Urban Reforestation

PREPARED FOR :

GroundWork San Diego,
Chollas Creek

Santa Clara University
Environmental Science &
Studies Department

Senior Capstone Project
Advisor: John Dialesandro

CONTRIBUTORS

BILLY GEORGENES

RYAN BURKE

LISA WAGNER

HARRISON MARSHALL

WILL JARRETT

Table of Contents


Photo by Billy Georgenes

Pg. 3	Executive Summary
4-5	Introduction
6	Research Questions
7-10	Urban Heat: Islands, Current Conditions, Vulnerability Comparison
10	Benefits of Urban Reforestation - Environmental
11-13	Benefits of Urban Reforestation - Economic + Cost/Benefit Analysis
13-14	Benefits of Urban Reforestation - Health & Social
15-17	GIS Methods
18-19	GIS Analysis Results
20	Research Gaps
21	Conclusion
22-24	References
25-26	Appendix

Executive Summary

The scope of this project is to discuss the environmental injustices regarding excessive urban heat in Southcrest, San Diego, and supply data-driven guidance as well as incentives to stakeholders who aim to tackle this problem. Groundwork USA is an environmental justice group dedicated to uplifting communities impacted by climate change. With chapters in many cities across the US, our team worked with a community partner at Groundwork USA's Chollas Creek, San Diego organization. We discussed their Climate Safe Neighborhoods Initiative, which includes a partnership with Tree San Diego to plant 50+ trees for free in the Southcrest Neighborhood. Southcrest is a historically redlined and marginalized community that is disproportionately affected by the extreme heat events in Southern California. Increasing the number of trees in the neighborhood is a natural mitigation tactic that could reduce land surface temperatures in the community and also improve economic, environmental, and health/social factors, as proven by our research involving relevant cited literature. Further, by conducting an action research design, our team collaborated with our community partner to identify a method to algorithmically determine the most suitable locations to plant trees in Southcrest. Our geospatial analysis found that certain areas within the neighborhood were favored to reduce urban heat and were more likely to have trees planted. A cost-benefit analysis was conducted to explain further the economic benefits of adding trees in the Southcrest neighborhood. Through a regression analysis, we concluded that there is an inverse relationship between tree canopy and neighborhood temperature. Using a conversion rate found in a study from 2015, we could correlate a decrease in urban heat with a reduction in energy bills in San Diego (Hoyt, 2015). Using our discovered metrics and data collected from San Diego energy and water utilities, we found that adding one to two trees to the average home could result in $788.28 in annual savings. Overall, we recommend that Southcrest increases its tree presence for a variety of economic, environmental, and health/social reasons. Such trees should be planted in locations found in our suitability analysis with careful consideration given to religious facilities and elementary schools.

Introduction

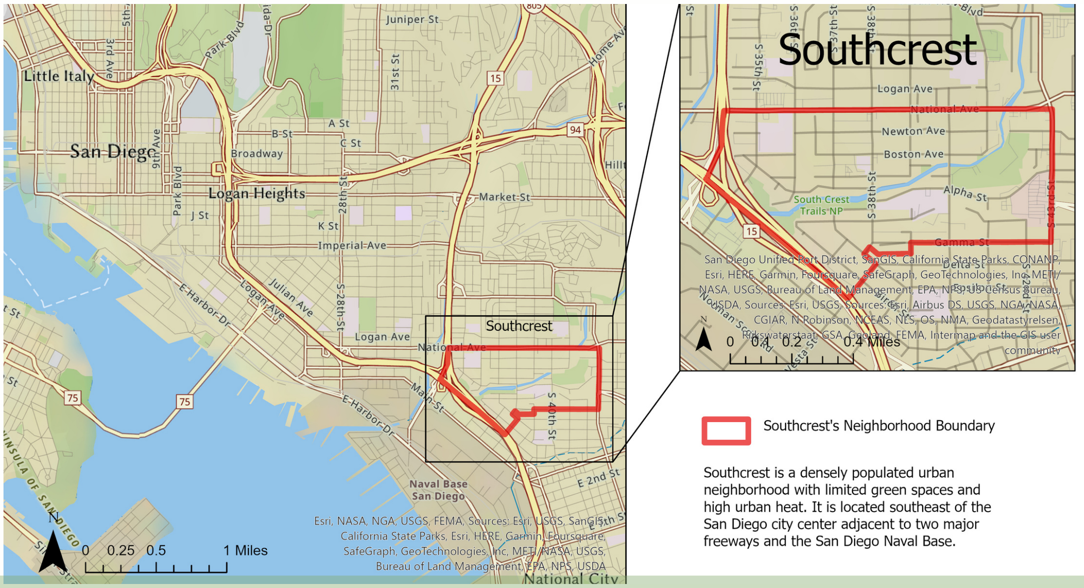

Figure 1. Southcrest Neighborhood. The boundary is determined by the City of San Diego Police department - https://data.sandiego.gov/datasets/pd-neighborhoods/. Created by Ryan Burke on 2/16/23.

The community of Southcrest is a dynamic and diverse neighborhood located in San Diego(Figure 1), a region known for its warm weather. While the abundance of sunshine can be a source of joy for many residents, it also presents some challenges as climate change continues to exacerbate extreme weather events(Khandekar, 2005). Southcrest is a neighborhood that is vulnerable to environmental justice issues and especially heat-related problems. The social, environmental, and economic inequality in this community is partially due to historic redlining and other policies that disproportionately isolate the community from necessary infrastructure. In the summer extreme heat demands the need for more trees in the area. The city copes with something called the Urban Heat Island(UHI) effect. Southcrest is a highly populated urban area with increased amounts of impervious surfaces and densely built forms, which can trap and amplify heat, leading to higher temperatures(Akbari, 2009). Additionally, Southcrest is located near major roads and highways, which can lead to higher levels of air pollution which further the UHI effect, making the area hotter and thus more vulnerable. Lastly, Southcrest has a high proportion of low-income residents who may not have access to air conditioning or other cooling resources, also making them more vulnerable to heat-related health problems such as kidney stones, asthma, and diabetes(Ebi et.al., 2021).

Trees provide essential shade and help to cool the air around them, making them a vital resource in combating the harmful effects of heat. However, to maximize tree benefits, it is important to choose the suitable species of trees for the area and plant them in a way that does not interfere with existing infrastructure and ecosystems. Furthermore, for drought-prone environments like Southcrest, it is better to plant drought-resistant trees that are well-adapted to dry conditions and can conserve water resources, help mitigate the effects of drought, and improve water efficiency in

Introduction

the landscape. Groundwork San Diego, Chollas Creek has specified seven drought-resistant trees for planting: Coast Live Oak(Quercus agrifolia), Cork Oak(Quercus suber), Southern Live Oak(Quercus virginiana), Pink Trumpet Tree(Handroanthus impetiginosa), Evergreen Ash(Fraxinus uhdei), Camphor Tree(Cinnamomum camphora), and Deodar Cedar(Cedrus deodara).

To conclude, planting more trees in the community of Southcrest can have numerous benefits, not only in terms of mitigating the impact of heat but also in improving the overall health and well-being of its residents. The following literature review will provide research-backed reasons as to why community leaders in Southcrest should plant more trees and examine the environmental, economic, social, and health benefits that additional tree canopy coverage can bring to a community.

Coast Live Oak
Max height:
70 ft
Canopy width:
20-70 ft
Growth rate:
~24 in/year

Cork Oak
Max height:
70 ft
Canopy width:
70 ft
Growth rate:
~24-36 in/year

Southern Live Oak
Max height:
80 ft
Canopy width:
60-100 ft
Growth rate:
~24-36 in/year

Pink Trumpet Tree
Max height:
20-40 ft
Canopy width:
30-40 ft
Growth rate:
~12-24 in/year

Evergreen Ash
Max height:
80 ft
Canopy width:
60 ft
Growth rate:
~36-127 in/year

Camphor Tree
Max height:
65 ft
Canopy width:
50-60 ft
Growth rate:
~24 in/year

Deodar Cedar
Max height:
60 ft
Canopy width:
20-30 ft
Growth rate:
~36 in/year

Research Questions

01. **Where are the most economic and feasible locations to place trees in Southcrest?**

02. **What are the cost and energy savings associated with the installation of trees in Southcrest?**

03. **What is the heat/social vulnerability of Southcrest residents compared to La Jolla?**

Urban Heat

Urban Heat Islands:

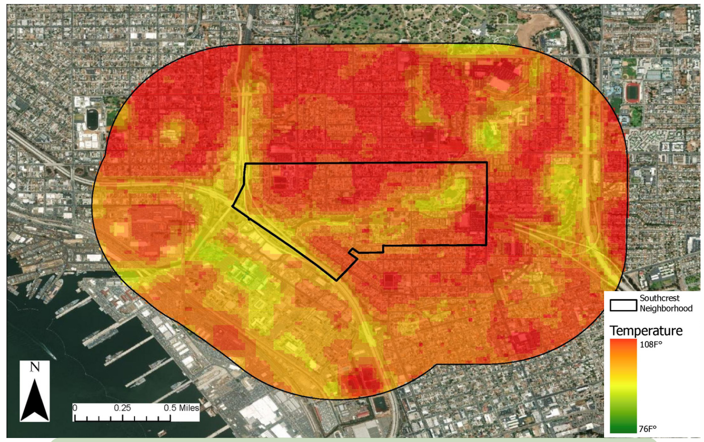

Figure 2. Urban Heat in Southcrest. Data from CalEPA. Created Billy Georgenes on 2/23/23.

San Diego is one of many cities at risk from changing temperatures as it contains various climate zones that experience heat in different ways. For example, neighborhoods which are more inland are prone to higher temperatures due to the increased distance from the ocean's cooling effect(Chamberlain, 2022). The built environment creates differing microclimates which can increase or decrease surrounding temperatures depending on the existence of heat sinks or heat-trapping surfaces. For instance, trees and vegetated surfaces are associated with cooling effects whereas concrete and impervious surfaces can be linked to heating effects.

Areas characterized by low vegetation and high temperatures are called Urban Heat Islands(UHI) (Zawadzka, 2021). There are many ways of locating UHIs. While air and surface temperatures are the most direct way of doing so, other factors such as the level of greenness/the Normalized Differenced Vegetation Index(NDVI), percentage of tree canopy, building density, presence of humidity and evapotranspiration, and distance to green spaces all contribute to the presence and intensity of a UHI(Hale, 2020; Brune, 2016). As climate change continues, global temperatures are expected to rise so adaptation and mitigation practices such as tree planting are necessary(IPCC, 2022).

Current Conditions & Vulnerability Comparison

San Diego faces unique challenges when it comes to planting new trees in the area. According to the United States Census Bureau, the estimated population of San Diego County, California, as of 2021, is approximately 3,387,000 people. Keeping pace with their substantial population, according to the California Department of Motor Vehicles, as of 2021, there were approximately 2,444,821 registered vehicles in San Diego County. Therefore, convincing property owners to sacrifice valuable parking spaces to plant trees is a difficult task. Additionally, the city of San Diego makes it difficult for private entities to plant on public lands through zoning and permits. Another hurdle that comes with planting a tree in the San Diego area is the lack of precipitation. This lack of precipitation means that once the trees are planted they cannot be left unattended. They must be watered for the first few years. Water in Southern California can be expensive and this makes planting a tree less attractive.

Further, San Diego is classified as a Mediterranean climate, characterized by mild wet winters and warm to hot, dry summers. The area experiences around 10 inches of precipitation a year(Taha, 2017).

Such rainfall is light thus its impact is short-term as most of the rain that falls will be quickly evaporated or used by plants.

According to a recent IPCC report, Climate Change 2021: The Physical Science Basis, cities should expect to see an increase in the frequency and severity of hot weather events, exacerbated by continued urbanization and global warming. Urban environments are particularly vulnerable to heat impacts due to the heat island effect. These areas are projected to experience threatening heat events that will become ten times more common by the end of the century(Chamberlain, 2022). San Diego is projected to experience a significant increase in the number of dangerously hot days in the coming decades due to climate change. By mid-century, the city is expected to experience an average of 30 dangerously hot days per year, and by the end of the century, this number could increase to 58-96 days per year, depending on the level of global carbon emissions(Union, 2020).

San Diego does not have enough trees to combat rising temperatures as the Forest Observatory estimates that in 2020, there was an average of 17.3% tree canopy in San Diego County. While the recommended amount of tree coverage for an urban city varies depending on the specific location and context, the optimal tree canopy is between 25-40%(Nowak et.al., 2002; McPherson et al., 2013).

As there is a degree of temperature correlation between tree presence and heat(further discussed in other sections), Figure 5 demonstrates the average temperature in Southcrest is 100°F while only 93.1°F in La Jolla. While other factors such as proximity to the ocean, infrastructure, soil condition, etc., may contribute to such temperature disparity, tree canopy plays a critical role in the cooling of cities. Southcrest has a tree canopy coverage of 14.5% while La Jolla has a tree canopy coverage of 21.8%(Figure 4.). Thus, as Southcrest has a lower percentage of tree coverage they ore vulnerable to heat.

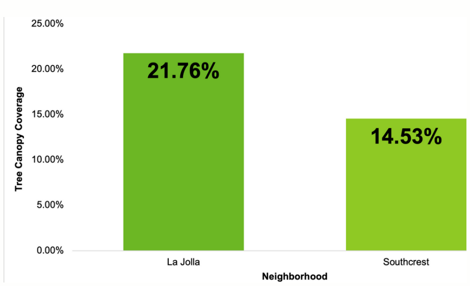

Figure 4. Average Tree Canopy Coverage in La Jolla and Southcrest.

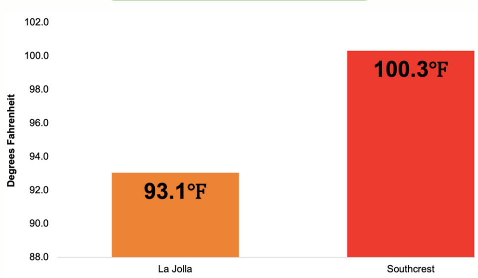

Figure 5. Average Temperature in La Jolla and Southcrest.

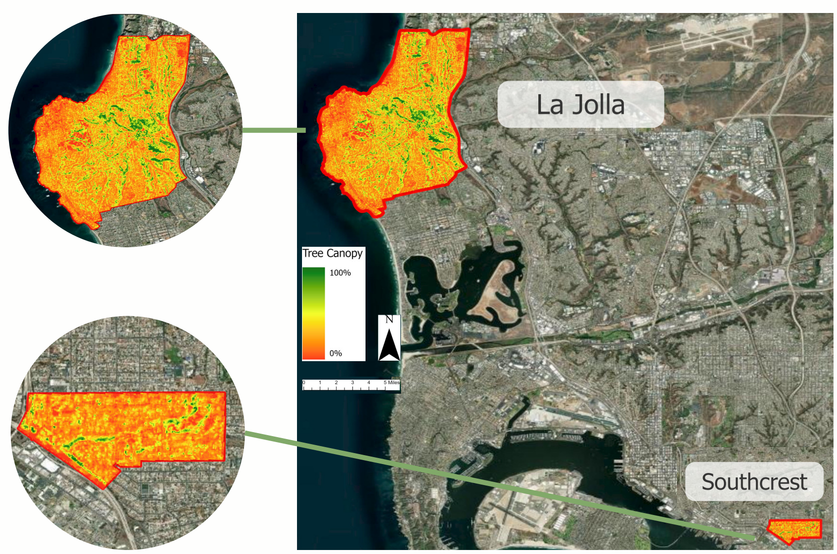

Figure 3. Tree Canopy locations and percentage in La Jolla and Southcrest. Data from NASA and ESA Satellite Imagery Raster Data. Created by Billy Georgenes 3/20/23

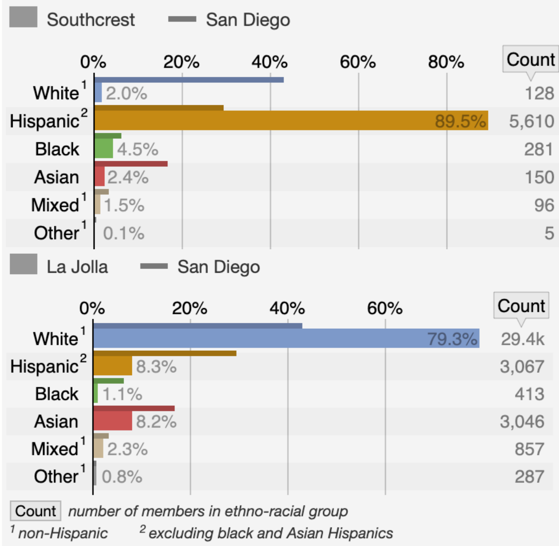

Figure 6. Race and Ethnicity: Southcrest & La Jolla Neighborhoods. Data from 2020 US Census Bureau. Data is the percentage of the total population. Created by Statistical Atlas.

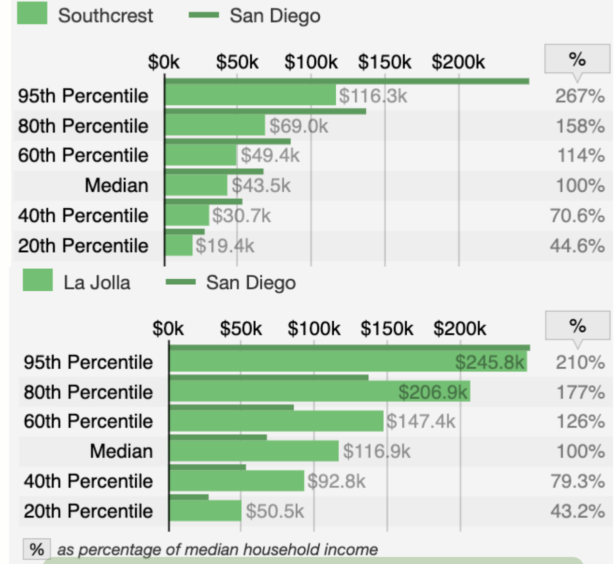

Figure 7. Household Income Percentiles: Southcrest & La Jolla Neighborhoods. Data from 2020 US Census Bureau. Data is the percentage of the total population. Created by Statistical Atlas.

The trees are also unevenly dispersed with the wealthier and white-dominated communities often having a higher percentage of tree canopy coverage than their predominantly minority counterparts. Thus, the Southcrest neighborhood, which has an 89.5% Hispanic and low-income population, may be more vulnerable to the effects of extreme heat compared to other neighborhoods in San Diego such as La Jolla, which has a predominantly white and middle/high-income population (Census).

As seen in Figure 9, the neighborhood of Southcrest has been historically redlined. Historically marginalized racial and ethnic communities, including Hispanic/Latinx populations, are more likely to live in areas with less tree canopy cover, less green space, and more impervious surfaces. These factors can exacerbate the urban heat island effect, leading to higher temperatures in these communities and increasing the risk of heat-related illness and mortality(Brouwer, 2019). Race and ethnicity can also affect the ability of individuals and communities to cope with extreme heat. Factors such as poverty(of which ~60 - 85% of Southcrest faces as seen in Figure 8), limited access to transportation, and lack of social networks can hinder the ability of people in vulnerable communities to access cooling resources or to receive assistance during extreme heat events. Further, different socioeconomic and racial groups often face unequal exposure to heat. On average, the poorest 10% of neighborhoods in an urban region were 4 °F hotter than the wealthiest 10% on both extreme heat days and average summer days. The difference was as high as 6–7 °F in California metro areas (Dialesandro et. al., 2021).

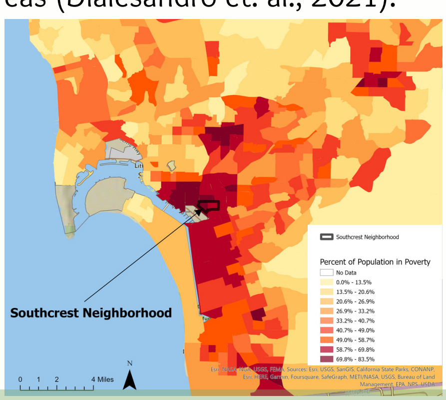

Figure 8. Poverty Rates in San Diego. ESRI data from CalEnviroScreen.Created by Ryan Burke 2/16/23.

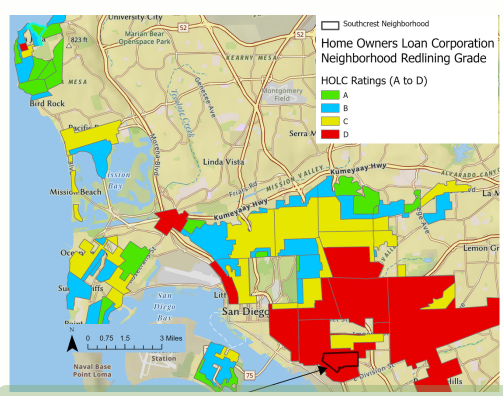

Figure 9. Historic Redlining in Southcrest. Data from ESRI HOLC Dataset.Created by Ryan Burke 2/27/23.

Overall, these studies suggest that race and ethnicity can lead to high heat vulnerability through a combination of environmental, social, and economic factors. By addressing these underlying factors, it may be possible to reduce heat vulnerability and improve health outcomes for historically marginalized communities such as Southcrest. By understanding the reasons why Southcrest is more vulnerable to heat, efforts can be made to address these challenges, such as increasing green spaces and providing resources to help vulnerable populations stay cool during the heat.

Benefits of Urban Reforestation

Environmental Benefits:

Planting trees in urban environments can lower temperatures in these areas in addition to other ecosystem services by reducing the UHI effect through shading buildings, sidewalks, and streets. Data from the United Kingdom shows that a 10% increase in tree canopy cover may result in a 5-7°F decrease in ambient temperature (Elmqvist, 2015). Similarly, an analysis of 94 urban areas around the world indicates that trees have a significant impact on the temperature, and are responsible for, on average, nearly 3.5°F of cooling in a city. Trees incorporated into the built environment can reduce a city's temperature by 16°F(Zawadzka, 2021).

Additionally, the roots provided by urban reforestation prevent erosion and improve soil capabilities by creating micropores that facilitate deep water infiltration(Czaja, 2020). Not only do these trees improve soil health, but they also prevent water runoff and act as natural barriers to flooding. Water runoff is a serious issue in the city environment, as runoff can increase exposure to pollution and cause property damage(Braden et.al., 2004). Furthermore, trees can help to prevent damage to homes and roads in case of heavy rains(Berland et.al., 2017). In an experiment carried out in Great Britain, trees planted reduced surface runoff by up to 60% when compared to an asphalt surface(Berland et.al., 2017).

Trees are also valuable via phytoremediation as they can remove heavy metals and other contaminants from the environment(French et. al., 2006). Further, trees can improve air quality by removing air pollutants, such as carbon dioxide and particulates, and act as carbon sinks which can have a positive impact on the health of homeowners and their families(Elmqvist, 2015). A tree planted in Los Angeles avoids the combustion of 18 kg of carbon annually, even though it sequesters only 4.5–11 kg(as it would if growing in a forest). In this sense, one shade tree in Los Angeles is equivalent to three to five forest trees(Akbari, 2002). The evaporation of water from the leaves of trees, known as transpiration, can also cool the air. Lastly, trees can provide habitat for wildlife, which can improve biodiversity in urban areas. By reducing the UHI effect and providing other environmental benefits, trees can help to make urban areas more livable and sustainable for residents.

Benefits of Urban Reforestation

Economic Benefits:

According to the U.S. Deptartment of Energy, the average residential electricity rate in San Diego County, CA is 36 ¢/kWh, which is 28% higher than the average electricity rate in California of 28.38 ¢/kWh. The average residential electricity rate in San Diego County, CA is 60% higher than the national average rate of 23¢/kWh. Also according to the Department of Energy, it takes 1% of your electric bill to cool 1°F. One study finds that a setpoint change from 71.2°F to 77°°F in buildings can result in a 29% cooling reduction in the energy bill (Akbari, 2009). Thus if one can achieve a 4.5°F of cooling(note: this is not the same as mathematics done by converting raw temperature) by increasing tree canopy by 32%, it will yield in a 29% decrease in an electric bill.

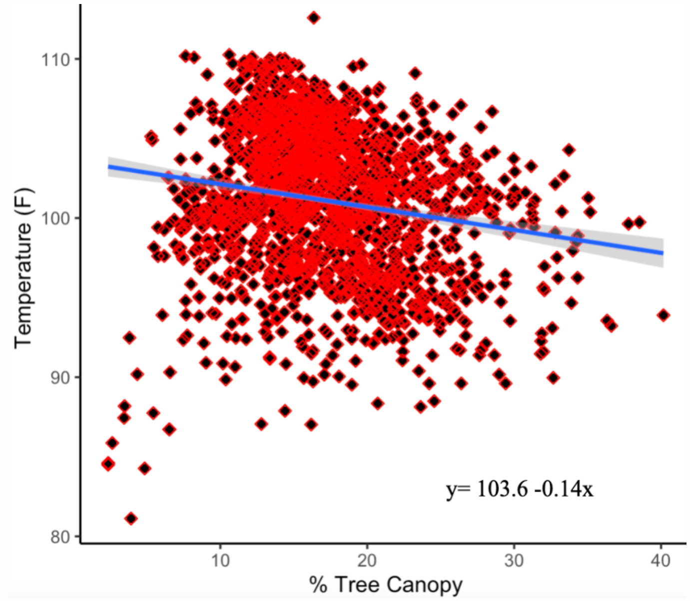

Figure 10: Temperature vs. Tree Canopy in San Diego. P value < 0.001. We found that a 1% increase in tree canopy led to a decrease in temperature of .14°F. R-value = .029. Regression ran by contributors with the assistance of John Dialesandro.

Figure 10 demonstrates a linear regression which was run because the data of temperature and percentage of tree canopy met the assumptions of normality and equal variance. The predictor variable was the percentage of tree canopy and the response variable was temperature. We tested for spatial autocorrelation using the Moran's I metric and found there was no spatial autocorrelation. Our P value was less than 0.001, marking there was a significant influence of tree canopy on temperature. We found that a 1% increase in tree canopy led to a decrease in temperature of .14°F. Our R-value was .029 indicating a significant factor, but there were other confounding variables such as impervious surfaces, income, demographics, etc for each 1% increase in tree canopy, we can reasonably expect a .14°F decrease in temperature. Even a modest 5% increase in tree canopy could cut electric bills by over $20 for every 1,000kWh used.

Trees play a role in energy savings by providing shade, effectively reducing the amount of direct sunlight as well as incident solar radiation(the radiant solar energy that hits the earth's surface) thereby reducing the amount of heat absorbed by buildings, therefore reducing the need for air conditioning and thus cooling costs(Simpson, 2002). This can be particularly beneficial for low-income homeowners who may not have the financial resources to purchase expensive energy-saving technologies. The savings associated with urban trees reducing building air-conditioning demand vary by climate region but can be up to $200 per tree(Akbari, 2002). These reductions only account for the direct reduction in the net cooling and heating-energy use of buildings. Once the impact of community cooling is included, these savings are increased by at least 25%(Akbari, 2002). Similarly, in winter, trees can block wind, which can reduce heating costs during the winter(Simpson, 2002). Lastly, while gray infrastructure depreciates over time, trees appreciate in value as they mature(Aguilera, 2021). Therefore, an investment in trees can make economic sense. The presence of shade trees can reduce the rate of aging of road and pavement surfaces(McPherson et.al., 2005), influence shoppers to visit a shopping area(Pandit, 2010), and increase the selling price of a home(Aguilera, 2021). On average, street trees add $8,870 to the sales price of houses in Portland. (Donovan et. al., 2010). As long as trees do not block the view of an office building, quality landscaping with properly maintained trees can increase rental rates(Aguilera, 2021). Trees can increase property values by improving the aesthetics of a neighborhood and making homes more attractive to potential buyers, develop the local economy, and support tourism(Nesbitt et. al., 2017). In the United States alone, it is estimated that trees provide $18.3 billion in annual value due to air pollution removal, reduced building energy use, carbon sequestration, and avoided pollutant emissions(Nowak et.al., 2018).

One economically motivated concern for residents of Southcrest is the amount of water a tree might need and, thus, cost. According to the City of San Diego's Public Utilities Department, monthly water billing rates, as of January 2023, for a typical single-family domestic customer are:

- 0 - 4 HCF used are billed at $5.550 per HCF.
- 5 - 12 HCF used are billed at $6.217 per HCF.
- 13 - 18 HCF used are billed at $8.881 per HCF.
- Each HCF used after the initial 18 HCF is billed at $12.488 per HCF.
- Each HCF equals 748.05 gallons.

According to the San Diego Water Authority Board, the average person used 134 gallons per day in 2021. Given that there are approximately 30 days in a month, the average person would use 4,020 gallons of water a month. Further, according to 2020 Census data, the average household size in Southcrest is 4.14, and the average family size is 4.37. Therefore, the average household water use is (4020gal/mo*4.14avg household size =)16,642.8 gallons of water per month. Such usage would put the average household in Southcrest in the (16,642.8gal/mo/(1HCF = 748.05)=)>18HCF range. Thus, 1 HCF = $12.488. In order to determine how much one gallon of water costs, we can substitute the variables, cross-multiply, and solve for x:

x = cost of 1 gal of water in Southcrest, San Diego

substitute: 1 HCF = $12.488; 1HCF = 748.05 gal

cross multiply: $12.488/x = 748.05 gal / 1 gal >>> 748.05 gal x = $12.488/gal

solve for x: x = ($12.488/gal)/(748.05/gal) = $.01669407

Given that Groundwork San Diego, Chollas Creek, is only offering drought-resistant trees, which on average require 15 gallons per week(Atlas Tree), and there are 52 weeks in a year, the yearly cost of watering a tree is ((15 gal)*(52)($.01669407)) = $13.02. Note that this calculation omits the monthly base meter fee of $27.77 as residents will pay this amount regardless of whether they are watering a tree.

Benefits of Urban Reforestation

Cost Benefit Analysis:

San Diego residents spend, on average, $2,808 on their energy bills annually (EnergySage). Based on our previous linear regression analysis, where a 32% increase in tree canopy can result in a 4.5 °F decrease in temperature, such will result in a 29% decrease in the electric bill (Hoyt, 2015). A 29% decrease in energy bills could save residents $814.32 annually. Given that the median lot size in Southcrest is 8,353.9 sq ft and the average area of tree options provided by Tree San Diego is 2767.83 sq ft, an additional one to two mature trees planted on a property in Southcreset would equate to a ~32% increase in tree canopy. Considering the cost of watering one of the drought-resistant trees offered by Groundwork USA at $13.02, adding one to two trees to a property in Southcrest could return a **net benefit of $788.28** to the homeowner through a decreased energy bill.

Health/Social Benefits:

One of the most pressing risks for human health associated with a changing climate are the increases in heat-related deaths, diseases, and infectious diseases. Recently, officials have reported increased heat-related hospital visits in the past 10 years (Hale, 2020). The increase in heat and heat-related health problems is especially prevalent in cities, where the Urban Heat Island Effect increases the impact of heat waves(Leal, 2018). Properly placed trees can mitigate temperatures in built environments by providing shade and actively cooling the air through evapotranspiration(EPA, 2008). Along with the benefits from the shade, the trees themselves remove pollutants from the air, reducing the amount people breathe which decreases the risk for respiratory problems(Hale, 2020). Air pollution is linked to bronchitic symptoms, intraocular pressure(leads to glaucoma), myocardial infarction(i.e. heart attacks), changes in autonomic and micro-vascular function, autism, blood pressure, cognitive development problems in children(slower processing speeds, behavioral problems, attention-deficit/hyperactivity disorder symptoms), blood mitochondrial abundance, heart failure, and mortality in humans(Pincetl et.al., 2013). It is estimated that urban trees remove 711,000 metric tons of air pollution each year(Helletsgruber et.al., 2020).

Beyond pollution removal, the presence of trees provides additional direct and indirect benefits to human health and wellness(Donovan, 2017). Trees and greener environments are strongly linked to reduced negative thoughts, reduced symptoms of depression, better-reported moods, and increased life satisfaction(Ebi et.al., 2021). Furthermore, residents of tree-lined communities report feeling healthier and have fewer cardio-metabolic conditions than their counterparts(Hale, 2020). The presence of trees and green spaces may encourage physical activity(Wang et.al., 2021), which is related to physical and mental health. Additionally, the very act of planting, caring for, and watering a tree can be a simple, repetitive task that can help to focus your attention, calm your mind, reduce stress, reinforce positive behaviors, and improve mental clarity for trees(Ebi et.al., 2021). Further, watering a tree and watching it grow is a rewarding experience that can improve self-esteem and confidence, and help to build a more positive outlook on life. Therefore, trees not only help to improve your overall well-being and quality of life, but they make communities more livable. Along with reducing the effects of the urban heat index, an increase in tree canopy can protect the overall UV exposure for people in the area which decreases the risk of skin cancer developing(Moreno et.al., 2015).

Additionally, tree cover is strongly linked to student academic performance (Kuo et al., 2018; Kweon et.al., 2017; Matsuoka, 2010). In one study, views of trees and shrubs at schools, as opposed to grass, were strongly related to future education plans and graduation rates (Matsuoka, 2010). Further, students who had views of trees and a green environment from their classrooms, as compared to those being in a room without windows or a room with a view of a brick wall, scored substantially higher on tests measuring attention, and they had a faster recovery from a stressful event(Li et.al., 2016). Students who learn in the presence of trees and nature have improved classroom engagement(Kuo et.al., 2018). Trees can promote a quality education, which has innumerable advantages for society. Therefore, children with views of trees are more likely to succeed in school(Turner-Skoff, 2019).

GIS Methods

Data Collection

- Neighborhood boundaries and Landuse for Southcrest via SanDag.gov.
- Poverty and demographics data from CalEnviroscreen.
- Redlining data from the HOLC dataset from ESRI
- Urban Heat Island(UHI) data from Landsat 9 OLI/ TRS
- Tree canopy data from Forest Observatory(NASA and ESA satellite imagery)

1

Data Processing

- All data processed in ArcGIS
- Buffer around Southcrest made to clip UHI and Tree Canopy raster data to the region of interest
- Poverty data queried to San Diego county and visualized using graduated colors with Jenks Natural Breaks
- Redlining Data shown in graduated colors of A-D rating
- Landuse processed to show churches and schools

2

Data Analysis

- Current tree canopy coverage shown visually as % per raster cell(10 meter).
- UHI shown visually as temperature per raster cell(30 meter) in °F.
- Poverty rates shown as a vector dataset with % of population in poverty for each census tract.
- Redlining data shown with a rating of A-D per neighborhood(A being best, D being the worst).

3

Data Visual

- Land use, UHI, and tree canopy data converted into integer raster datasets and used to create a weighted overlay showing the most feasible locations to plant 50 trees.
- Weights of 50%, 40%, and 10% were placed on UHI, land use, and tree canopy. Resulting in a representation of the hottest, least tree dense areas that fit our landuse criteria.

4

Data Layer/Name	Description	Datasource & Datatype	Source Access
Neighborhood Boundries	Data of neighborhood boundaries in San Diego. Used to show Southcrest neighborhood boundary.	San Diego County Police Department Shapefile	data.sandiego.gov
Tree Canopy Coverage	Shows the percent tree coverage of a given area. Used to represent tree canopy in Southcrest.	NASA and ESA Satellite Imagery Raster Data	forestobservatory.com
HOLC	Home Owners' Loan Corporation - Neighborhood Redlining data	ESRI Shapefile	arcgis.com
Urban Heat	Color coded intensity thermal radiation of California taken from an extreme heat event in 2022.	Landsat 9 OLI/ TRS Raster Data	developers.google.com
Landuse	Shows the specific designation for each individual census block. Used to determine where trees could be successfully planted.	City of San Diego Shapefile	https://data.sandiego.gov/datasets/zoning/
CalEnviroscreen	This shapefile layer illustrates 20 environmental and social metrics by tract. This data was used to show the spatial wealth inequality in San Diego.	California Office of Environmental Health Hazard Assesment	oehha.ca.gov

GIS Methods

ANSWERING RESEARCH QUESTION #1: WHERE ARE THE MOST ECONOMIC AND FEASIBLE LOCATIONS TO PLACE TREES IN SOUTHCREST?

In order to calculate and visually represent the most economical and feasible locations to plant trees in the Southcrest neighborhood, a suitability analysis was created through a weighted overlay process using the Land Surface Temperature, Tree Canopy, and Land Use Data. The data was converted to integer raster datasets to run a weighted overlay. The land surface temperature was assigned a weight of 50% to show the ideal locations for trees in the hottest areas. A weight of 40% was given to prioritized land use areas suggested by Margaret, a partner at Groundwork San Diego, Chollas Creek. These specified areas were designated as religious facilities and schools. Tree canopy received a weight of 10% to account for where trees already exist within the community. The algorithm returned a raster that had four values. One being areas of best fit and four being areas of least fit. To visualize where religious facilities and schools were located within the new suitable raster, multiple maps were created by zooming into these locations. The weighted overlay visually displays areas of Southcrest that would benefit most from the planting of trees. Further steps were taken to gather more information on the areas represented by the algorithmic analysis. Google Maps street view was used to walk through the neighborhoods to provide more information on where trees could actually be planted. The use of Google Maps provided an effective and simple method for visualizing planting locations based on specific criteria. The street address was also collected using Google Maps. Providing as much information to the community partner as possible was a focus of this step.

ANSWERING RESEARCH QUESTION #2: WHAT IS THE COST AND ENERGY SAVINGS ASSOCIATED WITH THE INSTALLATION OF TREES IN SOUTHCREST?

Many economic benefits come from increasing trees in a community. The focus of this economic analysis was to put a dollar value on the air condition cost reduction due to increased shade provided by additional trees in the Southcrest neighborhood. The flow of energy cost reduction starts by adding trees to the neighborhood. Trees reduce the Urban Heat Island effect, thus reducing the land surface temperature in the community. A regression was taken between land surface temperature and tree canopy density that indicated an inverse correlation. As tree canopy increases by 1%, land surface temperature decreases by 0.14%. This calls for fewer air conditioning needs, which lowers the monthly energy bill for the residents of Southcrest. According to a study published in the Building and Environment Journal, changing a building's internal thermostat from 22.2°C to 25°C could result in a 29% cooling reduction in energy bill (Hoyt, 2015). This means that a cooling effect of 2.5°C or 4.5°F in Southcrest could result in a reduction of energy bill costs. The regression was tested for spatial autocorrelation through Moran's I law. It can be said that there are no other relevant factors that would contribute to the reduction in outside thermal temperature other than tree canopy density. Besides the regression analysis of these two factors, data was collected from the San Diego Water Authority Board, the City of San Diego's Public Utilities Department, and the US Census to determine the cost-benefit analysis of additional trees in the Southcrest community. The land use dataset used in the suitability analysis was queried to represent single-family detached and single-family multiple-unit lots. Using this queried data, a statistical distribution was shown to illustrate the median area for every lot in Southcrest. The median lot size for single-family homes in Soutchcrest is 8,353.9 square ft. The tree width data from Tree San Diego was given as a measurement from end to end of the tree's branches, so the tree canopy area was assumed using the area of a circle, $A = \pi(d/2)^2$. The average area of the tree canopy among the trees provided was 2767.83 sq ft. Using the average tree canopy area and median lot size in Southcrest, the percentage of the lot size that a tree can cover can be found. Planting one mature tree on average would fulfill the 32% increase in the tree canopy that is required to see a 29% decrease in cooling energy bills. Therefore, adding one to two additional trees to a given property in Southcrest could reduce the occupant's electricity bill by $814.32, with the net benefits considering the cost of watering two trees, at $13.02 each, adding up to $788.28 saved annually.

ANSWERING RESEARCH QUESTION #3: WHAT IS THE HEAT/SOCIAL VULNERABILITY OF SOUTHCREST RESIDENTS COMPARED TO LA JOLLA?

A dataset containing the tree canopy percentages and land surface temperature data for each census tract in San Diego was used and filtered to show only La Jolla and Southcrest. The La Jolla neighborhood was chosen because of the large income gap and differences in demographics between La Jolla and Southcrest. The filtering process required all of the data point values within La Jolla and all of the data point values within Southcrest to be combined into a separate attribute table. With the filtered data, averages of both cities' tree canopy coverage and temperature were calculated. These averages were visualized and compared using bar graphs. This process was the same for finding the difference between the average urban surface temperatures for each city. The result of these GIS analytical processes were the maps and bar charts shown in figures 5 and 3.

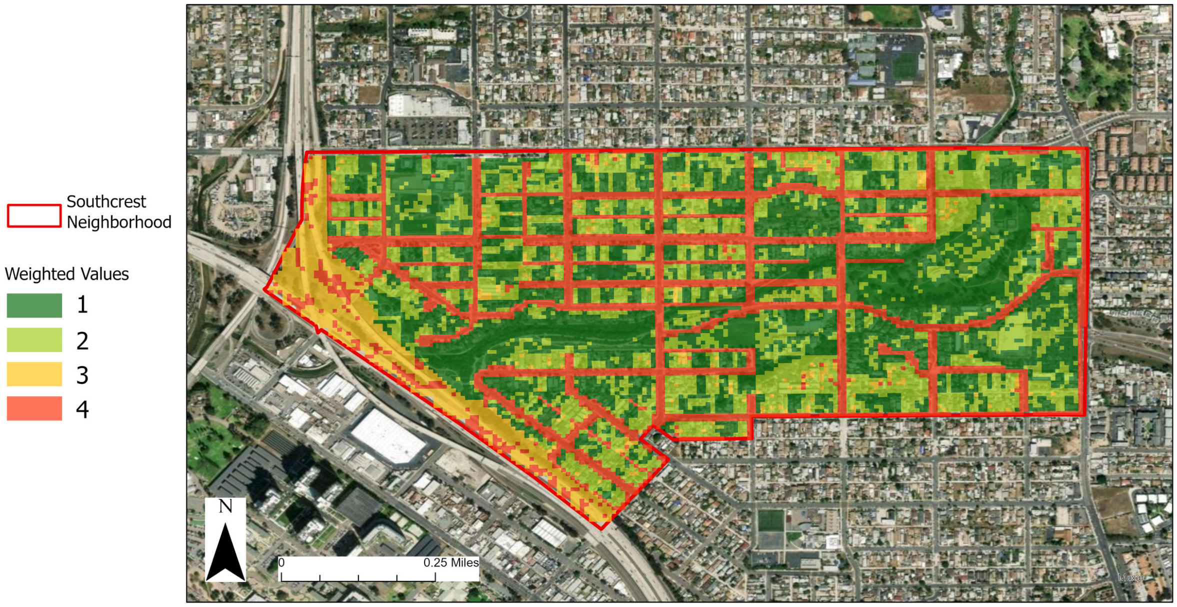

Figure 11. Suitability Analysis of Southcrest Neighborhood. Data from CalEPA, Landsat 9 OLI/ TRS, NASA and ESA Satellite Imagery. Created by Billy Georgenes 3/20/23

A weighted overlay was used to classify and visualize the locations in Southcrest that would have the highest amount of benefit from newly planted trees. This is shown in Figure 10. Four classes were used with dark green representing areas with the most benefit and suitability and red representing areas with the least. It is visually noticeable that the red values on this map are mostly representing roads and other paved surfaces that are already not possible locations to plant trees. The dark green values are fairly spread out throughout the neighborhood, with some areas having higher concentrations. The total area within Southcrest is not that large but there are certain areas with contrasting amounts of tree canopy coverage and heat, as seen in Figure 2 and Figure 3. This data is some of what was used to make the suitability analysis in Figure 11.

This suitability analysis can be used as a tool to see if certain areas in Southcrest are beneficial locations to plant trees. Deciding where to plant the trees solely based on this map is not possible as almost all of the land is occupied in some form. Instead, locations were chosen based on how likely the owners of the land may be to accept trees. These locations were then analyzed further using the suitability analysis to assess the amount of benefit that would come from planting trees. The foundation that Groundwork San Diego - Chollas Creek has created within this area and their experience with the local community, can be used alongside this suitability analysis when identifying and proposing a new tree planting location. Identifying a location and referencing it against the suitability analysis can provide a quick insight into how suitable that location is for planting trees. Margaret, a community partner, suggested a few religious facilities in Southcrest to look into, as they are more likely to accept trees than other land use areas.

Three religious facilities were located in Southcrest and highlighted on the weighted overlay to examine the ranking of their areas. Almost all of the area within the grounds of the religious facilities has values in the dark green and light green classes. Planting trees in these areas will provide some of the best economical, environmental, and health benefits for Southcrest. Knowing these areas are suitable in terms of overall benefit, and are potentially willing to accept trees, the next step would be to consult the owners of the property about the specifics that would go in to having the trees planted

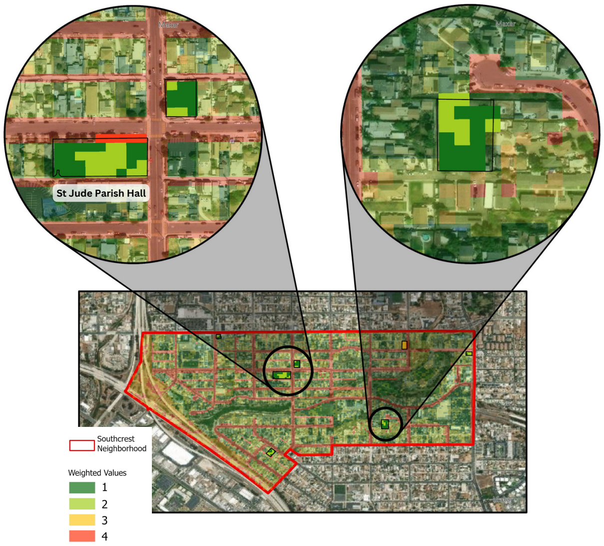

Figure 12. Religious Facilities - Suitability Analysis. Data from CalEPA, Landsat 9 OLI/ TRS, NASA and ESA Satellite Imagery. Created by Billy Georgenes 3/20/23

Finding actual land within these locations that has adequate soil and enough space to plant a tree has proven to be tough. Google Street View was used to obtain a ground level perspective of the highlighted areas. Looking at St Jude Parish Hall in Figure 13, we can see that most of the land that has not been built on is either paved or is already occupied by trees or plants. Some land by the front of the building (highlighted) looks to be mulch with small plants. Trees could potentially be planted here depending on the approval of St Jude Parish Hall. This area already has an irrigation system in place and is most likely not available and/or big enough to plant trees. Some or all of these plants could be removed and replaced with trees. The current plants provide little to no shade which could be improved with the addition of trees.

Figure 13. St Jude Parish Hall, Southcrest. Photo from Google Street View. Created by Billy Georgenes 3/20/23

Research Gaps

Impervious Surfaces and the Albedo Effect:

The relationship between tree canopy coverage and impervious surface area has a significant impact on the day and nighttime land surface temperatures(LST). The urban heat island effect has been exacerbated by a reduction of greenspaces in favor of increasing impervious surfaces such as parking lots, shopping centers, and other infrastructure. While tree canopies greatly reduce daytime LST, increasing canopy coverage would have a minimal effect on nighttime LST. Impervious surfaces absorb and retain heat, causing a substantial increase of nighttime LST. By increasing greenspace area and reducing impervious surface area, a decrease in both daytime and nighttime LST would occur(Ziter, 2019). Given that the research for this study was conducted over a period of ten weeks, the focus was primarily on determining suitability for planting new trees rather than decreasing impervious surface area. While a reduction in impervious surfaces would have increased the suitability for planting new trees in Southcrest, the time constraints for this project did not allow for such additional research to occur.

The albedo effect is the phenomenon that occurs when sunlight reaches the earth's surface; some surfaces, such as ice and snow, are very reflective and possess the ability to return much of the sunlight back into the atmosphere. Impervious surfaces such as asphalt, pavement, and other built up structures are not able to reflect light back into the atmosphere, instead absorbing it and increasing LST. Studies have shown that there is a negative relationship between albedo and LST. Regions with high albedo surfaces will experience lower temperatures during both the daytime and nighttime, while regions with an abundance of low albedo surfaces have been known to increase daytime and nighttime temperatures(Andres-Anaya, 2021).

Green Roofs:

In urban areas such as Southcrest, the majority of the ground area is covered by concrete and other impervious or semi-impervious surfaces. This leaves little to no space for planting trees on the ground level, prompting the use of alternative methods. One of these methods is green roofs when trees and other greenery are planted on the roofs of buildings in order to promote photosynthesis, remove particulate matter (PM) from the air, and reduce LST(Sierra-Vargas, 2012). Rooftops comprise a large portion of impervious surfaces in urban areas, creating a promising opportunity to increase the prevalence of high albedo surfaces by investing in green roofs. According to a study carried out in mid-Manhattan, 2,000 square meters of green roofs have the ability to remove up to 4,000 kilograms of PM(Sierra-Vargas, 2012). However, the preeminent focus of this study is to determine potentially suitable locations to plant trees in an urban reforestation attempt, and the environmental benefits of tree planting extend beyond simply improving air quality. Due to the focal point and time constraints of this study, additional research on green roofs as an accessory to urban reforestation was not feasible.

Conclusion

Recommendation

Below are our main recommendations for those involved in increasing the presence of trees in Southcrest. Using our suitability analysis and other map assets, one could communicate with city planners, the city council, or other community organizations to encourage financial and political support behind the Climate Safe Neighborhoods Initiative. Using the suitability analysis as a guide, one could also reach out to businesses, households, schools, churches, etc., about the option to have trees installed for free on their property. When leading the outreach process, one could use our calculated estimate for annual savings through energy cost reduction as a talking point. **Adding one to two trees on a property in Southcrest could save the occupant $788.28 annually; this includes the cost of watering the tree.** A more in-depth cost-benefit analysis could be done on adding trees into the community. For example, if the price of energy is forecasted to increase, the savings from one to two trees would be more than our estimate. Also, other factors such as lifespan and years until total growth were excluded from our analysis which would reduce the savings per tree. While assumptions were made, our economic analysis still shows an important estimation of tree canopy's potential to lower energy costs. The overall economic, social, health, and environmental benefits of planting trees in Southcrest are abundantly clear throughout our literature review. Our project could guide and inform potential stakeholders about the importance of trees in reducing the urban heat in Southcrest, San Diego.

Acknowledgements

This project would not have been possible without the guidance and support of our community partner, Margaret Brooke, at Groundwork San Diego, Chollas Creek. She helped answer questions and provided us with her subject matter expertise. Our team is highly grateful to our project advisor and professor Jake Dialesandroand. We could not have done this project without learning from such a great teacher!

REFERENCES

Aguilera, S. M. (2021). Prioritizing Tree Planting in Shade-Deprived Urban Areas as a Response to Climate Change. Hastings Env't LJ, 27, 101.

Akbari, H. (2002). Shade trees reduce building energy use and CO2 emissions from power plants. Environmental pollution, 116, S119-S126.

Akbari, H. (2009). Cooling our Communities. A Guidebook on Tree Planting and Light-Colored Surfacing. Lawrence Berkeley National Laboratory.

Andres-Anaya, P., Sánchez-Aparicio, M., del Pozo, S., & Lagüela, S. (2021). Correlation of Land Surface Temperature with IR Albedo for the Analysis of Urban Heat Island. Engineering Proceedings, 8(1), 9.

Atlas Tree. “Top 10 Drought Tolerant Trees for California Homeowners.” Atlas Tree, 25 Aug. 2022, https://www.atlas-tree.com/drought-tolerant-trees-for California.

Berland, A., Shiflett, S. A., Shuster, W. D., Garmestani, A. S., Goddard, H. C., Herrmann, D. L., & Hopton, M. E. (2017). The role of trees in urban stormwater management. Landscape and urban planning, 162, 167-177.

Braden, John B., and Stuart F. Johnston. "Urbanization and runoff: Implications for water management." Journal of Water Resources Planning and Management 130.4 (2004): 272-281.

Chamberlain, M. H. (2022). Heat Resilience Planning in San Diego: Local Plans, Barriers, and Tools to Facilitate Strategy Implementation.

Brouwer, Roy L., et al. "Racial/Ethnic Disparities in Heat-Related Mortality in Texas." American Journal of Public Health, vol. 109, no. 8, Aug. 2019, pp. 1112-1118.

Brune, M. (2016). Urban trees under climate change: potential impacts of dry spells and heat waves in three German regions in the 2050s (Doctoral dissertation, Climate Service Center Germany (GERICS)).

Dialesandro, J., Brazil, N., Wheeler, S., & Abunnasr, Y. (2021). Dimensions of thermal inequity: neighborhood social demographics and urban heat in the Southwestern US. International journal of environmental research and public health, 18(3), 941

Donovan, Geoffrey H. "Urban trees and human health and well-being." International Journal of Environmental Research and Public Health 14.8 (2017): 863.

Donovan, G. H., & Butry, D. T. (2010). Trees in the city: Valuing street trees in Portland, Oregon. Landscape and urban planning, 94(2), 77-83.

Ebi, K. L., Capon, A., Berry, P., Broderick, C., de Dear, R., Havenith, G., ... & Jay, O. (2021). Hot weather and heat extremes: health risks. The Lancet, 398(10301), 698-708.

Elmqvist, T., Setälä, H., Handel, S. N., van der Ploeg, S., Aronson, J., Blignaut, J. N., ... & de Groot, R. (2015). Benefits of restoring ecosystem services in urban areas. Current opinion in environmental sustainability, 14, 101-108

French, Katherine E., et al. "Phytoremediation of polycyclic aromatic hydrocarbons in urban stormwater runoff using an urban tree plantation." Environmental Science & Technology 40.23 (2006): 7190-7196.

Hale, M. (2020). Green Space as a Heat Wave Adaptation Strategy: A Health Impact Assessment for San Diego County.

Helletsgruber, C., Gillner, S., Gulyás, Á., Junker, R. R., Tanács, E., & Hof, A. (2020). Identifying tree traits for cooling urban heat islands—a cross-city empirical analysis. Forests, 11(10), 1064.

REFERENCES

Hoyt, T.; Arens, E.; Zhang, H. Extending air temperature setpoints: Simulated energy savings and design considerations for new and retrofit buildings. Build. Environ. 2015, 88, 89–96.

IPCC. https://www.ipcc.ch/sr15/

Khandekar, Madhav L. "Climate Change and Extreme Weather Events: Implications for Insurance, Energy, and Agriculture Sectors." Natural Hazards 36.1-2 (2005): 193-208.

Ko, Y., Lee, J. H., McPherson, E. G., & Roman, L. A. (2015). Long-term monitoring of Sacramento Shade program trees: Tree survival, growth and energy-saving performance. Landscape and Urban Planning, 143, 183-191.

Kuo, Ming, Matthew H. E. M. Browning, and William C. Sullivan, et al. "Do Lessons in Nature Boost Subsequent Classroom Engagement? Refueling Students in Flight." Frontiers in Psychology, vol. 9, no. 73, 2018, doi: 10.3389/fpsyg.2018.00073.\

Kweon, Byoung-Suk, Christopher K. Ellis, Sang-Mook Lee, and Kathryn H. Jacobs. "Trees, urban density and health in the United States." Landscape and Urban Planning 102.3 (2011): 202-214.

Li, Dian, and William C. Sullivan. "Impact of views to school landscapes on recovery from stress and mental fatigue." Landscape and Urban Planning 148 (2016): 149-158.

Leal Filho, W., Icaza, L. E., Neht, A., Klavins, M., & Morgan, E. A. (2018). Coping with the impacts of urban heat islands. A literature based study on understanding urban heat vulnerability and the need for resilience in cities in a global climate change context. Journal of Cleaner Production, 171, 1140-1149.

Matsuoka, R. H. "Student performance and high school landscapes: Examining the links." Landscape and Urban Planning 97.4 (2010): 273-282.

McPherson, E. Gregory, and Jana B. Muchnick. "Effects of street tree shade on asphalt concrete pavement performance." Journal of Arboriculture 31.6 (2005): 303-310.

McPherson, E. Gregory, et al. "The Urban Forest: Cultivating Green Infrastructure for People and the Environment." International Journal of Environmental Research and Public Health, vol. 10, no. 8, Aug. 2013, pp. 3833-3852.

Moreno A, Tangenberg J, Hilton BN, Hilton JK. 2015. An Environmental Assessment of School Shade Tree Canopy and Implications for Sun Safety Policies: The Los Angeles Unified School District. ISPRS International Journal of Geo-Information ; ; 4(2):607-625. https://doi.org/10.3390/ijgi4020607

Nesbitt, Laura, Anne Hotte, Suzanne Barron, Rich Cowan, and Stephen R. J. Sheppard. "The Economic Value of Trees in British Columbia Communities." Trees and Forests 3 (2017): 1-15.

Nowak, David J., and Eric J. Greenfield. "Tree and forest effects on air quality and human health in the United States." Environmental Pollution 237 (2018): 407-414.

Nowak, David J., and Daniel E. Crane. "The Benefits and Costs of Urban Forests." Journal of Arboriculture, vol. 28, no. 3, May 2002, pp. 148-155.

Pandit, R., & Laband, D. N. (2010). Energy savings from tree shade. Ecological Economics, 69(6), 1324-1329.

REFERENCES

Pincetl, S., Gillespie, T., Pataki, D. E., Saatchi, S., & Saphores, J. D. (2013). Urban tree planting programs, function or fashion? Los Angeles and urban tree planting campaigns. GeoJournal, 78, 475-493.

Sierra-Vargas, M. P., & Teran, L. M. (2012). Air pollution: Impact and prevention. Respirology, 17(7), 1031-1038.

Simpson, J. R. (2002). Improved estimates of tree-shade effects on residential energy use. Energy and Buildings, 34(10), 1067-1076.

Turner-Skoff, J. B., & Cavender, N. (2019). The benefits of trees for livable and sustainable communities. Plants, People, Planet, 1(4), 323-335.

Union of Concerned Scientists. "Killer Heat in the United States: Climate Choices and the Future of Dangerously Hot Days." Union of Concerned Scientists, Aug. 2020, https://www.ucsusa.org/resources/killer-heat-united-states.

United States Census Bureau. (2020). 2020 Census of Population and Housing: United States: Summary Population and Housing Characteristics, 2020. U.S. Department of Commerce. https://www.census.gov/library/publications/2021/dec/2020-summary-population-and-housing-characteristics.html

U.S. Environmental Protection Agency. "Green Infrastructure." EPA, 2008, www.epa.gov/green-infrastructure/green-infrastructure.

Wang, X., Dallimer, M., Scott, C. E., Shi, W., & Gao, J. (2021). Tree species richness and diversity predicts the magnitude of urban heat island mitigation effects of greenspaces. Science of The Total Environment, 770, 145211.

Zawadzka, J. E., Harris, J. A., & Corstanje, R. (2021). Assessment of heat mitigation capacity of urban greenspaces with the use of InVEST urban cooling model, verified with day-time land surface temperature data. Landscape and Urban Planning, 214, 104163.

Ziter, C. D., Pedersen, E. J., Kucharik, C. J., & Turner, M. G. (2019). Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. Proceedings of the National Academy of Sciences, 116(15), 7575-7580.

Appendix

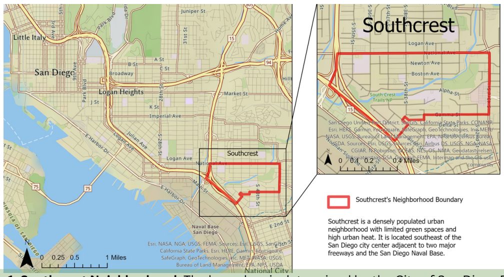

Figure 1. Southcrest Neighborhood. The boundary is determined by the City of San Diego Police department - https://data.sandiego.gov/datasets/pd-neighborhoods/. Created by Ryan Burke on 2/16/23.

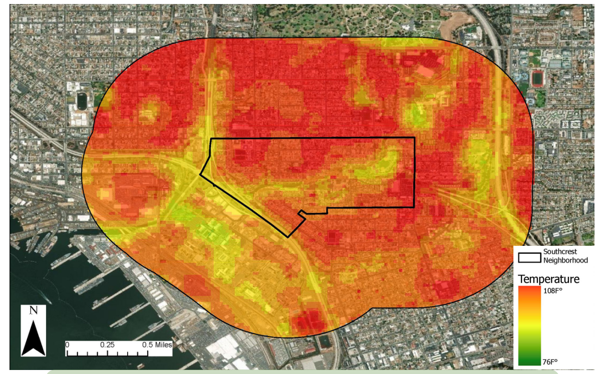

Figure 2. Urban Heat in Southcrest. Data from CalEPA. Created Billy Georgenes on 2/23/23.

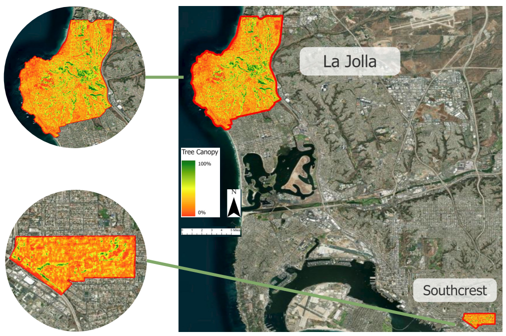

Figure 3. Tree Canopy locations and percentage in La Jolla and Southcrest. Data from NASA and ESA Satellite Imagery Raster Data. Created by Billy Georgenes 3/20/23

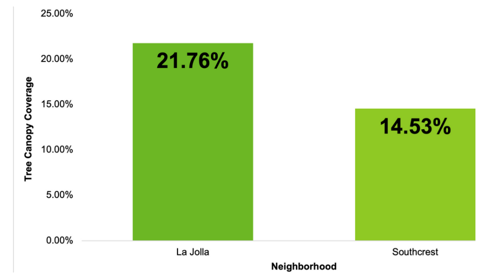

Figure 4. Average Tree Canopy Coverage in La Jolla and Southcrest.

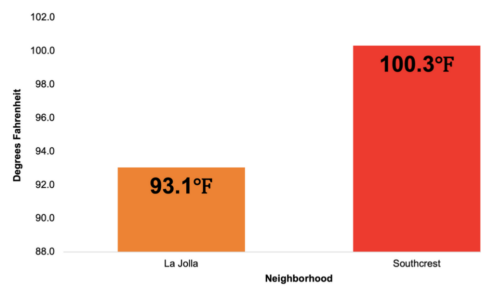

Figure 5. Average Temperature in La Jolla and Southcrest.

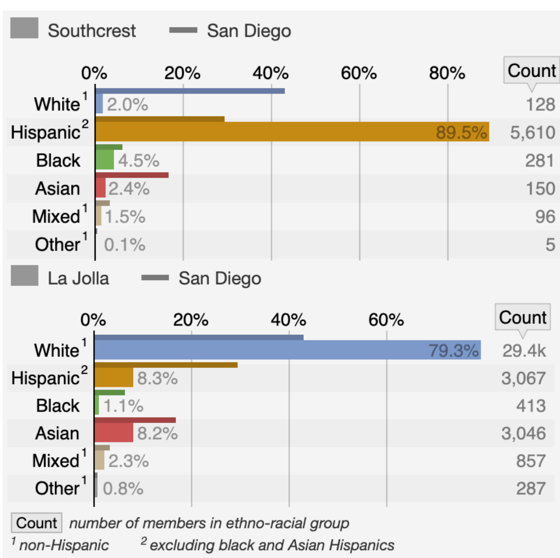

Figure 6. Race and Ethnicity: Southcrest & La Jolla Neighborhoods. Data from 2020 US Census Bureau. Data is the percentage of the total population. Created by Statistical Atlas.

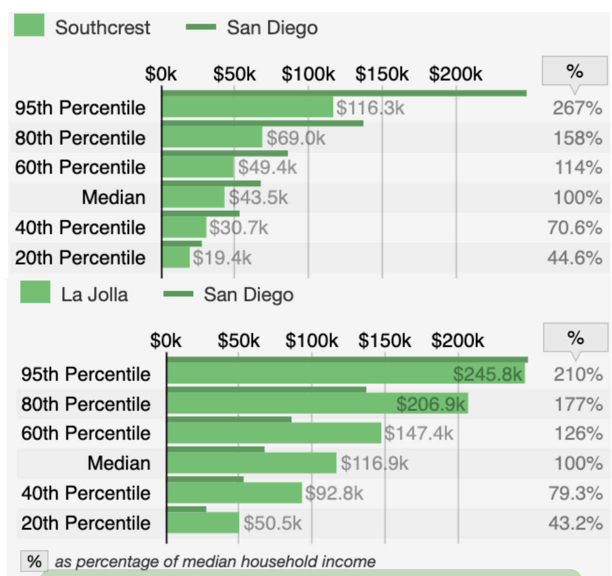

Figure 7. Household Income Percentiles: Southcrest & La Jolla Neighborhoods. Data from 2020 US Census Bureau. Data is the percentage of the total population. Created by Statistical Atlas.

Appendix

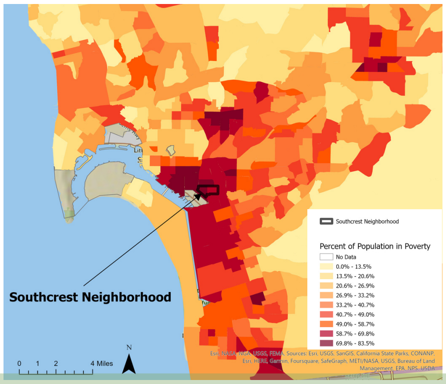

Figure 8. Poverty Rates in San Diego. ESRI data from CalEnviroScreen.Created by Ryan Burke 2/16/23.

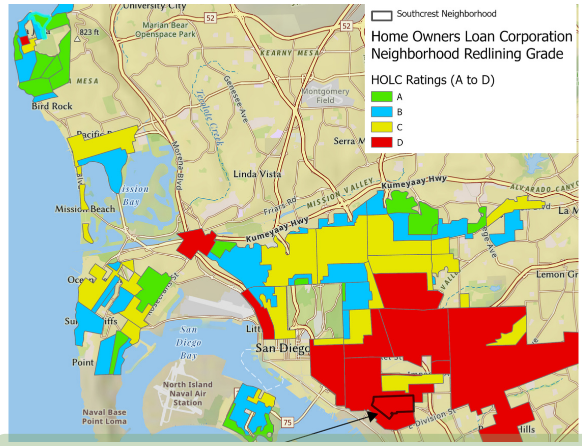

Figure 9. Historic Redlining in Southcrest. Data from ESRI HOLC Dataset.Created by Ryan Burke 2/27/23.

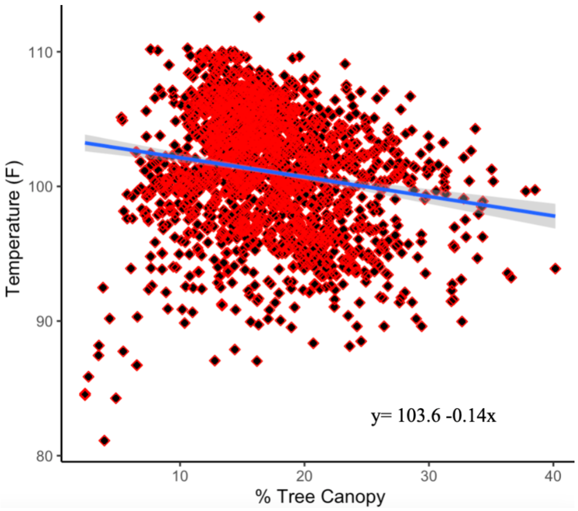

Figure 10: Temperature vs. Tree Canopy in San Diego. P value < 0.001. We found that a 1% increase in tree canopy led to a decrease in temperature of .14°F. R-value = .029. Regression ran by contributors with the assistance of John Dialesandro.

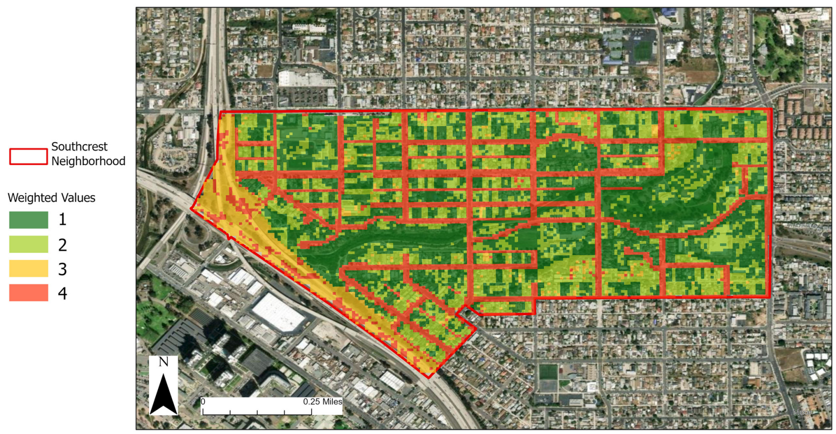

Figure 11. Suitability Analysis of Southcrest Neighborhood. Data from CalEPA, Landsat 9 OLI/ TRS, NASA and ESA Satellite Imagery. Created by Billy Georgenes 3/20/23

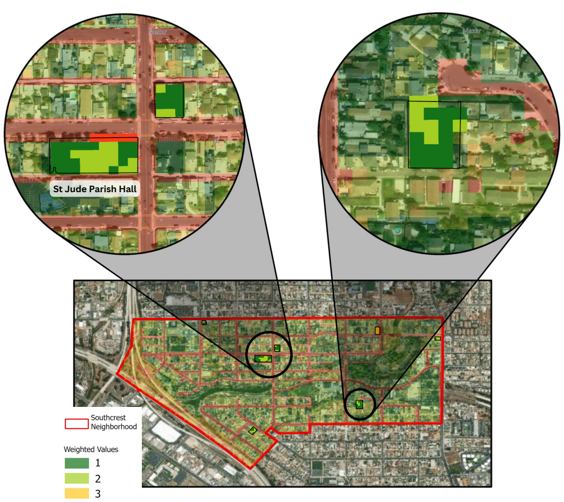

Figure 12. Religious Facilities - Suitability Analysis. Data from CalEPA, Landsat 9 OLI/ TRS, NASA and ESA Satellite Imagery. Created by Billy Georgenes 3/20/23

Figure 13. St Jude Parish Hall, Southcrest. Photo from Google Street View. Created by Billy Georgenes 3/20/23