessment.* Retrieved from https://www.laparks.org/sites/default/files/projects/2009%20Community%20Needs%20Assessment%20-%20Final.pdf

City of Los Angeles Mayor's Office. 2019. *L.A.'s Green New Deal Sustainable City pLAn.* Retrieved from https://plan.lamayor.org/sites/default/files/pLAn_2019_final.pdf

Cormie, A. 2020. *Rachel Malarich is planting a better future, tree by tree.* Retrieved from https://blog.google/products/earth/rachel-malarich-planting-better-future/

Deilami, K., Kamruzzaman, M., Liu, Y. 2018. Urban heat island effect: A systematic review of spatio-temporal factors, data, methods, and mitigation measures. *International Journal of Applied Earth Observation and Geoinformation, 67,* 30-42.

Edgar, C.B., Nowak, D.J., Majewsky, M.A., Lister, T.W., Westfall, J.A., Sonti, N.F. 2021. Strategic national urban forest inventory for the United States. *Journal of Forestry, 119,* 86-95.

Endreny, T.A. 2018. Strategically growing the urban forest will improve our world. *Nature Communications, 9,* 1160.

Endreny, T.A., Santagata, R., Perna, A., De Stefano, C., Rallo, R.F., Ulgiati, S. 2017. Implementing and managing urban forests: A much needed conservation strategy to increase ecosystem services and urban wellbeing. *Ecological Modelling, 360,* 328-335.

Gauderman, W.J., McConnell, R., Gilliland, F., London, S., Thomas, D., Avol, E., Vora, H., Berhane, K., Rappaport, E.B., Lurmann, F., Margolis, H.G., Peters, J. 2000. Association between air pollution and lung function growth in southern California children. *American Journal of Respiratory and Critical Care Medicine, 162*(4, Pt. 1), 1383-1390.

Gauderman, W.J., Vora, H., McConnell, R., Berhane, K., Gilliland, F., Thomas, D., Lurmann, F., Avol, E., Künzli, N., Jerrett, M., Peters, J. 2007. Effect of exposure to traffic on lung development from 10 to 18 years of age: A cohort study. *Lancet, 369*(9561), 571-577.

Haase, D., Kabisch, S., Haase, A., Andersson, E., Banzhaf, E., Baró, F., Brenck, M., Fischer, L. K., Frantzeskaki, N., Kabisch, N., Krellenberg, K, Kremer, P., Kronenberg, J., Larondelle, N., Mathey, J., Pauleit, S., Ring, I., Rink, D., Schwarz, N., Wolff, M. 2017. Greening cities – To be socially inclusive? About the alleged paradox of society and ecology in cities. *Habitat International, 64,* 41-48.

Habre, R., Girguis, M., Urman, R., Fruin, S., Lurmann, F., Shafer, M., Gorski, P., Franklin, M., McConnell, R., Avol, E., Gilliland, F. 2020. Contribution of tailpipe and non-tailpipe traffic sources to quasi-ultrafine, fine and coarse particulate matter in southern California. *Journal of the Air and Waste Management Association, 71*(2), 209-230.

Hassan, R., Hansen, T.B., Nordh, H. 2014. Visualizations in the planning process: A study of communication and understanding. In N. Gu, S. Watanabe, H. Erhan, M. Hank Haeusler, W. Huang, R. Sosa (Eds.), Rethinking comprehensive design: Speculative counterculture (pp. 65-74). Hong Kong, Association for Computer-Aided Architectural Design Research in Asia.

He, C., Qiu, K., Alahmad, A., Pott, R. 2020. Particulate matter capturing capacity of roadside evergreen vegetation during the winter season. *Urban Forestry and Urban Greening, 48,* 126510.

Hirabayashi, S., Kroll, C.N., Nowak, D.J. 2015. *i-Tree eco dry deposition model descriptions.* Retrieved from https://dev.itreetools.org/documents/60/iTree_Eco_Dry_Deposition_Model_Descriptions.pdf

Hulley, G.C., Dousset, B., Kahn, B.H. 2020. Rising trends in heatwave metrics across southern California. *Earth's Future, 8*(7), e2020EF001480.

Hulley, G.C., Shivers, S., Wetherley, E., Cudd, R. 2019. New ECOSTRESS and MODIS land surface temperature data reveal fine-scale heat vulnerability in cities: A case study for Los Angeles County, California. *Remote Sensing, 11*(18), 2136.

Hulley, M.E. 2012. The urban heat island effect: causes and potential solutions. In F. Zeman (Ed.), *Metropolitan sustainability: Understanding and improving the urban environment* (pp. 79-98). Sawston, UK: Woodhead Publishing.

Jelks, N.O., Jennings, V., Rigolon, A. 2021. Green gentrification and health: A scoping review. *International Journal of Environmental Research and Public Health, 18*(3), 907.

Künzli, N., McConnell, R., Bates, D., Bastain, T., Hricko, A., Lurmann, F., Avol, E., Gilliland, F., Peters, J. 2003. Breathless in Los Angeles: The exhausting search for clean air. *American Journal of Public Health, 93*(9), 1494-1499.

Lee, S.J., Longcore, T., Rich, C., Wilson, J.P. 2017. Increased home size and hardscape decreases urban forest cover in Los Angeles County's single-family residential neighborhoods. *Urban Forestry and Urban Greening, 24,* 222-235.

Letter, C., Jäger, G. 2020. Simulating the potential of trees to reduce particulate matter pollution in urban areas throughout the year. *Environment, Development and Sustainability, 22*(5), 4311-4321.

Litvak, E., Bijoor, N.S., Pataki, D.E. (2014). Adding trees to irrigated turfgrass lawns may be a water-saving measure in semi-arid environments. *Ecohydrology, 7*(5), 1314-1330.

Litvak, E., Manago, K., Hogue, T.S., Pataki, D.E. 2017a. Evapotranspiration of urban landscapes in Los Angeles, California at the municipal scale. *Water Resources Research, 53*(5), 4236-4252.

Litvak, E., McCarthy, H.R., Pataki, D.E. 2017b. A method for estimating transpiration from irrigated urban trees in California. *Landscape and Urban Planning, 158,* 48-61.

Litvak, E., Pataki, D.E. 2016. Evapotranspiration of urban lawns in a semi-arid environment: An in situ evaluation of microclimatic conditions and watering recommendations. *Journal of Arid Environments, 134,* 87-96.

Livesley, S.J., McPherson, E.G., Calfapietra, C. 2016. The urban forest and ecosystem services: Impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. *Journal of Environmental Quality, 45*(1), 119-124.

Lu, Y., Giuliano, G., Habre, R. 2021. Estimating hourly $PM_{2.5}$ concentrations at the neighborhood scale using a low-cost air sensor network: A Los Angeles case study. *Environmental Research, 195,* 110653.

Mackovich, R. 2018. *Is it hard to breathe in your corner of Los Angeles County? Neighborhood by neighborhood, a USC project pinpoints areas with cleaner or more-polluted air.* Retrieved from https://news.usc.edu/144493/air-pollution-in-los-angeles-county-neighborhoods/

Matasov, V., Marchesini, L.B., Yaroslavtsev, A., Sala, G., Fareeva, O., Seregin, I., Castaldi, S., Vasenev, V., Valentini, R. 2020. IoT monitoring of urban tree ecosystem services: Possibilities and challenges. *Forests, 11,* 775.

McPherson, E.G., Berry, A.M., van Doorn, N.S., Downer, J., Hartin, J., Haver, D., Teach, E. 2019. Climate-ready tree study: Update for southern California communities. *Western Arborist, Winter 2019,* 12-18.

McPherson, E.G., Simpson, J.R. 2003. Potential energy savings in buildings by an urban tree planting programme. *Urban Forestry and Urban Greening, 2,* 73-86.

McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., Xiao, Q. 2005. Municipal forest benefits and costs in five US cities. *Journal of Forestry, 103*(8), 411-416.

McPherson, E.G., Simpson, J.R., Xiao, Q., Wu, C. 2008. *Los Angeles 1-million tree canopy cover assessment* (General Technical Report PSW-GTR-207). Riverside, CA: U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station.

McPherson, E.G., van Doornb, N., de Goede, J. 2016. Structure, function and value of street trees in California, USA. *Urban Forestry and Urban Greening, 17,* 104-115.

Mell, I., Whitten, M. 2021. Access to nature in a post Covid-19 world: Opportunities for green infrastructure financing, distribution and equitability in urban planning. *International Journal of Environmental Research and Public Health, 18*(4), 1527.

Mori, J., Hanslinc, H.M., Burchi, G., Sæbø, A. 2015. Particulate matter and element accumulation on coniferous trees at different distances from a highway. *Urban Forestry and Urban Greening, 14,* 170–177.

Muhammad, S., Wuyts, K., Samson, R. 2019. Atmospheric net particle accumulation on 96 plant species with contrasting morphological and anatomical leaf characteristics in a common garden experiment. *Atmospheric Environment, 202,* 328-344.

Nicholson-Cole, S.A. 2005. Representing climate change futures: A critique on the use of images for visual communication. *Computers, Environment and Urban Systems, 29*(3), 255-273.

Nieuwenhuijsen, M.J. 2020. Urban and transport planning pathways to carbon neutral, liveable and healthy cities: A review of the current evidence. *Environment International, 140,* 105661.

Ozdemir, H. 2019. Mitigation impact of roadside trees on fine particle pollution. *Science of the Total Environment, 659,* 1176-1185.

Pallozzi, E., Guidolotti, G., Mattioni, M., Calfapietra, C. 2020. Particulate matter concentrations and fluxes within an urban park in Naples. *Environmental Pollution, 226,* 115134.

Pataki, D.E., McCarthy, H.R., Litvak, E., Pincetl, S. 2011. Transpiration of urban forests in the Los Angeles metropolitan area. *Ecological Applications, 21*(3), 661-677.

Porse, E., Mika, K.B., Litvak, E., Manago, K.F., Hogue, T.S., Gold, M., Pataki, D.E., Pincetl, S. (2018). The economic value of local water supplies in Los Angeles. *Nature Sustainability, 1,* 289-297.

Przybysz, A., Sæbø, A., Hanslin, H.M., Gawroński, S.W. 2014. Accumulation of particulate matter and trace elements on vegetation as affected by pollution level, rainfall and the passage of time. *Science of the Total Environment, 481,* 360-369.

Rahman, M.A., Stratopoulos, L.M.F., Moser-Reischl, A., Zölch, T., Häberle, K.-H., Rötzer, T., Pretzsch, H., Pauleit, S. 2020. Traits of trees for cooling urban heat islands: A meta-analysis. *Building and Environment, 170,* 106606.

Reichmuth, D. (2019). *Inequitable exposure to air pollution from vehicles in California: Who bears the burden?* Retrieved from https://www.ucsusa.org/sites/default/files/attach/2019/02/cv-air-pollution-CA-web.pdf

Rigolon, A., Christensen, J. 2000. *Greening without gentrification: Learning from parks-related anti-displacement strategies nationwide.* Los Angeles, CA: UCLA Institute of the Environment and Sustainability.

Rigolon, A., Keith, S. J., Harris, B., Mullenbach, L. E., Larson, L. R., Rushing, J. 2020. More than "just green enough:" Helping park professionals achieve equitable greening and limit environmental gentrification. *Journal of Park and Recreation Administration*, *38*(3), 29-54.

Rigolon, A., Németh, J. 2018. "We're not in the business of housing:" Environmental gentrification and the nonprofitization of green infrastructure projects. *Cities, 81,* 71-80.

Rigolon, A., Németh, J. 2020. Green gentrification or 'just green enough': Do park location, size and function affect whether a place gentrifies or not? *Urban Studies, 57*(2), 402-420.

Sæbø, A., Popek, R., Nawrot, B., Hanslin, H.M., Gawronska, H., Gawronski, S.W. 2012. Plant species differences in particulate matter accumulation on leaf surfaces. *Science of the Total Environment, 427-428,* 347-354.

Sailor, D.J., Anand, J., Kalkstein, L. 2020. Potential overall heat exposure reduction associated with implementation of heat mitigation strategies in Los Angeles. *International Journal of Biometeorology, 65,* in press.

Samson, R., Grote, R., Calfapietra, C., Cariñanos, P., Fares, S., Paoletti, E., Tiwary, A. 2017. Urban trees and their relation to air pollution. In D. Pearlmutter, C. Calfapietra, R. Samson, L. O'Brien, S. Krajter Ostoić, G. Sanesi, R. Alonso del Amo, R. (Eds.), *The urban forest: Cultivating green infrastructure for people and the environment* (pp. 21-30). Cham, Switzerland: Springer.

Tomasso, L.P., Yin, J., Cedeño Laurent, J.G., Chen, J.T., Catalano, P.J., Spengler, J.D. (2021). The relationship between nature deprivation and individual wellbeing across urban gradients under COVID-19. *International Journal of Environmental Research and Public Health*, *18*(4), 1511.

Tong, Z., Whitlow, T.H., MacRae, P.F., Landers, A.J., Harada, Y. 2015. Quantifying the effect of vegetation on near-road air quality using brief campaigns. *Environmental Pollution, 201,* 141-149.

Traverso, V. 2020. *The best trees to reduce air pollution*. Retrieved from https://www.bbc.com/future/article/20200504-which-trees-reduce-air-pollution-best

TreePeople. 2018. *Los Angeles County tree canopy basic viewer: Exploring the existing and possible tree canopy from the parcel to the city level* (Web application). Retrieved from https://www.treepeople.org/los-angeles-county-tree-canopy-map-viewer/

Urban Forest Ecosystems Institute. 2021. *Holly oak, Quercus ilex.* Retrieved from https://selectree.calpoly.edu/tree-detail/quercus-ilex

United Nations. 2019. *The sustainable development goals report 2019.* Retrieved from https://sustainabledevelopment.un.org

U.S. Environmental Protection Agency. (2019). EnviroAtlas meter scale urban land cover dataset for Los Angeles County. Retrieved from https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/Supplemental/Landcover.pdf

Wolf, K.L., Lam, S.T., McKeen, J.K., Richardson, G.R.A., van den Bosch, M., Bardekjian, A.C. 2020. Urban trees and human health: A scoping review. *International Journal of Environmental Research and Public Health*, *17*(12), 4371.

Wu, Z., Chen, L. 2017. Optimizing the spatial arrangement of trees in residential neighborhoods for better cooling effects: Integrating modeling with in-situ measurements. *Landscape and Urban Planning, 167,* 463-472.

Wujeska-Klause, A., Pfautsch, S. 2020. The best urban trees for daytime cooling leave nights slightly warmer. *Forests, 11*(9), 945.

Xiao, Q., McPherson, E.G. 2016. Surface water storage capacity of twenty tree species in Davis, California. *Journal of Environmental Quality, 45,* 188-198.

Xu, X., Xinxiao Yu, X., Mo, L., Xu, Y., Bao, L., Lun, X. 2019. Atmospheric particulate matter accumulation on trees: A comparison of boles, branches and leaves. *Journal of Cleaner Production, 226,* 349-356.

Yao, R., Wang, L., Huang, X., Niu, Y., Chen, Y., Niu, Z. 2018. The influence of different data and method on estimating the surface urban heat island intensity. *Ecological Indicators, 89,* 45-55.

Zhou, W., Wang, J., Cadenasso, M.L. 2017. Effects of the spatial configuration of trees on urban heat mitigation: A comparative study. *Remote Sensing of Environment, 195,* 1-12.

9. Appendix

Figure A1 summarizes the census block groups that overlapped the study site. We used the census data compiled for these units to describe the residents of the study site. We adjusted the data for the census block groups partially included in the study site on a proportional basis based on area around the margins of the study site.

Table A1 compares the results of our own street tree inventory with that of the Urban Forestry Division of the City of Los Angeles Bureau of Street Services for 429 street segments in El Sereno. We built our inventory using the aforementioned imagery sources and the second was created using GPS and other automated tools in the field. We used the city's street tree inventory wherever it was available and the differences between the two counts offer an assessment of the efficacy of the imagery-based methods we used to count and describe trees. These are the best results using the imagery-based methods given the earlier comment that trees on streets were more visible on average than the trees on private lots in many parts of the study site.

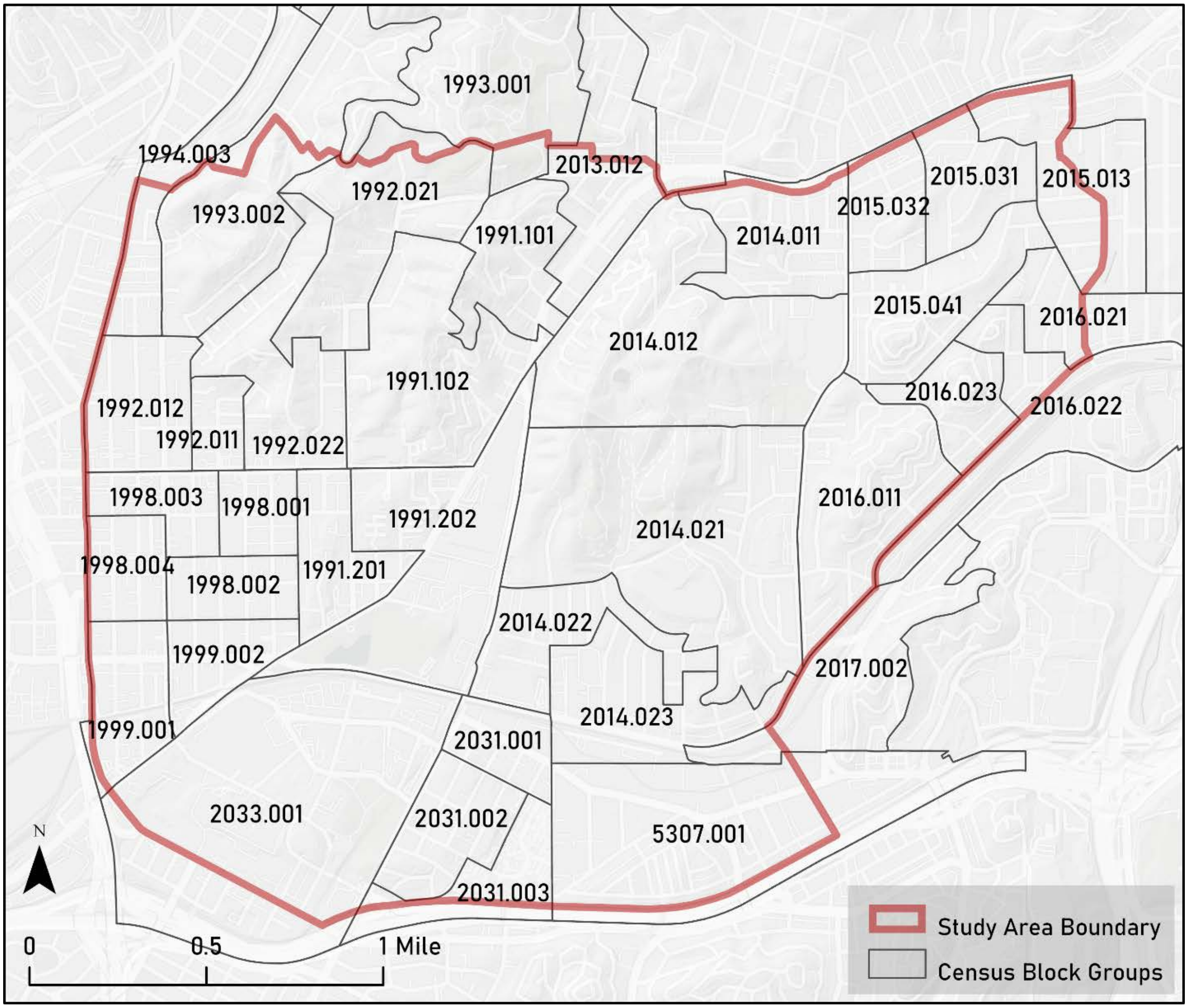


Figure A1: Map of census block groups used to delineate and describe the people of the place

Table A1: Comparison of tree counts using Urban Forestry Division of the City of Los Angeles Bureau of Street Services street tree inventory (STI) and the project team's imagery-based counts (IBC) for selected street segments in El Sereno

Street	No. of segments	STI counts	IBC counts	Differences (STI – IBC)	Differences (%)
Abner St	3	43	42	1	2.3
Adkins Ave	6	17	6	11	64.7
Alhambra Ave	9	77	58	19	24.7
Almadale Ave	1	19	5	14	73.7
Axtell St	3	36	38	-2	5.6
Ballard St	3	1	3	-2	200.0
Barstow St	3	0	18	-18	---
Beagle St	4	2	12	-10	500.0
Bedilion St	3	7	15	-8	114.3
Belleglade Ave	4	16	6	10	62.5
Betty Dr	1	12	12	0	0.0
Boca Ave	6	35	38	-3	8.6
Bowman Blvd	7	68	63	5	7.4
Brawley St	2	10	10	0	0.0
Budau Pl	1	11	8	3	27.3
Budau Ave	7	129	73	56	43.4
Bullard Ave	2	25	26	-1	4.0
Butterfly Lane	1	8	8	0	0.0
Carter Dr	3	3	8	-5	166.7
Castalia Ave	4	12	26	-14	116.7
Castleman Ave	1	11	4	7	63.6
Catalpa St	6	72	39	33	45.8
Cato St	4	10	14	-4	40.0
Cato Way	1	2	3	-1	50.0
Chadwick Cir	2	14	14	0	0.0
Chadwick Dr	5	112	72	40	35.7
Chester St	9	35	35	0	0.0
Converse St	1	22	23	-1	4.5
Cronus St	2	46	37	9	19.6
Cyril Ave	3	68	59	9	13.2
Dartmouth Ave	2	18	8	10	55.6
Del Paso Ave	4	22	21	1	4.5
Del Paso Ct	1	7	2	5	71.4
Delor Dr	1	2	1	1	50.0
Ditman Ave	3	33	17	16	48.5
Druid St	8	80	37	43	53.8
Dudley Dr	4	1	15	-14	1400.0
Dudley Way	1	0	1	-1	---
Eastern Ave	18	191	199	-8	4.2
Edelle Pl	1	2	2	0	0.0

Edloft Ave	4	14	19	-5	35.7
Edna St	3	48	44	4	8.3
Endicott St	2	33	35	-2	6.1
Far Pl	1	0	0	0	---
Farnsworth Ave	5	41	40	1	2.4
Ferntop Dr	2	0	3	-3	---
Fithian Ave	1	23	28	-5	21.7
Gambier St	5	43	44	-1	1.0
Gateside Dr	3	0	0	0	---
Gratiot St	1	9	8	1	11.1
Grey Dr	2	4	4	0	0.0
Hatfield Pl	4	9	8	1	11.1
Haven St	4	28	29	-1	3.6
Hicks Ave	1	17	15	2	11.8
Hollister Ave	4	54	51	3	5.6
E Huntington Dr	10	51	58	-7	13.7
N Huntington Dr	12	24	48	-24	100.0
Hyde St	1	22	19	3	13.6
Indiana Ave	4	31	23	8	25.8
Ithaca Ave	7	112	75	37	33.0
Jade St	1	10	10	0	0.0
Jasper St	1	0	7	-7	---
Jones Ave	2	39	16	23	59.0
Kenneth Dr	2	20	26	-6	30.0
Kewanee St	2	3	9	-6	200.0
Kimball St	2	59	4	55	93.2
Kings Pl	1	0	1	-1	---
Klamath Pl	3	18	15	3	16.6
Klamath St	4	31	30	1	3.2
La Calandria Dr	3	23	3	20	87.0
La Calandria Way	2	18	7	11	61.1
Ladd Ave	2	12	8	4	33.3
Lifur Ave	5	27	25	2	7.4
Linda Vista Ter	1	53	45	8	15.1
Lombardy Blvd	8	42	35	7	16.7
Lynnfield St	8	4	6	-2	50.0
Lynnfield Cir	1	4	7	-3	75.0
Mallory St	1	6	9	-3	50.0
Martin St	5	23	21	2	8.7
McPherson Ave	2	36	15	21	58.3
Mcherson Pl	2	14	11	3	21.4
Minto Ct	2	16	18	-2	12.5
Multnomah St	7	50	58	-8	16.0
Navarro St	7	101	80	21	20.8
Newark Ave	2	0	1	-1	---
Norelle St	3	21	9	12	57.1

O’Neil St	1	2	8	-6	300.0
Oakland St	2	31	31	0	0.0
Okell Dr	1	4	2	2	50.0
Otero Dr	3	0	18	-18	---
Paola Ave	4	33	31	2	6.1
Phelps Ave	5	34	37	-3	8.8
Portola Ave	5	69	62	7	10.1
Pueblo Ave	6	46	46	0	0.0
Richelieu Ave	5	19	18	1	5.3
Richelieu Pl	1	1	1	0	0.0
Richelieu Ter	1	7	1	6	85.7
Ronda Dr	4	52	54	-2	3.8
Round Dr	5	10	13	-3	30.0
Rowan Ave	3	30	12	18	60.0
Ruth Swiggett Dr	1	0	6	-6	---
Soto St	7	8	20	-12	150.0
Templeton St	11	150	137	13	8.7
Thelma Ave	3	13	18	-5	38.5
Topaz St	1	0	1	-1	---
Turquoise St	1	0	2	-2	---
Twining St	10	48	47	1	2.1
Valley Blvd	11	151	116	35	23.2
Vaquero Ave	3	61	49	12	19.7
Verdemour Ave	3	8	10	-2	25.0
Vineburn Ave	2	3	17	-14	466.7
Waldo Ct	1	0	0	0	---
Warwick Ave	9	110	101	9	8.2
Wilson Way	1	0	0	0	---
Yellowstone St	10	55	34	21	38.2
Zane St	3	0	7	-7	---
Zella Pl	1	8	3	5	62.5
Totals	**429**	**3,425**	**3,007**	**418**	**12.2**