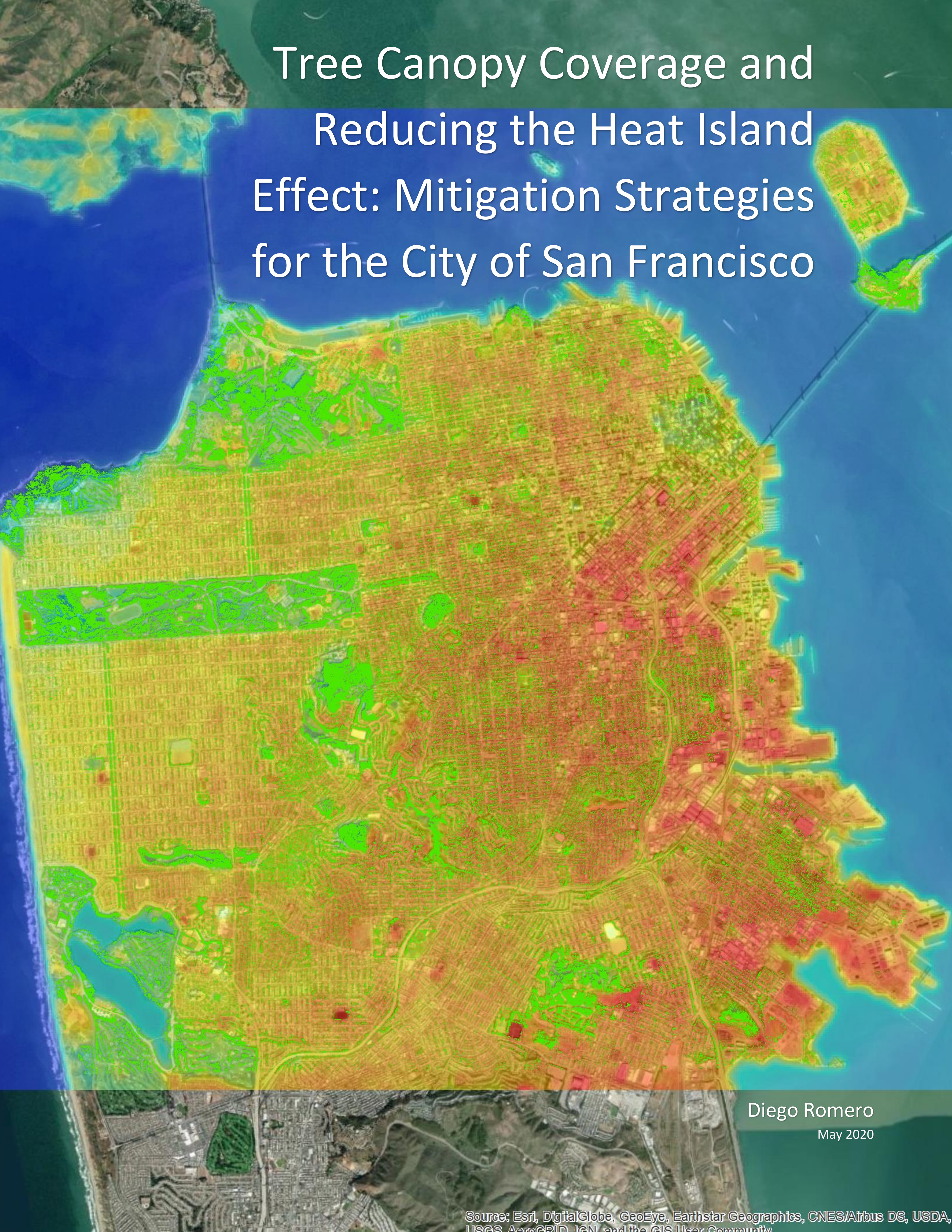
Tree Canopy Coverage and Reducing the Heat Island Effect: Mitigation Strategies for the City of San Francisco



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TREE CANOPY COVERAGE AND REDUCING THE HEAT ISLAND EFFECT: MITIGATION STRATEGIES FOR THE CITY OF SAN FRANCISCO

A Planning Report

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Executive Summary

The purpose of this report is to attempt to determine where new tree plantings can be facilitated in order to have the greatest impact on reducing the heat island effect within the City of San Francisco. While San Francisco may not be known as one of the warmest cities in the region, it will still be likely to see extreme temperature events in the future; for this reason it is important to help mitigate this by increasing tree canopy strategically. San Francisco has already begun implementing many programs to address climate change; thus, addressing heat islands would already be a portion of those holistic approaches. The core research question of the report is: Which neighborhoods in San Francisco are most devoid of trees when compared to the citywide average, and thus, are more strategically situated to dramatically reduce heat island effects?

To determine which neighborhoods could benefit the most from new tree plantings, a comparison was made between neighborhoods that experienced the highest temperatures during the summer months of 2019 and neighborhoods that had the least amount of tree canopy cover during the same period. This comparison identified the following four neighborhoods as having the least amount of tree canopy cover and experiencing the highest temperatures during the summer of 2019: South of Market, Mission, Bayview, and Nob Hill. Within each of these neighborhoods, recommendations were made of areas where tree plantings could be focused in order to have the greatest reduction of temperatures.

Existing City policies, as well as other cities' policies and procedures, were examined to catalog policies already in place and to identify policies that could be implemented in San Francisco to achieve the goal. These policies were then grouped into three alternatives, the first being he Cost-Effective Alternative which aims to increase tree canopy while taking costs into consideration. The Largest Impact Alternative aims to achieve greatest increases in tree canopy without worrying about budgetary constraints as much. The Balanced Approach Alternative aims to be the middle ground between the Cost-Effective Alternative and the Largest Impact Alternative. Out of these three alternatives that were proposed, the Balanced Approach alternative scored the best. This was to be expected because it was the alternative that offered

a middle ground between the other two and aimed to be the most realistic and easy to implement.

Chapter 1: The Impact of Urban Heat Islands and the Importance of Mitigation

1.1 Background

The City of San Francisco is located in the heart of the San Francisco Bay Area in Northern California. It is approximately 46 square miles and it has a population of 884,363.[1] San Francisco is a world-famous city that could be considered the soul of the region. It has long been a magnet for economic development, being the home to many tech companies, culture, tourism and educational institutions.[2] Due to its geographic location at the end of a peninsula, the City is connected to the majority of the Bay Area by two major bridges. The Golden Gate Bridge connects to Marin County in the north and the Bay Bridge connects to Oakland and the rest of the East Bay. To the south, San Mateo County is the only physical land connection to the City. Another distinctive fact about San Francisco is that it is one of the most compact cities in the state, which makes it unique when compared to many other American cities. Because much of the City has already been developed, it is one of the few cities where sprawl is not a major concern.[3]

It is difficult to imagine that this metropolitan city was once a landscape devoid of trees that consisted mostly of grassy hills and sand dunes.[4] Since the City's founding, the landscape has changed greatly; although it is no longer a landscape without trees, there is still a great potential to increase the number of trees around the City. For this reason, in 2014 the City implemented its Urban Forest Plan which aims to identify policies and strategies to create an expanded, healthy, and thriving street tree population for all of San Francisco.[5] One of the goals of the City's Urban Forest Plan was for the City to take responsibility for the maintenance of street trees, which until 2016 had largely been the responsibility of property owners. When Proposition E was passed in November 2016, this responsibility was shifted from property

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[1] Gladys Cox Hansen, San Francisco, August 30, 2019, https://www.britannica.com/place/San-Francisco-California (accessed September 13, 2019).
[2] City of San Francisco, San Francisco General Plan, June 27, 1996, https://generalplan.sfplanning.org/(accessed September 13, 2019).
[3] Ibid.
[4] City of San Francisco, "Urban Forest Plan," 2014.
[5] Ibid.

owners to the City. Even with all these efforts, San Francisco still has the smallest tree canopy measured by the amount of land covered by trees, when viewed from above, of any major city in the United States.[6]

1.2 Research Question and Hypothesis

This research examines the relationship between increasing tree canopy and lowering temperatures. As such, the primary question explored in this research is:

- Which neighborhoods in San Francisco are most devoid of trees when compared to the citywide average, and thus are more strategically situated to dramatically reduce heat island effects?

It is a safe assumption that there are several neighborhoods within the City of San Francisco that have low tree canopy coverage and higher land surface temperatures (LST) which could benefit from increased tree plantings to reduce LST. The hypothesis is that the Bayview, Mission, and the Financial District neighborhoods will be likely candidates to focus on for increased tree plantings.

Because San Francisco has a very temperate climate, the urban heat island effect may not be as significant of a concern when compared to other cities that experience much higher temperatures. Even though there are other cities within the San Francisco Bay Area that experience much higher temperatures and as a result experience much more severe heat islands. It is still important to mitigate San Francisco's heat islands because when there are extreme heat events, the City's residents might not be as equipped to handle such events. The City understands this and acknowledges that its urban tree canopy is inadequate and that it needs to be increased. A review of tree canopy coverage using aerial photography revealed that the areas that have the least number of trees tend to be the areas that have the most intense

[6] City of San Francisco, "Urban Forest Plan," 2014.

development, as measured by impervious land cover. This also causes these areas to retain the most heat due to all these impervious surfaces absorbing heat.[7]

1.3 Importance of Mitigating Urban Heat Islands

At one time or another, almost everyone has felt the effects of urban heat islands even if they do not realize what it is. For example, on a sunny day, the space located directly above asphalt will feel much hotter than an area of open space that has no paving; even the sidewalk right next to the asphalt will feel cooler because it will absorb less heat than the darker asphalt. This phenomenon is a very common occurrence within cities worldwide and the contributing factors are many and varied. One of the more logical arguments for this occurrence is that cities tend to have a significant amount of darker paved areas which absorb more heat.[8] Daytime temperatures within a city can be, on average, 1-6 degrees warmer than their rural counterparts, but at night temperatures can be as much as 22 degrees warmer because the heat is slowly radiated from the pavement throughout the night.[9]

One of the main reasons the urban heat island effect is a matter of great importance and deserves attention, is that it can lead to an increase in energy consumption and additional air pollution. For instance, in the summer months when temperatures tend to be at their highest, buildings will consume more energy in order to properly stay cool. According to the Environmental Protection Agency (EPA), the heat island effect alone can account for an increase of 5-10 percent in our energy demand.[10] Depending from what source that energy is produced, it may also increase the amount of pollution being released into the atmosphere, adding to the list of concerns.

As it is well known, atmospheric pollution can have dire consequences on the health of people. Consequently, another reason for concern is the health impact the urban heat island

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[7] CalEPA, *Understanding the Urban Heat Island Index,* n.d., https://calepa.ca.gov/climate/urban-heat-island-index-for-california/understanding-the-urban-heat-island-index/ (accessed September 13, 2019).
[8] CalEPA, *Understanding the Urban Heat Island Index,* n.d., https://calepa.ca.gov/climate/urban-heat-island-index-for-california/understanding-the-urban-heat-island-index/ (accessed September 13, 2019).
[9] Ibid.
[10] EPA, *Heat Island Impacts,* n.d., https://www.epa.gov/heat-islands/heat-island-impacts (accessed September 13, 2019).

effect can have on the community. We could even argue that the urban heat island effect can be a significant hazard to humans because the more energy we use to address it, the more we pollute the air, which in turn affects people's health and wellbeing. Furthermore, warmer temperatures can directly increase the rate at which ground level ozone or smog is produced.[11] Smog, in turn, can have a negative impact on those with respiratory problems. Moreover, sensitive populations such as children and the elderly are particularly at risk because heat islands can also intensify the effects of heat waves.[12] The Centers for Disease Control and Prevention (CDC) estimates that between 1979 and 2003 excessive heat exposure contributed to more deaths in the United States than from hurricanes, lightning, tornadoes, floods, and earthquakes combined.[13]

In 2006 California experienced a heat wave which highlighted San Francisco's specific vulnerabilities to extreme heat events.[14] Subsequently, the City, in a partnership with the CDC, developed a Heat Vulnerability Spatial Index which examined social vulnerability, as well as land surface temperature to understand urban variations of risk during potential extreme heat events. The findings of this study revealed that households with limited English communication skills were most at risk of death during an extreme heat event.[15] In an effort to address this, one of the adaptations the City is considering is the development of pilot projects in which cool pavements and cool roofs are installed on city-owned property and in locations with vulnerable populations.[16]

In addition to the above, there are several other strategies that the City can explore to help tackle the problem of the urban heat island effect. Most of these strategies directly work by limiting how much heat the built environment can absorb during the day. One such method

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[11] EPA, *Heat Island Impacts,* n.d., https://www.epa.gov/heat-islands/heat-island-impacts (accessed September 13, 2019).
[12] Ibid.
[13] Ibid.
[14] Cynthia Scully, San Francisco's climate and health program: Progress and lessons learned, City and County of San Francisco, Dept. of Public Health, October 2012, https://ww3.arb.ca.gov/cc/ab32publichealth/meetings/120512/san%20francisco%20climate%20health%20program%20progress%20lessons%20learned(scully).pdf (accessed September 13, 2019).
[15] Ibid.
[16] Ibid.

that could be considered to alleviate this problem is to increase the albedo of pavement and roofs so that more light is reflected.[17] This could be accomplished by something as simple as painting the roofs of buildings white or light colors, or by using materials that do not absorb as much heat. An indirect method that could reduce the intensity of urban heat islands, would be to lower the amount of emissions being released into the atmosphere, doing so would decrease the effects of climate change and global warming but this would need to be done on a much more significant scale in order to have an impact.[18]

A more natural method that cities can contemplate to reduce the heat island effect is to increase vegetation in targeted areas. This could be accomplished by having more unpaved open space, installing green roofs, increasing tree canopy cover, and increasing shade coverage.[19] Many of these actions not only reduce the heat island effect, but they also have added benefits such as improving air quality and, as a result, residents' health and quality of life. It is the intention of this report to help identify areas where increasing tree canopy would be beneficial for the City of San Francisco and for the people who live and work there.

Considering that one of the City's goals, according to their Urban Forest Plan, is to increase the number of street trees by planting 50 percent more trees by the year 2035,[20] increasing tree canopy will be the main focus of this report. Some models show that covering urban streets with 50 percent tree coverage and decreasing the amount of asphalt on the street by 10 percent could reduce air surface temperatures by 7.4 degrees Fahrenheit and road surface temperatures by as much as 27.7 degrees Fahrenheit.[21] One of the benefits of using

[17] Zahra Jandaghian, "The effects of increasing surface reflectivity on heat-related mortality in Greater Montreal Area, Canada," *Urban Climate*, 2018: 135-151.
[18] EPA, *Heat Island Impacts,* n.d., https://www.epa.gov/heat-islands/heat-island-impacts (accessed September 13, 2019).
[19] Hashem Akbari, "Three decades of urban heat islands and mitigation technologies research," *Energy and Buildings*, 2016: 834-842.
[20] City of San Francisco, "Urban Forest Plan," 2014.
[21] Christopher Loughner, "Roles of Urban Tree Canopy and Buildings in Urban Heat Island Effects: Parameterization and Preliminary Results," Journal of Applied Meteorology and Climatology, 2012: 1775–1793.

vegetation to cool temperatures, compared to other mitigations like cool pavements, is the secondary benefit of increasing the cooling effect from water and wind sources.[22]

Although it is true that San Francisco is more commonly known for its foggy and mild climate rather than high temperatures that could cause heat advisories, no one can deny the record-breaking temperatures the City has experienced in recent years. The average year-round high temperature for the City tends to be around 63.8 degrees Fahrenheit,[23] but in June of 2019 the City reached temperatures as high as 100 degrees. This was only the seventh time on record,[24] compared to the average high temperature in June which is 66 degrees. Unfortunately, as time goes on, climate change will make these types of events more frequent and more severe. For this reason, the sooner these concerns are addressed, the better prepared the City of San Francisco will be to reduce the negative impact of extreme heat events on its residents.

1.4 Report Overview

The rest of the report proceeds as follows:

- **Chapter 2** details some of the urban forest policies that are currently being implemented in San Francisco as well as policies in place in three different cities in California and in Chicago, Illinois.
- **Chapter 3** explores the current amount of tree canopy in San Francisco and looks at the average temperatures the city experiences. This chapter also outlines the methodology for this research.
- **Chapter 4** explores available tree planting policy tools that could be applied to the City of San Francisco.

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[22] Abbas Mohajerani, "The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete," *Journal of Environmental Management*, 2017: 522-538.

[23] U.S. Climate Data, Climate San Francisco – California, 2019, https://www.usclimatedata.com/climate/san-francisco/california/united-states/usca0987 (accessed September 13, 2019).

[24] Doyle Rice, "120 degrees in the shade?! Record-breaking, 'dangerous' heat wave bakes western U.S.," *USA Today*, June 11, 2019. https://www.usatoday.com/story/news/nation/2019/06/11/heat-wave-western-us-bakes-temperatures-soar-120-degrees/1419639001/ (accessed September 13, 2019).

- **Chapter 5** explores the implications of this study and provides final recommendations.

Chapter 2: A Review of Existing Policies Regarding Urban Tree Canopy and Urban Heat Islands

2.1 Introduction

While the concept of the urban heat island effect is not something new, many cities have yet to begin examining whether it is something that will cause concern. One would think that reducing the effects of urban heat islands would only be required in locations that already have problems with high temperatures. Unfortunately, the negative effects of climate change will continue to worsen and impact all of us. While many cities have not begun to examine heat islands, there are many actions these cities already have undertaken which will mitigate the adverse effects of heat islands, even if that was not their primary intent. One such action is increasing tree canopy, which many cities already do even when their main goal is not necessarily addressing the effects of heat islands.

Many studies are essentially in agreement that trees provide many potential benefits, especially when it comes to mitigating urban heat islands. If one were to think about it logically, it would make sense that trees can provide cooling benefits because of the shade they provide. Some studies have found that adding trees to an urban environment leads to a decrease in the surrounding temperatures, but in a couple of these studies it was found that the spatial configuration of trees could provide an even greater heat mitigation. According to Greene's 2018 study, which analyzed the impact of urban tree canopy structure on surface urban heat islands, larger unbroken patches of tree canopy appeared to provide additional mitigations to the average surface temperatures within Toronto.[25] Greene also states that while planting more trees locally will result in more trees at the city scale, which would also reduce temperatures, there are improved reductions and reduced costs by enhancing existing urban forest patches.[26] These findings were also supported by the 2017 study conducted by Zhou, which examined the effects of the spatial configuration of trees on urban heat mitigation. While Greene's study focused on comparing two spatial scales (local and city scale) within Toronto,

[25] Christopher S. Greene, "Beyond Fractional Coverage: A Multilevel Approach to Analyzing the Impact of Urban Tree Canopy Structure on Surface Urban Heat Islands," *Applied Geography*, 2018: 45-53.
[26] Ibid.

Zhou's study instead compared spatial configuration of trees between two different cities, Sacramento and Baltimore. Zhou's study found that in Baltimore the percentage of tree cover was more important than spatial configuration when predicting land surface temperature, but this was the opposite in Sacramento.[27] Average patch size of trees actually had positive effects on land surface temperature in Baltimore, but negative effects in Sacramento.[28] One would expect that Baltimore and Toronto would share more similarities because of their closer geographic proximity, but this does not seem to be the case. Both studies examined the spatial configuration of trees, but Zhou's study did not focus on the different scales within each city which could have changed the results.

Rahman's 2017 study, which examined tree canopy temperature differences and the cooling ability of trees grown in urban conditions, similarly found that tree shading reduces temperatures underneath the tree canopy.[29] By examining transpiration Rahman made the interesting finding that without any transpiration tree canopies would increase heat retention.

Bowler's 2010 study preformed a metadata analysis of 47 different case studies from around the world which investigated whether interventions, such as tree planting or the creation of parks or green roofs, affected the air temperature of the surrounding urban areas.[30] Bowler found that when it came to urban trees and forests, there was evidence that both clusters of trees and individual trees had lower temperatures when compared to locations in close proximity that had no trees.[31] Both Bowler and Rahman determined that tree canopy can reduce daytime temperatures. Bowler concludes that the value of adding trees will vary with the specific urban topography and geographic context, which is further substantiated by Zhou's and Greene's studies, which show that the same tree planting strategy may not be viable everywhere.

[27] Weiqi Zhou, "Effects of The Spatial Configuration of Trees on Urban Heat Mitigation: A Comparative Study," *Remote Sensing of Environment*, 2017: 1-12.
[28] Ibid.
[29] Mohammad A. Rahman, "Within Canopy Temperature Differences and Cooling Ability of *Tilia cordata* Trees Grown in Urban Conditions," *Building and Environment*, 2017: 118-128.
[30] Diana E. Bowler, "Urban Greening to Cool Towns and Cities: A Systematic Review of the Empirical Evidence," *Landscape and Urban Planning*, 2010: 147-155.
[31] Ibid.

While much of the literature agrees that adding trees to an urban area will reduce temperatures, the method by how this may be accomplished is more varied and complex. Also not all programs are implemented to increase trees because of the value they add to a community. For instance, Pincetl found that the tree program to plant one million trees in Los Angeles was started in order to distinguish Mayor Villaraigosa from his opponent as a green-oriented candidate.[32] The main finding from Pincetl's 2010 study was that the implementation of such a program in Los Angeles was complicated. Several factors were responsible, such as the number of organizations that were responsible for tree planting and maintenance, the funding came from multiple sources, acceptance varied by neighborhood as did tree canopy cover, and the availability of supply was limited.[33] In Pincetl's et al. 2013 study it was found that where tree cover was higher, air temperatures were significantly lower. The complexity of implementing this initiative, as mentioned in Pincetl's 2010 study, helps explain their findings that the Los Angeles Million-Tree Initiative does not have any plan for implementing its goals, because it plants opportunistically.[34] Pincetl et al. mentions that a problem with this initiative is that there is no monitoring program in place, which makes the exact number of trees planted and their survival rate unknown.[35] The researchers conclude that tree planting programs need to be implemented differently in different places, further supporting the findings previously mentioned in this section.

As mentioned in both of Pincetl's studies, cities around the world are beginning to increase tree canopy within their jurisdiction because of the multiple benefits that trees provide. Two studies argue that there are numerous aspects that should be considered when developing a new tree planting program. Petri's study determined that when microclimates were considered for the tree siting process in a neighborhood in Chicago, those trees would have a greater impact on surface and air temperatures.[36] Petri also concluded that tree

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[32] Stephanie Pincetl, "Implementing Municipal Tree Planting: Los Angeles Million-Tree Initiative," *Environmental Management*, 2010: 227–238.
[33] Ibid.
[34] Stephanie Pincetl, et al., "Urban Tree Planting Programs, Function or Fashion? Los Angeles and Urban Tree Planting Campaigns." *GeoJournal*, 2013: 475–493.
[35] Ibid.
[36] Aaron C. Petri, "Planning the Urban Forest: Adding Microclimate Simulation to the Planner's Toolkit," *Land Use Policy*, 2019: 104117.

plantings along impervious surfaces are of greater value than increasing coverage in parks.[37] This finding is further supported by Rahman's study which found that paving surfaces had a significant impact on the air temperature within tree shade.[38] In a meta-analysis performed by Gerrish it was revealed that there is significant income-based inequity when it comes to tree canopy coverage.[39] These findings are in line with what Pincetl's 2010 study determined, which is that low-income communities of color had the least canopy cover, and that tree canopy is strongly correlated with affluence.[40]

On top of the benefits that trees provide in reducing urban heat islands, there are many other additional benefits that trees may provide. Trees provide such benefits as energy savings, carbon sequestration, improved air quality, and storm-water management.[41] While these benefits tend to be the most touted when arguing for urban forests, trees have also been found to have a significant impact of public health. Residents of neighborhoods that saw increased greenery were found to exercise more, spend more time outdoors, have reduced stress levels, and improved health.[42]

San Francisco is already pursing a variety of programs to address climate change and as part of these programs the City will address heat islands, even if they are not explicitly mentioned in these programs. Many cities, including San Francisco, have already implemented, or are planning to implement policies to increase tree canopy coverage which will also help to mitigate urban heat islands. Section 2.2 examines specific policies the City of San Francisco has implemented, while Section 2.3 examines what actions other cities have taken in this regard.

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[37] Aaron C. Petri, "Planning the Urban Forest: Adding Microclimate Simulation to the Planner's Toolkit," *Land Use Policy*, 2019: 104117.
[38] Mohammad A. Rahman, "Within Canopy Temperature Differences and Cooling Ability of Tilia Cordata Trees Grown in Urban Conditions," *Building and Environment*, 2017: 118-128.
[39] Ed Gerrish, "The relationship between urban forests and income: A meta-analysis," *Landscape and Urban Planning*, 2018: 293-308.
[40] Stephanie Pincetl, "Implementing Municipal Tree Planting: Los Angeles Million-Tree Initiative," *Environmental Management*, 2010: 227–238.
[41] Geoffrey H. Donovan, "Including Public-Health Benefits of Trees in Urban-Forestry Decision Making," *Urban Forestry & Urban Greening*, 2017.
[42] Ibid.

Finally, Section 2.4 explores best practices from other cities that could be adapted by San Francisco to increase its tree canopy coverage.

2.2 Current Tree Policies in San Francisco

This section explores some of the policies the City of San Francisco has examined and implemented to increase tree canopy. In 2012 the City commissioned a study in order to determine the cost of transferring the responsibility of maintaining the City's street trees and surrounding sidewalks from property owners to the City itself. From this study's findings and recommendations, the City then developed the first phase of its Urban Forest Plan. Then, in 2017 the City implemented the StreetTreeSF program which delivered on the goal to transfer street tree maintenance responsibility to the Public Works Department.

2.2.1 Financing San Francisco's Urban Forest

In an effort to address San Francisco's declining urban forestry budget, the Planning Department commissioned a street tree financing study prepared by the consultants AECOM in 2012.[43] The primary objective of this study was to examine the costs and benefits of a municipally operated street tree program where the Department of Public Works would be wholly responsible for the planting and maintenance of all trees in the public right of way.[44] This study examined what the maintenance costs would be if private property owners were responsible; what the cost would be if street trees were maintained by the municipality; availability of financing options to the Department of Public Works; and finally, findings and recommendations.

Property Owner Costs. The first section of ACEOM's study examined the costs to private property owners related to pruning, sidewalk liability, removal permits, and monetary fines. The consultants analyzed a survey conducted by the Planning Department, which found that the average pruning cost per tree per year was $115.[45] It was also determined that tree-related

[43] City of San Francisco, "Urban Forest Plan," 2014.
[44] AECOM, "Financing San Francisco's Urban Forest," San Francisco, 2012.
[45] Ibid.

repair expenses averaged $50-$60 per tree per year.[46] While this may not sound like a significant amount of money, a single tree could cause, on average, $1,591 in sidewalk damage and $2,667 in sewer damage over five years, meaning the property owners could be liable for thousands of dollars in damage over a period of a couple of years.[47] The average cost of a removal permit came out to $3 per tree per year, but actual cost of a permit to remove a tree is a flat fee of $300. The average citation cost of illegally removing a tree also came out to $3 per tree, but this was because the Public Works Department did not have the resources to peruse all infractions. For the year of 2010-11 the department only issued 51 citations, the average citation issued was approximately $3,200 per fine. If people were injured due to privately maintained street trees, then property owners would be liable. These costs averaged between $8-$10 per tree, but the average claim payment was just over $23,000.[48] When solely looking at the average costs of trees, it comes out to $175-$190 per tree per year, but the actual amount that a single person could have to pay is not an insignificant amount.

Municipal Program Costs. The second section of the AECOM study presents cost projections if street trees were maintained by the municipality instead. In order to develop these cost projections, the study examined what the costs would be for planting, early tree care, maintenance, and sidewalk repair over a period of 20 years. The study developed two planting scenarios: (1) an *accelerated* planting scenario that would see 5,000 new trees every year for 20 years, totaling 205,000 trees and (2) a *moderate* planting scenario that would see the same total number of trees, but instead they would be planted over a period of 35 years. It was determined that the accelerated planting scenario would cost an average of $33.1 million per year, whereas the moderate planting scenario would cost an average of $27 million per year.[49] Both scenarios were determined to be more cost effective than if the trees were privately maintained. Under the accelerated planting scenario, property owners could see an annual benefit of $15-$75 per tree per year due to the reduced tree maintenance. Under the moderate planting scenario property owners could see an annual benefit of $15-$70 per tree

[46] Ibid.
[47] Ibid.
[48] AECOM, "Financing San Francisco's Urban Forest," San Francisco, 2012.
[49] Ibid.

per year.[50] If street trees were maintained by the municipality instead, the program was found to be more cost effective than if property owners maintained the trees, it was also associated with a higher standard of tree care.[51]

Financing Options. Tree plantings and maintenance funding in San Francisco has traditionally come from four different sources: gas taxes, Prop K, General Fund Expenditures, and the State Transportation Development Act.[52] Each of these funding sources pays for different types of activities, which means that if an action does not fall within one of those sources' scope, funds will not be made available for said activity. The AECOM study outlined the following financing options available to the City: Special Assessment Districts, Parcel Taxes, Mello-Roos Community Facilities Districts, Service Fees, General Fund Expenditures, General Obligation Bonds, partnerships, cap and trade, and an urban forestry joint powers authority.[53] Of these options, the study found that the most feasible options were Landscape and Lighting Assessment Districts (LLAD), Parcel Taxes, and General Obligation Bonds.[54] LLADs have the ability to fund the entire street tree program, which is the case in Sacramento, but LLADs will also typically fund more than just street trees.[55] Parcel Taxes can be directly related to program costs and can be tax deductible for property owners, but they need two-thirds voter approval and these flat taxes tend to be distrusted inequitably.[56] General Obligation Bonds are a tool that is frequently used in San Francisco for tree plantings, but the funding is only available for a specified period of time and maintenance is not eligible for this funding.[57]

Findings and Recommendations. The AECOM study found that transferring tree maintenance duties from property owners to the Department of Public Works would result in a net benefit for residents. It was also determined that routine maintenance would be more cost effective and efficient because it would prevent many complications from occurring in the first

[50] Ibid.
[51] Ibid.
[52] Ibid.
[53] AECOM, "Financing San Francisco's Urban Forest," San Francisco, 2012.
[54] Ibid.
[55] Ibid.
[56] Ibid.
[57] Ibid.

place.[58] The study recommends that the City pursue a moderate expansion program, with funding coming from outside sources so that it complements internal funding that focuses on operation and maintenance.[59]

2.2.2 Urban Forest Plan

In the Fall of 2014 the City of San Francisco published the first phase of its Urban Forest Plan. This plan comprises three different phases. The first phase discusses the overall urban forest but focuses primarily on street trees. The second phase aims to create a specific vision and strategy for trees in parks and open spaces, while the third and final phase will develop recommendations for trees on private property and other greening opportunities.[60] The Urban

Figure 1: Ficus Tree. *Source: San Francisco Public Works, Ficus Trees, n.d. https://sfpublicworks.org/ficustrees (accessed November 27, 2019).*

Figure 2: Ficus Tree Damage. *Source: San Francisco Public Works, Ficus Trees, n.d. https://sfpublicworks.org/ficustrees (accessed November 27, 2019).*

Forest Plan was developed by the San Francisco Planning and Public Works departments with input from various non-profit organizations, as well as being informed by public meetings, workshops, forums, and think tanks.[61] While phase one has already been published, phases two and three have yet to be published and it is unclear if there is any timeline for the plan in place yet.

[58] Ibid.
[59] Ibid.
[60] City of San Francisco, "Urban Forest Plan," 2014.
[61] City of San Francisco, "Urban Forest Plan," 2014.

The Urban Forest Plan has four key recommendations. The first is that San Francisco needs to maximize the benefits of its urban trees.[62] The City needs to identify which species of trees will provide the most benefits for improving air quality, stormwater retention, habitat creation, and carbon sequestration. But the City needs to be careful when choosing what type of trees will be planted. For example, Ficus trees, initially seem like an ideal candidate due to their impressive canopy shown in Figure 1, but upon examining them further, they potentially have some major flaws, such as being susceptible to limb failure and collapse which can put people and property at risk (Figure 2). These trees are such a risk that they have not been allowed to be planted as new street trees since the late 1990's.[63]

The second recommendation the Urban Forest Plan makes is that the City needs to increase the current street tree population by 50 percent by the year 2034. As of 2014, when the report was written, there were 105,000 street trees, which means by the year 2034 there should be 155,000 street trees.[64] In 2017, arborists mapped and recorded every street tree in the City and it was revealed that there were over 124,000 street trees with more than 500 different species.[65] The Plan estimated that an average of 2,500 new trees needed to be planted every year in order to reach the 2034 target. As of 2017 the City is slightly ahead of schedule to reach the 2034 target.

The third recommendation is to establish a fund that will maintain a city-wide street maintenance program. Cities which are recognized as leaders in urban forestry all have one thing in common: they are responsible for managing and maintaining their city's street trees.[66] On average, trees which are privately maintained will fare worse when compared to trees which are publicly maintained.[67]

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62 Ibid.
63 San Francisco Public Works, Ficus Trees, n.d. https://sfpublicworks.org/ficustrees (accessed November 27, 2019).
64 City of San Francisco, "Urban Forest Plan," 2014.
65 San Francisco Planning Department, *EveryTreeSF Street Tree Census,* n.d. https://sfplanning.org/project/everytreesf-street-tree-census (accessed November 25, 2019).
66 City of San Francisco, "Urban Forest Plan," 2014.
67 Ibid.

The fourth and final recommendation is that trees need to be managed throughout their entire life cycle.[68] This recommendation states that new street trees should be grown locally and once these trees are ready to be removed, instead of sending them to a landfill, they should be transformed into wood that can be used for wood products such as building materials or furniture. If none of these options are feasible, then the trees should be turned into compost for nurseries to grow new street trees.

The Urban Forest Plan also outlines five goals, with each goal accompanied by a series of strategies that are required to achieve that goal. Whereas the four recommendations are specific outcomes that the City should aim to accomplish, the five goals are broader in nature. These goals include growing the urban forest by planting new trees, protecting current trees, managing current trees with a coordinated effort, developing a long-term funding strategy, and engaging the public so that they feel a sense of ownership for these trees.[69]

The first goal (growing the urban forest by planting new trees) outlines three overarching strategies.

- Expand the distribution of trees and greenery throughout the City in a manner that is equitable. To accomplish this, the Plan recommends that the City should continue to enforce existing tree planting requirements while at the same time trying to expand these requirements. It also recommends that the City establish a city-wide tree planting strategy as well as tree coverage goals that the City should strive to achieve.
- Maximize the social, economic, and environmental benefits of the urban forest by selecting species of trees based on their ability to improve air quality, stormwater retention, habitat creation, and carbon sequestration.
- Promote a range of greening tools by taking advantage of existing programs to expand greenery in the public right-of-way, such as the Sidewalk Landscaping Program by the Public Works Department.[70]

[68] City of San Francisco, "Urban Forest Plan," 2014.
[69] Ibid.
[70] City of San Francisco, "Urban Forest Plan," 2014.

The second goal is to protect the urban forest by preserving the City's existing trees, and includes the following four strategies:

- Achieve a net zero loss of trees by replacing all dead trees; anytime a tree is going to be removed it should be replaced on a 1 to 1 basis. By discouraging tree removal it will help improve enforcement of existing tree removal codes.
- Reduce the impacts of development on existing trees by encouraging developers to incorporate existing trees into their site and building designs.
- Combat pests and disease by increasing species diversity, creating a monitoring program, and training City staff annually.
- Enforce the City's Urban Forestry ordinance, facilitate audits of tree care, and to create a program to help educate the public on proper tree care.[71]

The third goal aims to manage current trees through a coordinated effort by creating a cohesive management plan.

- The City should establish a Bureau of Urban Forestry within the Public Works Department, that would be responsible of creating the management plan. While this Bureau has not been established the responsibilities for all tree maintenance in the public right of way has been transferred the Public Works department.[72]
- The City should also care for trees from cradle to grave as well as employing best management practices.
- Improve coordination between public agencies, policy makers, and the community by establishing an advisory body which would facilitate coordination, make policy recommendations, review projects affecting trees, and track and report on the current state of the urban forest.[73]

[71] Ibid.
[72] San Francisco Public Works, *Street Tree SF - Frequently Asked Questions*, n.d. http://sfpublicworks.org/streettreesf-faq (accessed November 27, 2019).
[73] City of San Francisco, "Urban Forest Plan," 2014.

The fourth, and perhaps one the most important goals is to develop a method in which to fund the maintenance of the City's trees.

- Develop a dedicated long-term funding source. Without this long-term funding, maintaining an Urban Forest program would not be feasible.
- Develop programs which encourage donations by private entities and to explore non-traditional funding sources such as "crowd sourcing".[74]

The final goal is to engage the public so that they feel a sense of ownership for these trees.

- Improve the ecological literacy of residents and City staff. This will lead to an increase in awareness as to why it is important to have street trees.[75]
- Encourage participation in the planting of new trees so that community residents will foster a sense of ownership and are more likely to be engaged and care what happens to those trees.[76]

2.2.3 Street Tree SF

In November of 2016, San Francisco voters approved Proposition E with 79 percent support, which transferred the responsibility of maintaining the City's street trees and surrounding sidewalks from property owners to the Public Works Department.[77] This ballot measure became known as the StreetTreeSF program which took effect in July 2017.[78] As part of this program voters approved a set-aside of $19 million annually, an amount which is adjusted annually based on revenues from the City's General Fund to routinely and proactively maintain trees.[79] This program goes as far as to fine people, as much as $2,000 per tree, if they

[74] Ibid.
[75] City of San Francisco, "Urban Forest Plan," 2014.
[76] City of San Francisco, "Urban Forest Plan," 2014.
[77] San Francisco Public Works, *Street Tree SF - Frequently Asked Questions*, n.d. http://sfpublicworks.org/streettreesf-faq (accessed November 27, 2019).
[78] Ibid.
[79] Ibid.

prune a tree in the public right of way.[80] Through this program trees are pruned on a three to five year cycle.[81]

2.3 What Urban Forest Policies Have Other Cities Implemented?

This section explores some the policies that other cities have examined and implemented to increase tree canopy coverage and to reduce the heat island effect.

2.3.1 Sacramento

The City of Sacramento is one the cities that is recognized as a leader in urban forestry by the San Francisco Urban Forest Plan (2014).[82] Sacramento gathers and maintains a database of 100,000 public trees, and whenever a tree is planted, pruned, maintained or removed, the database is updated so that the current conditions of the urban forest are readily available.[83] Sacramento is rated as one of the top ten urban forests in the country and in the 1980's its urban forestry program was internationally recognized for its beautiful tree canopy, partnerships and innovative elm preservation programs.[84] Sacramento has implemented a variety of programs such as multiple tree ordinances, development of an Urban Forest Management Plan, and is in the process of creating a new Urban Forest Master Plan. Sacramento's urban forest is of such importance that it receives its own goal in the Environmental Resources section of the 2035 General Plan.[85]

In the 2035 General Plan, policy ER 3.1.6 states that the City of Sacramento shall continue to promote planting substantial canopies in order to minimize heat island effects.[86] This makes the City of Sacramento one of the few cities that is aspiring to explicitly mitigate

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[80] San Francisco Public Works, *StreetTreeSF,* n.d. http://sfpublicworks.org/streettreesf (accessed November 27, 2019).
[81] San Francisco Public Works, *Street Tree SF - Frequently Asked Questions*, n.d. http://sfpublicworks.org/streettreesf-faq (accessed November 27, 2019).
[82] City of San Francisco, "Urban Forest Plan," 2014.
[83] City of Sacramento Public Works, *Tree Programs,* n.d. https://www.cityofsacramento.org/Public-Works/Maintenance-Services/Trees/Programs (accessed November 30, 2019).
[84] City of Sacramento Public Works, *Tree Programs,* n.d. https://www.cityofsacramento.org/Public-Works/Maintenance-Services/Trees/Programs (accessed November 30, 2019).
[85] City of Sacramento, "2035 General Plan," 2015.
[86] Ibid.

heat islands using tree canopy. The City's 1994 Urban Forest Management Plan outlines several goals that the plan should aim to accomplish. The first is to assign a value to the urban forest in order to recognize the benefits that trees can provide to the community.[87] The second goal is to consolidate all tree management policies and practices into a cohesive document and to integrate design guidelines into a cohesive City wide tree plan.[88] The last goals are to define the scope of responsibility for municipal tree care and to increase public awareness and stewardship of trees.[89]

The Management Plan states that a program must always work within the means of its budget and that there are different ways to manage a maintenance program with a limited budget. These strategies range from reactive to proactive and some examples are as basic as only taking care of landscapes in case of emergency, maintenance preformed on a request basis, limited high priority maintenance, and a systematic long-term care program. Although it may be appealing to defer maintenance as a cost saving measure (and in the short-term this may be true), as time goes on, the cost of care and liability will also increase.[90]

The City of Sacramento plants approximately 1,200 trees per year and they tend to be planted as replacements when City crews remove trees or when homeowners request new trees for their front yard.[91] All new trees are added to the City-maintained database and are selected from an approved tree planting list of 38 species. An assumption of conservation is that in order to maintain a stable resource, a certain amount of trees will need to be removed and replaced every year; typically, urban forests can lose up to 2 percent of their population annually.[92] Sacramento uses a rotational replacement strategy where it removes and replaces 0.5 percent of its trees annually.[93]

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[87] City of Sacramento, "Sacramento Urban Forest Management Plan," 1994.
[88] Ibid.
[89] Ibid.
[90] City of Sacramento, "Sacramento Urban Forest Management Plan," 1994.
[91] Ibid.
[92] Ibid.
[93] Ibid.

In order to maintain species diversity, it is recommended that when a species is close to exceeding its quota it should be placed on a conditional list until the tree population shifts to become more diverse.[94] Tree maintenance programs need to transition from a reactive to a proactive approach if they aim to offer quality tree maintenance on a cost effective basis. Cities should also aim to maintain their trees on a three to five-year cycle depending on the species of tree.[95]

One of the most important aspects of any program, not just those pertaining to urban forestry, is that there needs to be community involvement because a supportive community will ultimately lead to a successful program.[96] The first step in building public stewardship starts with educating the public that trees have a value and benefit everyone, but at the same time the public must understand that one tree can be removed and replanted without it affecting the overall health of the entire urban forest.[97] Residents should be allowed to participate in everything from tree plantings and care of neighborhood trees to developing legislation.[98] The more involved residents feel they are, the more likely it is that they will care what happens to the City's urban forest.

The Urban Forest Management Plan outlines three funding options that could be used to grow and maintain the City's urban forest. The first option is to rely on the City's general fund. This option by its very nature is unstable because it must compete against changing priorities for other services in order to be funded each cycle.[99] Reliance on this funding source makes it much more difficult to respond to changing demands and service levels. The second option is to use the general fund, but at the same time to augment it with benefit assessment funding. This option also carries the same risk as the first option, but it is somewhat mitigated by the funds that would come from a Landscape and Lighting Assessment District.[100] An obstacle that arises with this option is that the mixed funds can make it difficult to define the

[94] Ibid.
[95] Ibid.
[96] Ibid.
[97] Ibid.
[98] City of Sacramento, "Sacramento Urban Forest Management Plan," 1994.
[99] Ibid.
[100] Ibid.

benefits received from the special benefit district. The third (and preferred) option is that the City phase out the use of the general fund and use only special district funding.[101] One of the benefits of using this funding option is that it frees up an equivalent amount from the general fund that can be used for other priorities.[102]

2.3.2 Santa Monica

The City of Santa Monica is another city that is recognized as a leader in urban forestry by the San Francisco Urban Forest Plan (2014).[103] The City of Santa Monica first implemented its Urban Forest Master Plan in 2011 and later revised their Master Plan in 2017. There are over 34,000 trees currently in Santa Monica's urban forest and the city estimates that the forest is worth $141 million by their replacement value alone, but if environmental benefits were also taken into consideration, then the forest could be worth as much as $300 million.[104] The Santa Monica Urban Forest Master Plan (2017) is supported by, and helps reinforce, elements of the Santa Monica General Plan.

Santa Monica enjoys a classic Mediterranean climate with cool breezes coming from the Pacific Ocean and over 300 days of sunshine throughout the year. Morning fog that normally dissipates in the afternoon is a common phenomenon during the summer months, but there are also times when the weather will remain cool and cloudy all day.[105] Santa Monica could be divided into four different microclimates with the areas closest to the ocean experiencing the coldest temperatures and inland areas tending to be warmer with increasing distance from the ocean.[106] In the past, Santa Monica once contained a wide range of different animal and plant species, but today the City is fully developed and it lacks any undisturbed native habitat.

In 2010, as part of initial phase of the Urban Forest Master Plan (2017), the City determined that there are approximately 33,800 public trees which are comprised of over 250

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[101] Ibid.
[102] Ibid.
[103] City of San Francisco, "Urban Forest Plan," 2014.
[104] City of Santa Monica, *Santa Monica Urban Forest,* n.d. https://www.smgov.net/Portals/UrbanForest/content.aspx?id=14794 (accessed February 5, 2020).
[105] City of Santa Monica, "Santa Monica's Urban Forest Master Plan," 2017.
[106] Ibid.

species, but the majority of the trees represent just 15 species.[107] As part of the Master Plan, the City interviewed the public to determine what the community's top concerns were when it came to an urban forest; it was determined that the community cared primarily about aesthetics followed by sustainability and then water conservation.[108]

The Master Plan developed multiple guiding principles which were used to provide the framework for the goals and strategies of the document. The first guiding principle is to enhance the understanding of the ecosystem services that are provided by the Santa Monica's urban forest. This is accomplished by having the City's Public Landscape Division submit annual reports to an Urban Forest Task Force on the total number of trees, new tree plantings, trees removed, and the number of trees pruned.[109] Each time an opportunity presents itself, the City of Santa Monica also works with the US Forest Service to conduct a benefit-cost analysis of the urban forest. The Task force continually evaluates the implementation and effectiveness of the Urban Forest Master Plan.[110]

The second guiding principle is to ensure that the public is educated on the benefits that trees offer to the community and that the residents are familiar with industry standards and best management practices for tree plantings and tree care.[111] In order to accomplish this, the City developed a marketing campaign to raise awareness of the urban forest within a wide audience by conducting periodic public workshops and creating programs that are focused on youths.[112] The City also implemented a heritage tree program, which provided the community opportunities to participate in public tree plantings, and to cooperate with other local agencies to promote awareness.[113]

The third guiding principle is to gather enough financial resources so that it is possible to preserve and enhance the urban forest. This is accomplished by devoting City funds to maintain

[107] Ibid.
[108] Ibid.
[109] Ibid.
[110] City of Santa Monica, "Santa Monica's Urban Forest Master Plan," 2017.
[111] Ibid.
[112] Ibid.
[113] Ibid.

the urban forest. The City also examines external funding sources such as grants and fundraising opportunities.[114]

Santa Monica also aims to legally protect trees by requiring a permit to plant, remove, or maintain any public tree. It is only possible to remove a public tree if the tree is dead, is dying and cannot be saved, the tree presents a structural failure risk, or if the tree presents unavoidable conflict with a construction project.[115] In order to ensure the longevity of its urban forest, the City makes sure that no genus will exceed ten percent and no species will exceed five percent of the total tree population.[116] This ensures that a monoculture is not created, thus providing resilience to disease and other threats. Santa Monica also selects the species of trees based on the site conditions of the location and its resilience to drought.[117]

2.3.3 Palo Alto

The City of Palo Alto is located approximately 35 miles south of San Francisco. The City first implemented its Urban Forest Master Plan in 2015 but then later revised the Master Plan in 2019. The Urban Forestry Section of the City of Palo Alto covers maintenance of both public and private street trees, totaling approximately 66,000.[118] Palo Alto's objective for its Urban Forest Master Plan was to establish a value for the trees, document a baseline for future monitoring, to engage the community, and to provide an action plan.[119]

Palo Alto maintains a diverse species of trees; 38 percent of the tree population is comprised of only four species, whereas the rest of the population much more diverse and scattered throughout the city.[120] Ninety-five percent of the urban forest is made of a type broadleaf species, which tend to provide the most benefits when it comes to providing shade, but have also been identified as undesirable because of their water requirements or because of

[114] Ibid.
[115] Ibid.
[116] Ibid.
[117] Ibid.
[118] City of Palo Alto. Palo Alto's Urban Forest, n.d. https://www.cityofpaloalto.org/gov/depts/pwd/trees/ (accessed February 10, 2020).
[119] City of Palo Alto, "Palo Alto Urban Forest Master Plan," 2019.
[120] Ibid.

the damage they could cause to public infrastructure.[121] Currently, approximately four percent of Palo Alto's urban forest accounts for native species, meaning that 95 percent of the trees within the City are non-native species.[122]

The Urban Forest Master Plan (2019) lays out six overarching goals with a variety of policies and programs to help accomplish those goals.

The first goal of the master plan is to develop a contiguous, healthy, and ecologically resilient urban forest.[123]

- The City shall strive for a greater percentage of native and drought tolerant tree species.
- The City shall also aim to conserve viable tree planting locations and maintain planting levels so that they exceed removals so that the urban forest can continue to grow.[124]

The second goal is to regenerate native woodland and riparian landscapes so that they can act as the basis of the urban forest.[125]

- The City shall attempt to conserve and grow adaptive tree populations which consist of either native or introduced tree species, so that the native woodland ecosystem can recover and regenerate.

The third goal is to develop a citywide sustainability plan that could integrate the goals of the Urban Forest Master Plan with other related goals on water conservation, carbon neutrality, and solar energy. [126]

- Anytime decisions are being made on the environment, sustainability, and capital Improvements, the City shall consider the wellbeing of the urban forest and identify conflicts or alignments between other goals the City has set in place.

[121] Ibid.
[122] Ibid.
[123] Ibid.
[124] Ibid.
[125] City of Palo Alto, "Palo Alto Urban Forest Master Plan," 2019.
[126] Ibid.

The fourth goal is to create a community that appreciates the urban forest, and one that partners with the City and other local organizations to help steward it.[127]

- The City shall help optimize communication between its residents, property owners, business owners, and non-profits.
- The City shall explore the concerns that resulted from the Master Plan survey to ensure that residents' voices are being heard.[128]

The fifth goal of the City is to establish an effective Urban Forestry Division, whose job is to ensure the City has enough baseline information so that changes in the urban forest can be monitored.

The last goal is to create an urban forest that enhances the built environment while at the same time connecting it to the natural environment.[129]

- The City shall update its zoning regulations and other development practices so that tree conservation and the overall health of the urban forest are taken into consideration.
- Both public and private projects shall seek ways in which trees, canopy, and habitat can be added early in the design phase, they also shall seek to promote shade for pedestrians and bicyclists, and projects should also promote green space systems within communities.[130]
- Aim to achieve no net loss in canopy cover, specifically prioritizing areas that saw the greatest decreases in tree canopy between 1982-2010, and the City shall also provide incentives to increase canopy and ecological benefits.[131]

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[127] Ibid.
[128] Ibid.
[129] Ibid.
[130] City of Palo Alto, "Palo Alto Urban Forest Master Plan," 2019.
[131] Ibid.

2.3.4 Chicago

The City of Chicago is another city that is recognized nationally as a leader in urban forestry.[132] Chicago has long understood the importance of trees in contributing to quality of life improvements for its people. Chicago has led an aggressive survey and removal campaign against an invasive species which could have killed half of all of the city's trees if nothing was done.[133] Chicago has also installed cooling and reflective landscapes to address urban heat islands, which can cause a rise in energy costs and heat-related fatalities each year, and they have also used urban heat island mapping to prioritize where tree planting should be performed.[134]

In 2013, the Chicago Region Trees Initiative (CRTI) was established as a collaboration between different partners in the Chicago region to develop and implement a strategy to build a healthier and more diverse urban forest by the year 2050.[135] In 2019, CRTI implemented its Master Plan to inspire people to value trees, increase the region's tree canopy, reduce the threats to trees, and to enhance oak ecosystems.[136]

The first goal of the Master Plan is to inspire people to value trees. The CRTI helps people and organizations across the Chicago region understand why increased canopy is important and what the proper methods are to care for the trees.[137] The CRTI also works with decision makers to implement tree preservation policies on both public and private land. The organization also supports urban forestry funding as part of capital improvements because trees are critical infrastructure which need to be supported.[138]

The second goal of the Master Plan is to achieve 22 percent tree canopy cover by the year 2050.[139] To accomplish this goal, the CRTI has to ensure that landowners and managers are

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[132] City of San Francisco, "Urban Forest Plan," 2014.
[133] City of Chicago, "Chicago's Urban Forest Agenda," 2009.
[134] Ibid.
[135] CRTI, *Chicago Region Trees Initiative,* n.d. http://chicagorti.org/about-chicago-rti/vision-outcomes (accessed February 15, 2020).
[136] CRTI, "Chicago Region Trees Initiative Master Plan," 2019.
[137] Ibid.
[138] Ibid.
[139] Ibid.

trained to plant trees correctly, so that the trees have the proper root space and have the highest chance of survival.[140] The CRTI also regularly collects and analyzes forest composition data and then distributes it to the proper decision makers. They recommend that this data collection occurs at least every ten years, and as technology develops that makes this process easier, then the timeframe should be shortened accordingly.[141]

The third goal of the Master Plan is to reduce the overall threats to trees. Eight percent of the Chicago region's tree loss can be attributed to invasive pest infestations alone.[142] In order to help combat this, the CRTI recommends that no more than five percent of any one species should be planted at any one time, so that the urban forest cannot be wiped out.[143] According to the Master Plan, studies have shown that early management of pests and routine pruning are less costly, result in lower catastrophic loss, and can help improve the value and services an urban forest provides.[144]

The last goal of the Master Plan is to enhance the oak ecosystems in the Chicago region. The CRTI works with both public and private property owners to increase the regeneration of oaks and associated species.[145] This results in a higher biological diversity through active management and reintroductions of native species.[146] By working with state and federal agencies, CRTI can secure funding to implement an Oak Ecosystem Recovery Plan, which will include educating landowners on local, state, and federal programs that provide tax incentives or funding assistance for protection.[147]

2.4 Lessons Learned for Application in San Francisco

While many of the goals and strategies mentioned in this chapter could be applied to any one city, it is not realistically feasible to implement every single one. Many of the urban

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[140] Ibid.
[141] Ibid.
[142] Ibid.
[143] Ibid.
[144] Ibid.
[145] CRTI, "Chicago Region Trees Initiative Master Plan," 2019.
[146] Ibid.
[147] Ibid.

forest documents share similar goals and ideas, but the specifics of to implement these goals are slightly different. All of these documents share the same overarching goal and that is to increase and maintain a vibrant and healthy urban forest. Some cities create an entire new division to deal with that city's urban forest while others will delegate those functions to divisions that already exist. Many cities aim to maximize the benefits that trees can provide such as increasing habitat for native species or examining the carbon sequestration potential of a tree. While the amount of shade that trees provide is important, it is also just as important to examine trees holistically so that an urban forest can provide a wide range of benefits. In order for any policy, regardless of what it is trying to accomplish, to be effective there needs to community support, which was a sentiment shared by all of the cities. Cities also need to have some sort of method to track the status of their urban forest so that they can determine if they are meeting their goals or not.

Now that some of the tree canopy policies in other cities as well as in San Francisco have been examined, it is necessary to determine which neighborhoods within San Francisco have the greatest need for an increase in tree canopy.

Chapter 3: San Francisco Tree Canopy and Land Surface Temperatures

This chapter explores possible actions the City of San Francisco can consider to increase tree canopy coverage and, as a result, mitigate urban heat islands and their effects. The first section of this chapter examines current conditions as they relate to tree canopy coverage and average neighborhood temperatures within the City. Section 3.2 presents a list of the neighborhoods the research identified as prime candidates for new tree planting to realize the greatest heat island reductions. The last section summarizes all relevant findings outlined in this chapter.

3.1 Determining Current Conditions

In order to identify which neighborhoods would be the most ideally suited for new tree plantings, it was first necessary to ascertain the current conditions of tree canopy cover and the average temperatures across the City. A comparison of these two datasets provided the necessary information to make a list of the highest priority neighborhoods in need of additional trees.

3.1.1 San Francisco Tree Canopy Geospatial Analysis

For this section of the analysis, specific data was necessary to determine the current tree canopy coverage within San Francisco. By examining the tree canopy using GIS, it was possible to visualize which parts of the City have the most trees and which parts have the least. It was suspected that land use would play a significant role in whether a neighborhood has a significant number of trees. It is also believed that areas that experience higher temperatures will have less tree canopy. Understanding that land use will affect a neighborhood's tree canopy, it is safe to assume that industrial areas would be especially devoid of trees when compared to the rest of the City.

The City of San Francisco has a public dataset of urban tree canopy which includes the location and the area of the tree canopy for the majority of trees within the City, including Treasure Island. This dataset contains both public and private trees located within the City. This information is displayed in Figure 3. The other dataset necessary to conduct this analysis of the tree canopy within the City, is a shapefile titled "Planning Neighborhood Groups." This shapefile divides the City into the following 37 neighborhoods (Figure 4):

1. Seacliff
2. Haight Ashbury
3. Outer Mission
4. Inner Sunset
5. Downtown/Civic Center
6. Diamond Heights
7. Lakeshore
8. Russian Hill
9. Noe Valley
10. Treasure Island/YBI
11. Outer Richmond
12. Crocker Amazon
13. Excelsior
14. Parkside
15. Financial District
16. Ocean View
17. Mission
18. West of Twin Peaks
19. Inner Richmond
20. Marina
21. Bayview
22. Visitacion Valley
23. Pacific Heights
24. Presidio Heights
25. South of Market
26. Glen Park
27. Potrero Hill
28. Castro/Upper Market
29. Twin Peaks
30. Bernal Heights
31. Presidio
32. Nob Hill
33. Chinatown
34. North Beach
35. Outer Sunset
36. Western Addition
37. Golden Gate Park

Figure 3: San Francisco Tree Canopy. Source: Map Created by Author Using Basemap Layers from Esri; Shapefiles obtained from http://data.sfgov.org.

Figure 4: San Francisco Neighborhoods. Source: Map Created by Author Using Basemap Layers from Esri; Shapefiles obtained from http://data.sfgov.org.

Once all the needed data was collected, it was imported into ArcMap where it was used to create a map to display the results. Figure 5 displays the current tree canopy as well as the outlines of the neighborhood boundaries to illustrate where the tree canopy currently exists within the City.

Figure 5: San Francisco Neighborhoods and Tree Canopy. Source: Map Created by Author Using Basemap Layers from Esri; Shapefiles obtained from http://data.sfgov.org.

Figure 6 displays a choropleth map which compares the percentage of the neighborhood's land area that has a tree canopy. In order to create this map, it was first necessary to clip the tree canopy layer with each of the 37 specific neighborhoods. Once each of the neighborhood boundaries was used to clip the tree canopy, it was then possible to calculate the area, in acres, using the 'calculate geometry' function in ArcMap.

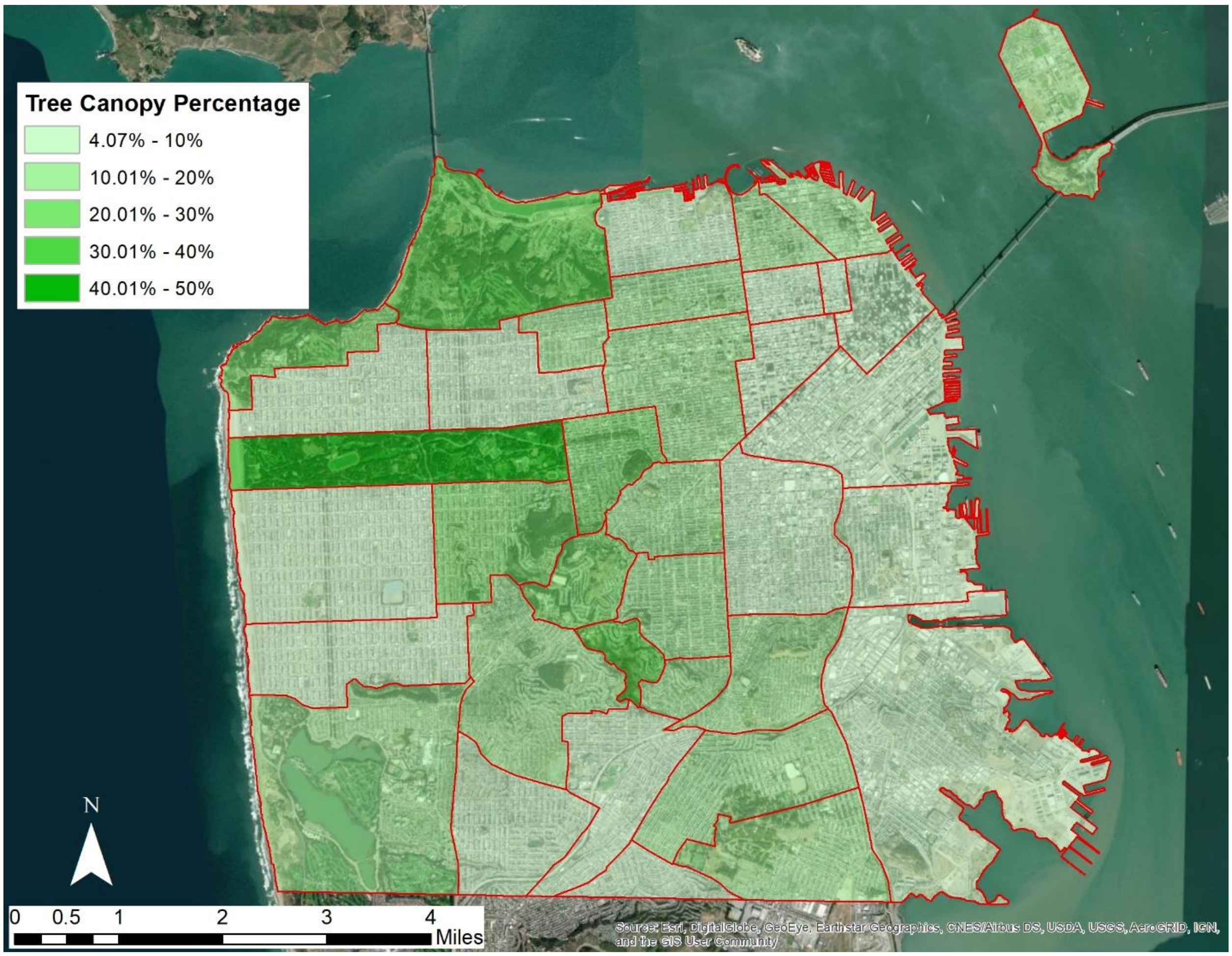

Figure 6: Percentage of Tree Canopy for each Neighborhood in San Francisco. Source: Map Created by Author Using Basemap Layers from Esri; Shapefiles obtained from http://data.sfgov.org.

The results were imported and entered into an Excel spreadsheet which included each neighborhood and the size of their tree canopy as shown in Table 1. Once the spreadsheet was completed, it was joined to the “Planning Neighborhood Groups” layer using the neighborhood column as the key field upon which to base the join. A resulting new field was added to the attribute table so that it would enable the calculation of the percentage of tree cover by dividing the area of each neighborhood with the corresponding area of the tree canopy. With this complete, a map was generated which illustrated the percentage of tree canopy for each neighborhood within the City (Figure 6).

Table 1. Area of Tree Canopy, ordered by Tree Cover Percentage

Neighborhood ID	Neighborhood	Tree Area (acres)	Tree Cover Percentage
5	Downtown/Civic Center	16.80	4.07%
25	South of Market	55.48	4.11%
32	Nob Hill	11.77	4.99%
33	Chinatown	4.29	5.00%
35	Outer Sunset	78.62	5.03%
12	Crocker Amazon	15.59	5.22%
14	Parkside	51.81	5.34%
11	Outer Richmond	50.25	5.79%
21	Bayview	211.35	6.75%
17	Mission	83.18	7.51%
16	Ocean View	71.06	8.29%
3	Outer Mission	74.11	8.42%
27	Potrero Hill	76.64	8.74%
15	Financial District	41.18	9.27%
19	Inner Richmond	79.98	9.51%
20	Marina	60.55	9.76%
13	Excelsior	106.17	10.35%
36	Western Addition	106.26	10.95%
24	Presidio Heights	32.45	11.53%
34	North Beach	46.65	11.68%
30	Bernal Heights	90.45	12.10%
8	Russian Hill	38.22	12.52%
23	Pacific Heights	59.68	13.92%
28	Castro/Upper Market	79.52	14.51%
9	Noe Valley	88.95	15.50%
7	Lakeshore	405.43	17.38%
18	West of Twin Peaks	211.87	17.50%
22	Visitacion Valley	167.38	17.64%
10	Treasure Island/YBI	103.88	18.27%
26	Glen Park	46.89	19.63%
2	Haight Ashbury	98.13	20.10%
4	Inner Sunset	175.04	20.49%
29	Twin Peaks	96.57	22.75%
1	Seacliff	135.16	29.28%

Neighborhood ID	Neighborhood	Tree Area (acres)	Tree Cover Percentage
6	Diamond Heights	69.35	31.65%
31	Presidio	499.00	32.78%
37	Golden Gate Park	514.36	47.69%

Source: Author's data

3.1.2 Calculating the Average Land Surface Temperature of San Francisco by Neighborhood

For this section of the analysis, it was necessary to determine the current land surface temperatures in San Francisco. Land Surface Temperature (LST) is defined as the temperature felt when the surface is touched with the hands or it could also be thought of as the skin temperature of the ground.[148]

To accomplish the above task, first, Landsat 8 satellite images taken from the USGS EarthExplorer Viewer website needed to be collected.[149] Landsat 8 is a satellite that orbits the earth at an altitude of 438 miles, capturing imagery in bands. This satellite has a total of 11 bands and each band captures a specific frequency of light. It captures daytime images every 16 days and, depending on the band, the images captured can have a resolution from 15 to 100 meters.[150] The months of July through October were chosen as the months to collect the Landsat 8 images because they tend to be the warmest months of the year for San Francisco. The images collected span five years between 2014 and 2019.

Once the above step was completed, it was decided that the only images that would be downloaded were those that had little to no cloud cover over San Francisco, so that calculations could be as accurate as possible. Once the desired image was found, the Level-1 GeoTIFF Data Product image was downloaded. This in turn transferred a file containing 11 different raster images which correspond to the specific bands of the satellite as well as a .txt file containing the metadata for those bands.

With all the necessary images downloaded, it was then possible to begin the calculations to compute Land Surface Temperature. The main bands required for this part of the analysis were band 10, which has a resolution of 100 meters and is the thermal band, and

[148] Ugur Avdan, "Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data," *Research Institute of Earth and Space Sciences*, 2016.
[149] USGS, *EarthExplorer,* n.d. https://earthexplorer.usgs.gov/ (accessed January 15, 2020).
[150] USGS, Landsat 8, n.d. https://www.usgs.gov/land-resources/nli/landsat/landsat-8?qt-science_support_page_related_con=0#qt-science_support_page_related_con (accessed April 9, 2020).

bands 4 and 5, which are used to calculate the Normal Difference Vegetation Index (NDVI) and have a resolution of 30 meters.

The formulas used for this analysis were obtained from Avdan's 2016 study.[151] The main tool used to calculate LST was the Raster Calculator tool in ArcMap.

The first step was to calculate the Top of Atmospheric (TOA) Spectral Radiance, which is a unitless measurement that provides the ratio of radiation reflected to the incident solar radiation on a given surface.[152] The following equation was used to calculate TOA:

$$\text{TOA (L)} = \text{ML} * \text{Qcal} + \text{AL}$$

ML is the band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_10). Qcal corresponds to the band 10 raster, and AL represents the band specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_10). The equation was solved using the Raster Calculator tool in ArcMap.

The second step was to convert TOA to Brightness Temperature (BT) using the formula:

$$\text{BT} = (\text{K2} / (\ln (\text{K1} / \text{L}) + 1)) - 273.15$$

K1 is the band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_10) and k2 is the band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_10) and L is TOA. Then, in order to obtain the results in Celsius, the radiant temperature was adjusted by adding absolute zero (approx. -273.15°C) using the Raster Calculator tool in ArcMap.

The third step involved the calculation of the Normalized Difference Vegetation Index (NDVI) using the Raster Calculator tool in ArcMap where:

$$\text{NDVI} = \text{Float(Band\_5} - \text{Band\_4)} / \text{Float(Band\_5} + \text{Band\_4)}$$

[151] Ugur Avdan, "Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data," *Research Institute of Earth and Space Sciences*, 2016.
[152] Ibid.

Band_5 corresponds to the Band 5 raster and Band_4 corresponds to the Band 4 raster. NDVI is a graphical indicator that can be used to analyze remote sensing measurements.[153]

The fourth step was to calculate the Proportion of Vegetation (Pv) where:

$$Pv = Square\,((NDVI - NDVImin) / (NDVImax - NDVImin))$$

using the Raster Calculator tool in ArcMap. NDVImax corresponds to the maximum value from the raster created in third step and NDVImin corresponds to the minimum value from the raster created in the third step. Proportion of Vegetation is defined as the ratio of the vertical projection area of vegetation on the ground to the total vegetation area.[154]

The fifth step required calculating Emissivity (ε) using methods from Sobrino's 2004 study to estimate land surface emissivity using the NDVI method where:

$$\varepsilon = [\varepsilon_v - \varepsilon_s - (1 - \varepsilon_s)F*\varepsilon_v] * Pv + [\varepsilon_s + (1 - \varepsilon_s)F\varepsilon_v]$$

where ε_v is the vegetation emissivity and ε_s is the soil emissivity. Emissivity is the measure of an object's ability to emit infrared energy.[155] In Sobrino's study an emissivity value of 0.99 for vegetation is stated to be typical, whereas for soil emissivity due to the higher variation in emissivity values, an average of .97 was chosen.[156] F represents the surface roughness taken as a constant value of 0.55.[157] Thus, the equation could then be further simplified to:

$$\varepsilon = 0.004 * Pv + 0.986$$

This equation was subsequently entered into the Raster Calculator tool in ArcMap to determine emissivity.

The final step consisted of calculations to determine the land surface temperature where:

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[153] Ugur Avdan, "Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data," *Research Institute of Earth and Space Sciences*, 2016.
[154] Elnaz Neinavaz, "Effects of Prediction Accuracy of the Proportion of Vegetation Cover on Land Surface Emissivity and Temperature Using the NDVI Threshold Method," *International Journal of Applied Earth Observation and Geoinformation*, 2020: 101984.
[155] Ibid.
[156] Jose A. Sobrino, "Land Surface Temperature Retrieval from LANDSAT TM 5," *Remote Sensing of Environment*, pp. 434–440, 2004.
[157] Ibid.

$$LST = (BT / (1 + (\lambda * BT / p) * Ln(\varepsilon)))$$

BT is the raster produced in step 2 and ε is the raster produced in step 5. λ is the wavelength of emitted radiance for Band 10 which is 10.895 µm and p is the following:

$$p = h(c/\sigma) = 1.438 \times 10^{-2} \text{ mK}$$

where σ is the Boltzmann constant (1.38×10^{-23} J/K), h is Planck's constant (6.626×10^{-34} J*s), and c is the velocity of light (2.998×10^{8} m/s).[158] Thus the equation could be further simplified to:

$$LST = (BT / (1 + (0.0010895 * BT / 1.4380) * Ln(\varepsilon)))$$

This equation was then entered into the Raster Calculator tool in ArcMap to determine LST.

Completion of the above listed steps resulted in an LST map with a resolution of 30 meters. Because the original images taken from the USGS included the entire Bay Area, it was necessary to first clip the image so that only San Francisco was displayed. This was accomplished by using the Clip tool in the Raster Processing toolbox and selecting the Planning Neighborhood layer as the layer with which to clip the LST map. While the information is the same even if the LST raster is not clipped, not clipping it makes it more difficult to display the data of a specific city because the spatial extent will be much larger. Figure 7 shows what the map would look like if one did not clip the LST raster to just display San Francisco; it also shows the spatial extent of the original image. Figure 8 shows what the map looks like when the LST raster is clipped to San Francisco. Figures 8 and 9 display the surface temperature in Celsius, with colder temperatures being displayed in blue and warmer temperatures displayed in red. In Figure 7 the highest temperature shown is 44 degrees and the lowest is shown as -125 degrees. The low value is due to bands 4 and 5 having a higher resolution than band 10, meaning it is not possible to determine the temperature on the edges of the image.

[158] Elnaz Neinavaz, "Effects of Prediction Accuracy of the Proportion of Vegetation Cover on Land Surface Emissivity and Temperature Using the NDVI Threshold Method," *International Journal of Applied Earth Observation and Geoinformation*, 2020: 101984.

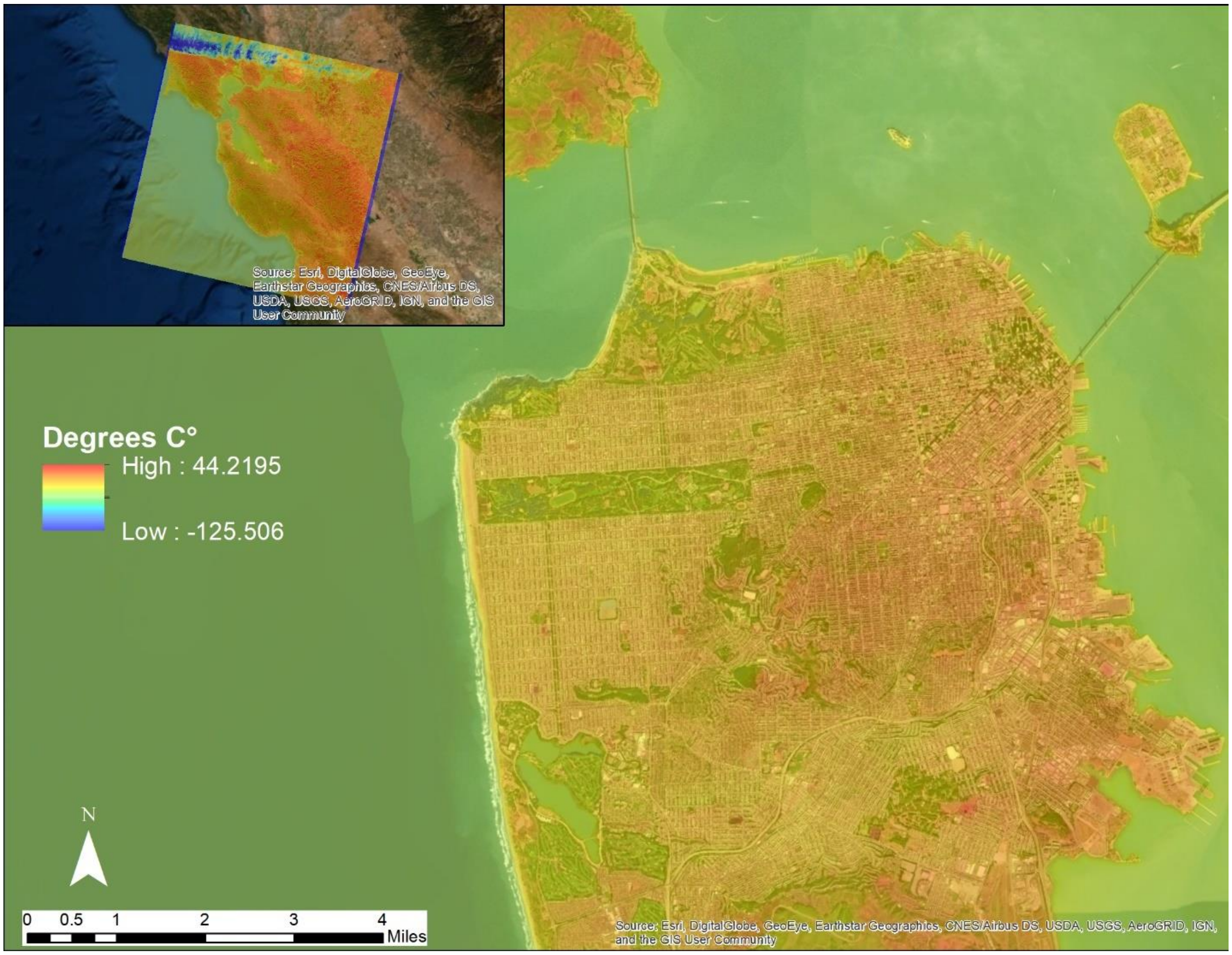

Figure 7*:* Land Surface Temperature of the Bay Area, Zoomed into San Francisco*.* Source: Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

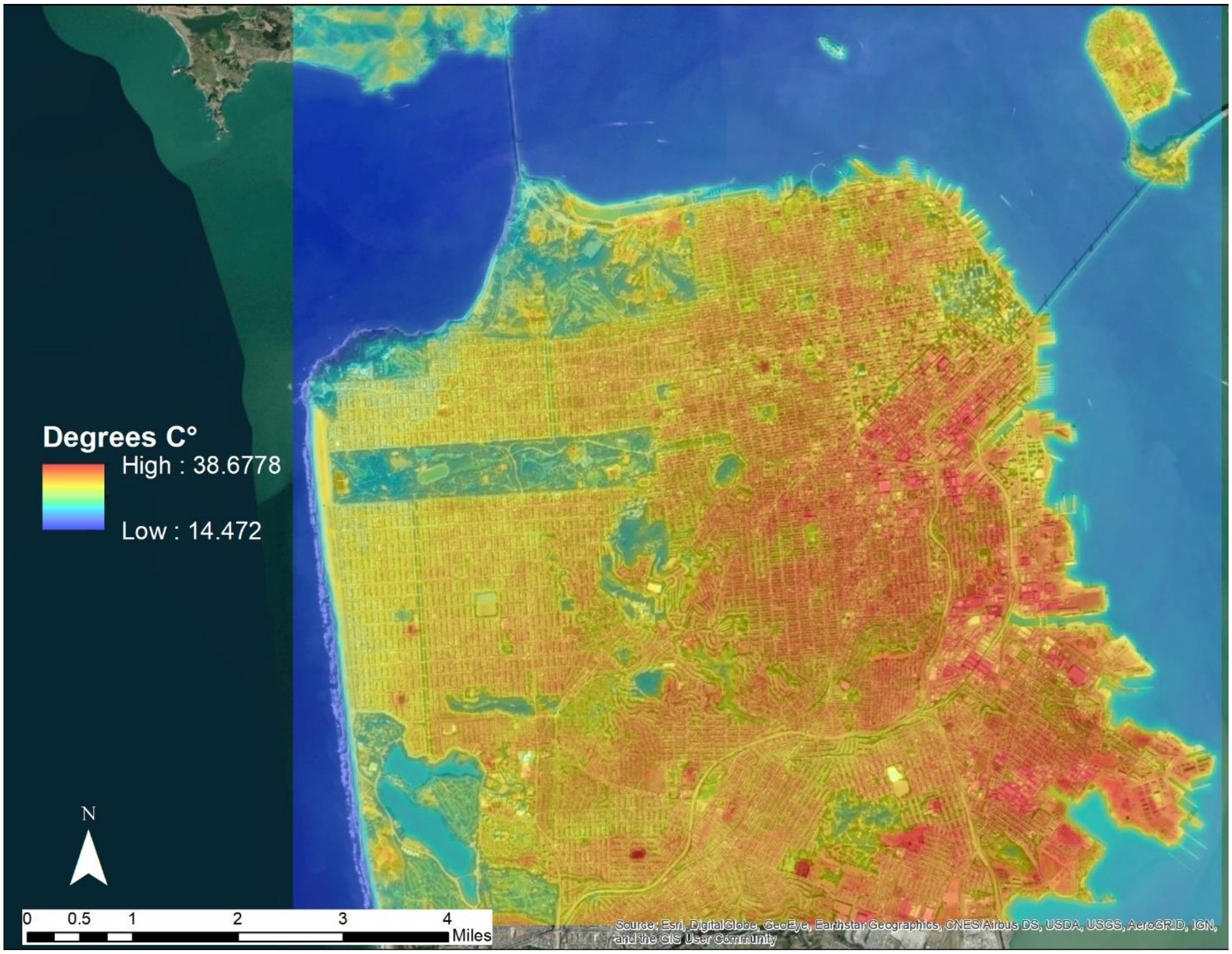

Figure 8: Land Surface Temperature of San Francisco. Source: Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

3.1.3 Determining Neighborhoods of Focus: An Analysis of Tree Canopy and Land Surface Temperature

Once the Land Surface Temperature map was created, it was possible to begin the review to determine which neighborhoods should be the focus for increased tree plantings. The first step was to take all the LST raster images that were produced for the year 2019 and average all of them in order to produce an average for the year. This was accomplished by using the Raster Calculator tool as shown in Figure 9 below. Figure 10 shows the results of this calculation, displaying the average Land Surface Temperature for the summer of 2019.

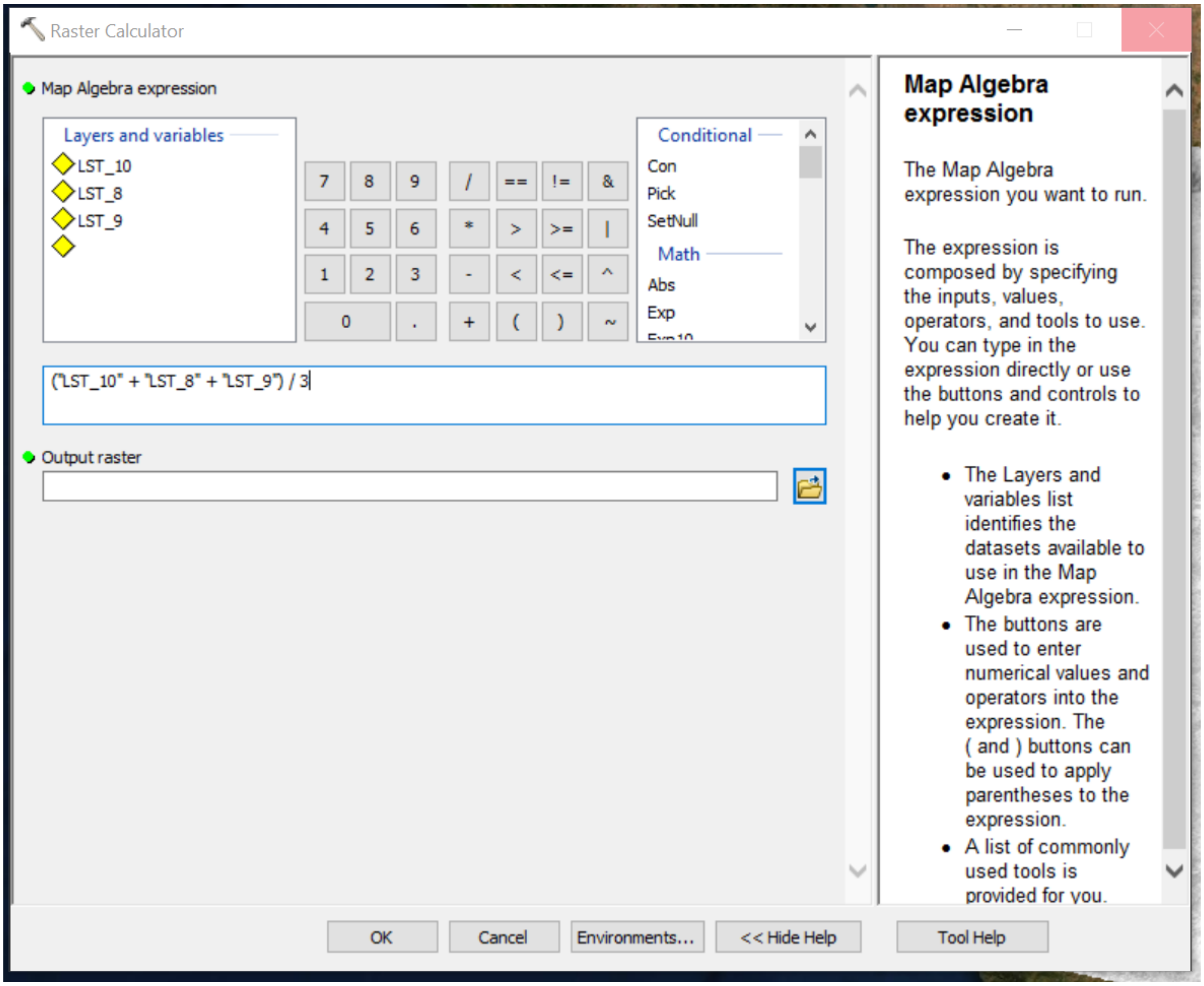

Figure 9: Raster Calculator Tool Averaging the LST Rasters for the Months of July, September, and October 2019. Source: Image created by author.

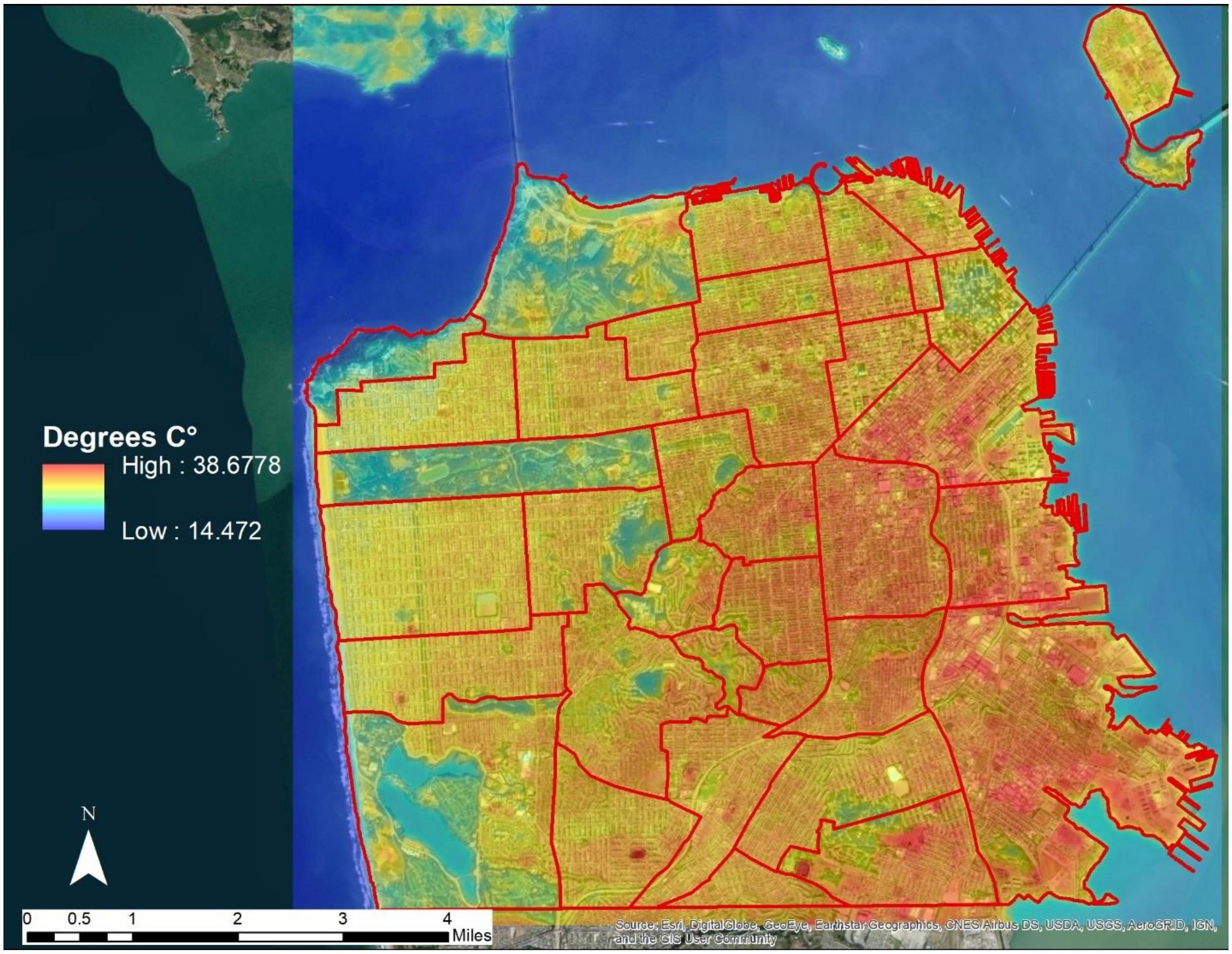

Figure 10: Land Surface Temperature of San Francisco. Source: Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

Once the average temperatures for 2019 were calculated, the needed information to determine the average temperature for each neighborhood was set. The following step included running the Zonal Statistics tool in ArcMap (this tool can calculate the average values of a raster within the 'zones', or polygonal extent, of another dataset). With the Zonal Statistics tool open, the "Planning Neighborhood Groups" layer was selected as the input feature (the zones being used to determine the spatial extent), and the LST raster was selected as the input value raster (the values that were going to be averaged), as shown in Figure 11. These actions created a new layer which averaged the LST values of all cells within a neighborhood's extent, shown in Figure 12 below.

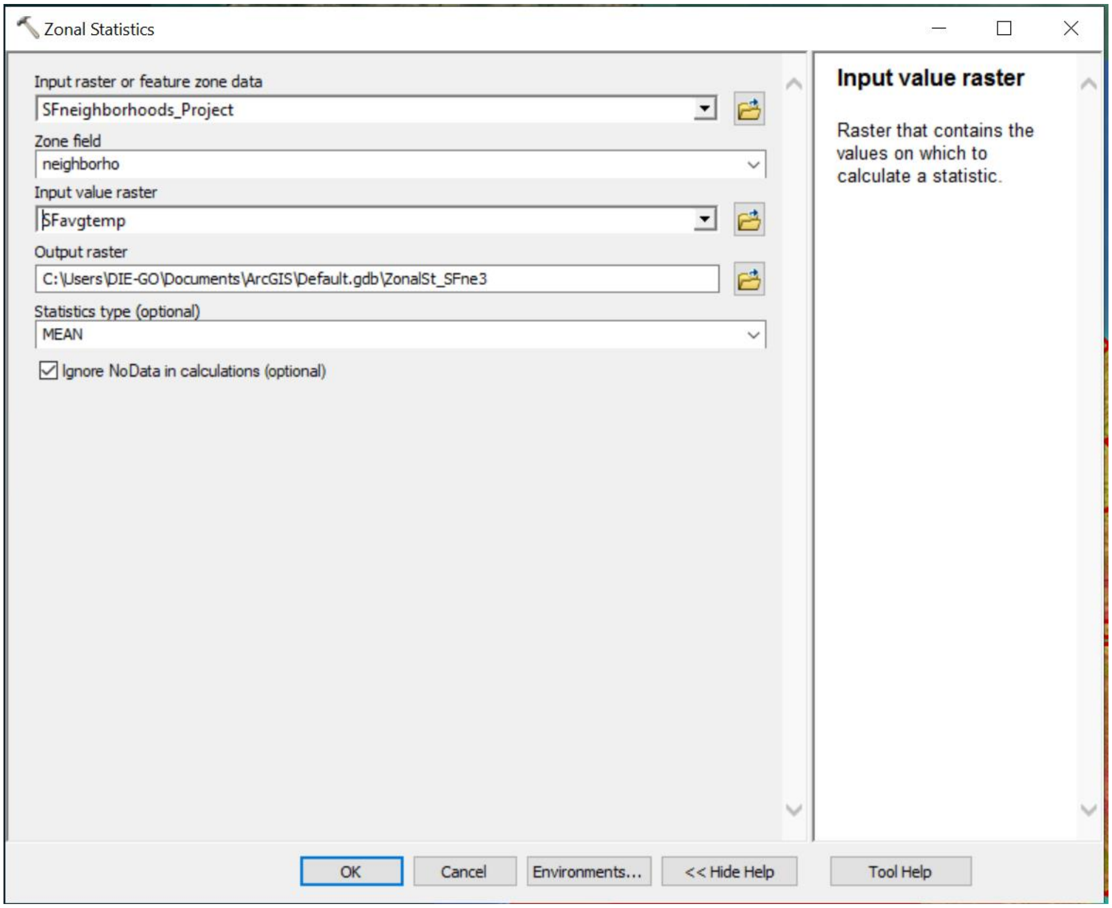

Figure 11: Zonal Statistics Tool Used to Determine Mean Temperature of Each Neighborhood Within San Francisco. Source: Image created by author.

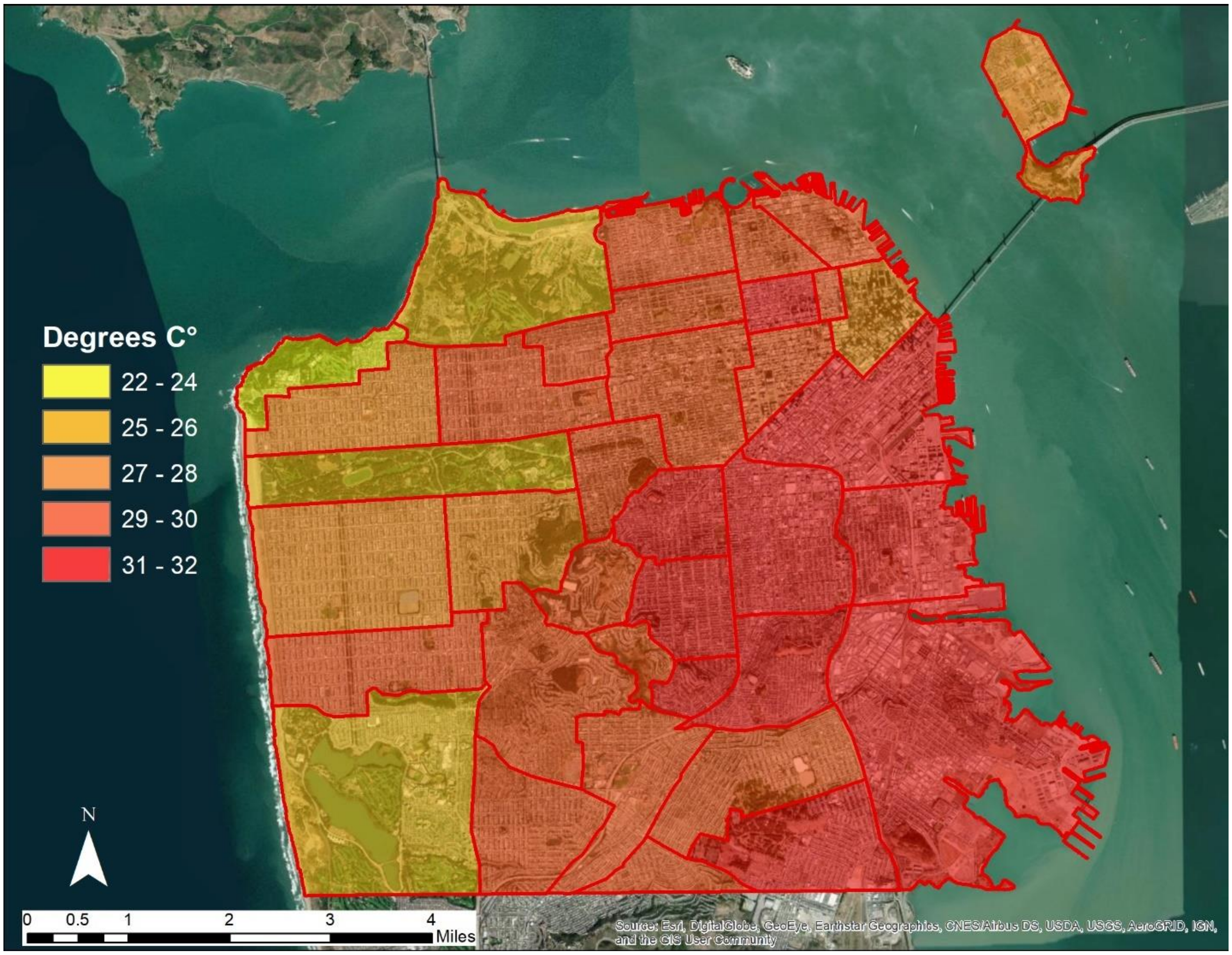

Figure 12: Neighborhood Temperature Map. Source*:* Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

The next step in the analysis was to input the temperatures and the percentage of tree canopy cover into an Excel spreadsheet for each neighborhood. After this was completed, a rank was assigned to each neighborhood for each category. Neighborhoods that have a lower tree cover percentage will rank higher, so if a neighborhood had the lowest percentage of tree cover it will get a rank of 1 and if a neighborhood had the highest percentage of tree cover it would get a rank of 37. This ranking system was also applied to neighborhood temperatures, so if a neighborhood experienced a higher average temperature it would rank higher than neighborhoods that experienced lower temperatures. The two scores were then averaged, to yield a final ranking (Table 2). Figure 13 maps the combined ranking score of each neighborhood.

Table 2. Neighborhood Rankings, ordered by Combined Ranking Score

Neighborhood ID	Neighborhood	Tree Cover (%)	Tree Cover Ranking (1 to 37)	Average Temperature (C°)	Average Temperature (F°)	Average Temperature Ranking (1 to 37)	Combined Average Score for Tree and Temperature Rankings (columns 4 and 7)
25	South of Market	4.11%	2	30.21	86.38	8	5
17	Mission	7.51%	10	31.53	88.76	1	5.5
21	Bayview	6.75%	9	30.77	87.38	3	6
32	Nob Hill	4.99%	3	30.16	86.29	9	6
27	Potrero Hill	8.74%	13	30.87	87.57	2	7.5
5	Downtown/Civic Center	4.07%	1	29.49	85.09	14	7.5
12	Crocker Amazon	5.22%	6	29.57	85.23	12	9
33	Chinatown	5.00%	4	29.12	84.41	16	10
3	Outer Mission	8.42%	12	29.51	85.12	13	12.5
30	Bernal Heights	12.10%	21	30.46	86.82	6	13.5
16	Ocean View	8.29%	11	29.00	84.19	17	14
9	Noe Valley	15.50%	25	30.70	87.26	4	14.5

Neighborhood ID	Neighborhood	Tree Cover (%)	Tree Cover Ranking (1 to 37)	Average Temperature (C°)	Average Temperature (F°)	Average Temperature Ranking (1 to 37)	Combined Average Score for Tree and Temperature Rankings (columns 4 and 7)
28	Castro/Upper Market	14.51%	24	30.55	86.98	5	14.5
36	Western Addition	10.95%	18	29.73	85.51	11	14.5
13	Excelsior	10.35%	17	29.24	84.64	15	16
14	Parkside	5.34%	7	28.15	82.68	27	17
22	Visitacion Valley	17.64%	28	30.26	86.47	7	17.5
35	Outer Sunset	5.03%	5	27.47	81.44	30	17.5
19	Inner Richmond	9.51%	15	28.39	83.10	24	19.5
26	Glen Park	19.63%	30	30.01	86.01	10	20
8	Russian Hill	12.52%	22	28.90	84.03	18	20
11	Outer Richmond	5.79%	8	26.83	80.30	32	20
20	Marina	9.76%	16	28.35	83.03	25	20.5
24	Presidio Heights	11.53%	19	28.48	83.26	23	21
23	Pacific Heights	13.92%	23	28.76	83.77	20	21.5

Neighborhood ID	Neighborhood	Tree Cover (%)	Tree Cover Ranking (1 to 37)	Average Temperature (C°)	Average Temperature (F°)	Average Temperature Ranking (1 to 37)	Combined Average Score for Tree and Temperature Rankings (columns 4 and 7)
15	Financial District	9.27%	14	27.37	81.26	31	22.5
18	West of Twin Peaks	17.50%	27	28.84	83.91	19	23
34	North Beach	11.68%	20	28.24	82.83	26	23
2	Haight Ashbury	20.10%	31	28.56	83.41	22	26.5
6	Diamond Heights	31.65%	35	28.72	83.70	21	28
7	Lakeshore	17.38%	26	25.24	77.43	34	30
29	Twin Peaks	22.75%	33	28.13	82.63	28	30.5
4	Inner Sunset	20.49%	32	27.54	81.57	29	30.5
10	Treasure Island/YBI	18.27%	29	26.45	79.61	33	31
31	Presidio	32.78%	36	24.49	76.08	35	35.5
1	Seacliff	29.28%	34	21.69	71.05	37	35.5
37	Golden Gate Park	47.69%	37	24.02	75.23	36	36.5

Source: Author’s data

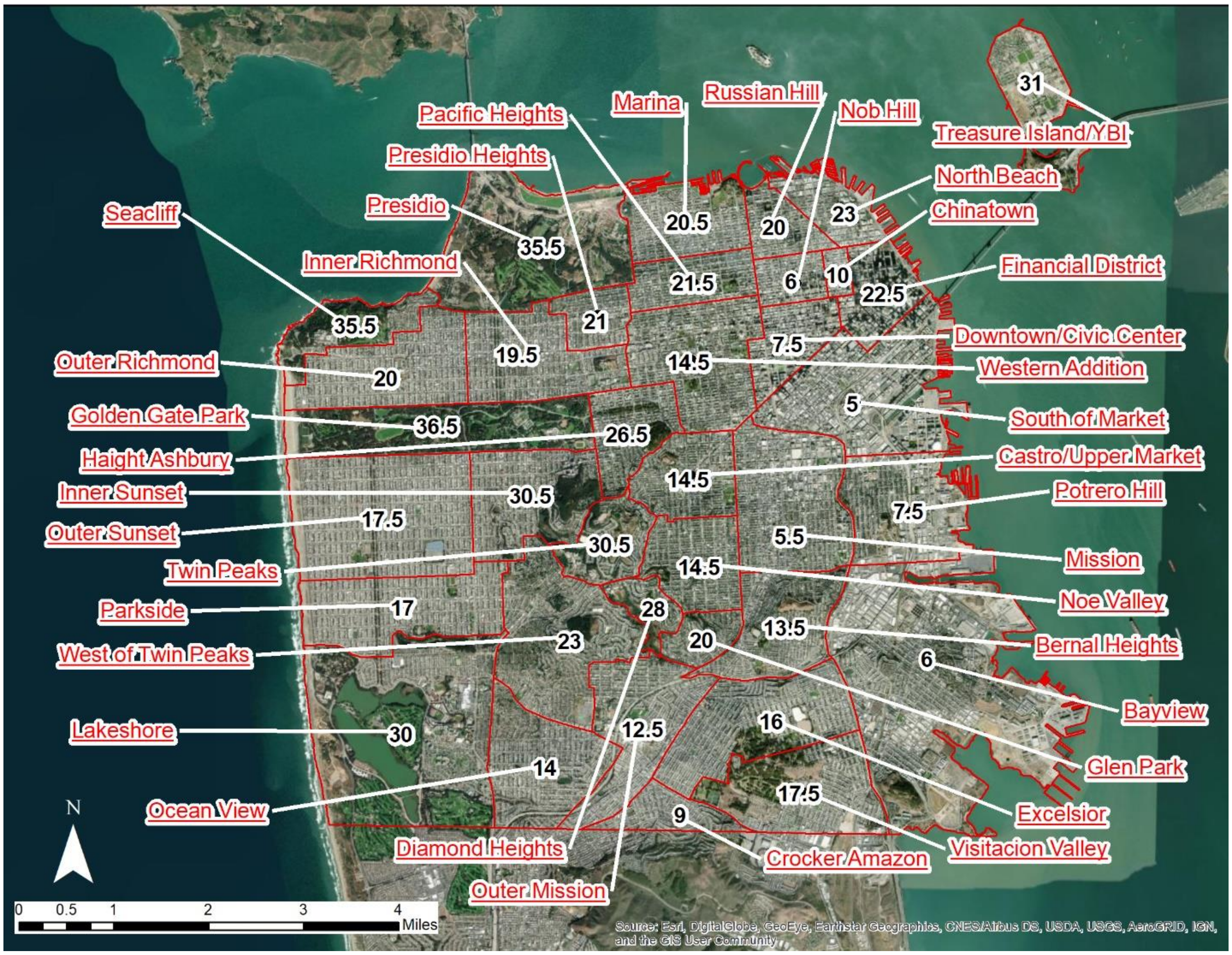

Figure 13: Combined Ranking Score of Each Neighborhood Within San Francisco. Source: Map created by Author Using Basemap Layers from Esri.

Once all the LandSat 8 images were collected and made into LST rasters, the average temperature for the City for that month was established and recorded into an Excel spreadsheet. The resulting data was then plotted to determine whether temperatures have been increasing during the summer as the years have gone by (Figure 14).

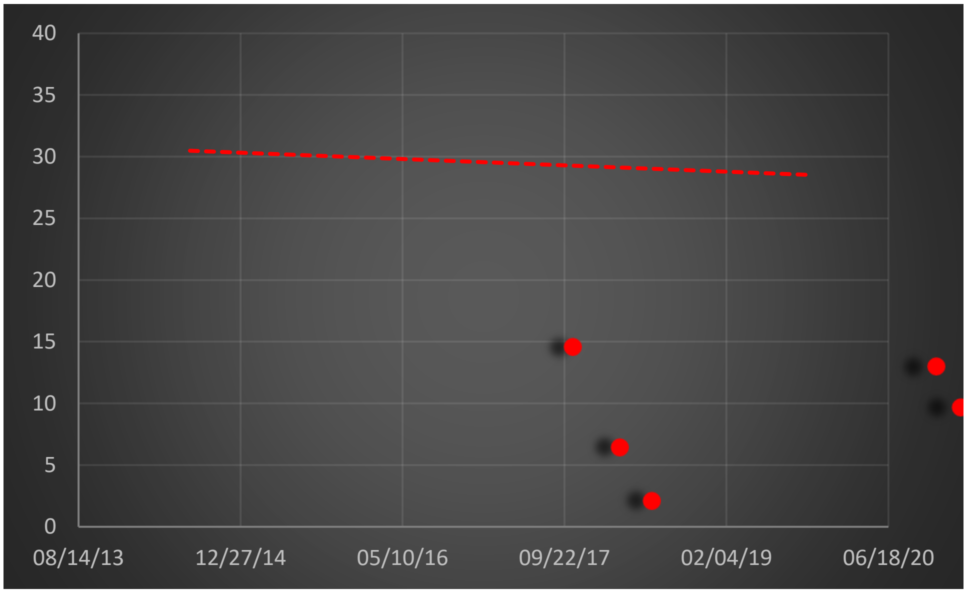

Figure 14: San Francisco Temperature Change Over Time. The dashed line shows best fit line. Source: Image created by author.

3.2 Which Neighborhoods Should be Prioritized for Increases in Tree Canopy

In order to find which neighborhoods could benefit the most from new tree plantings, the average temperature for the highest-ranking neighborhoods was carefully examined. Once the highest-ranking neighborhoods were selected, the Raster Calculator was used to help identify which areas in those neighborhoods experienced the highest temperatures. An examination of Table 2 shows that the top ranked neighborhoods, in terms of combined low tree canopy cover and high average temperatures, were the South of Market neighborhood, followed by the Mission neighborhood. Tied for third place were the Bayview and Nob Hill neighborhoods.

3.2.1 South of Market Neighborhood

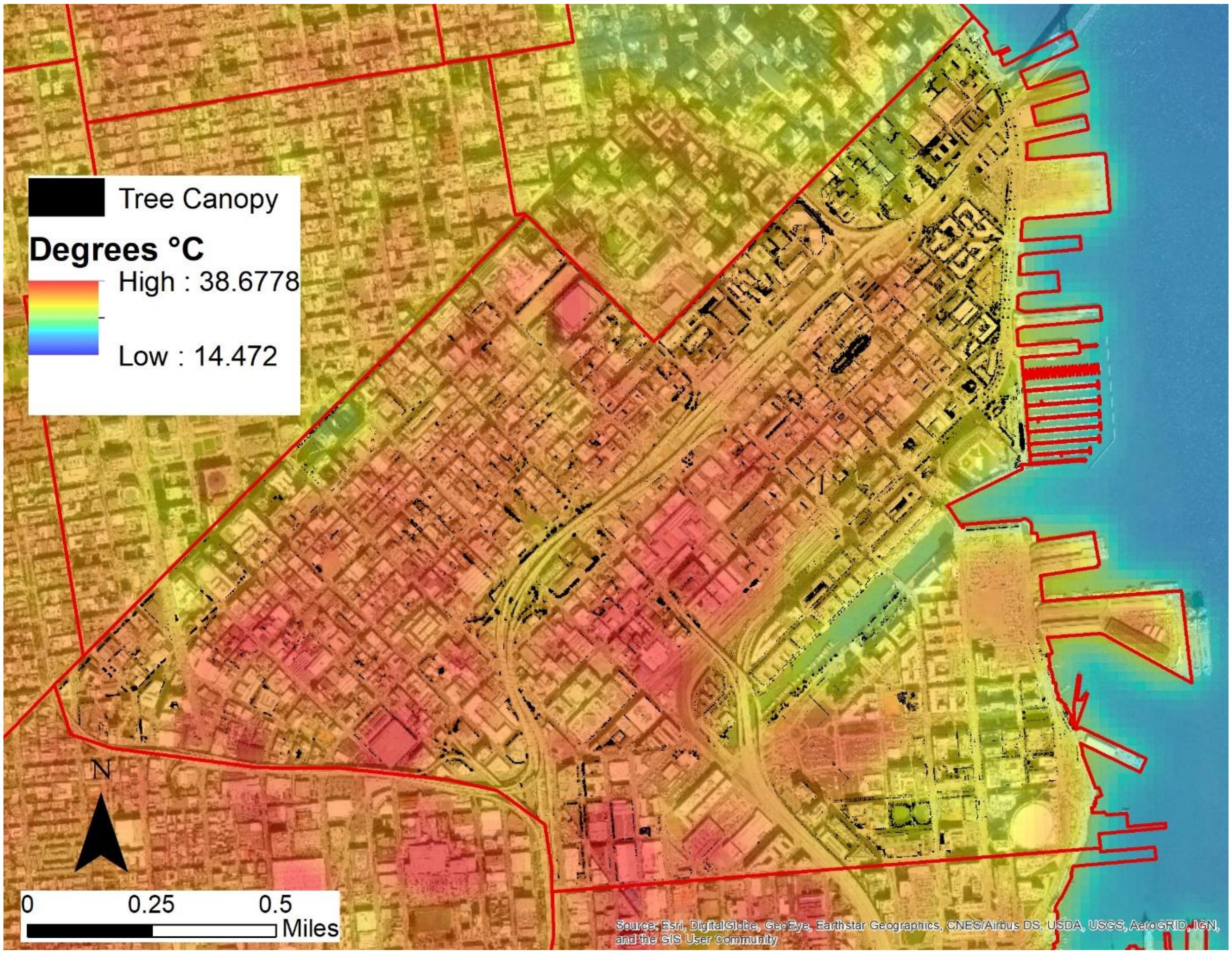

Figure 15: South of Market Neighborhood LST Map. Source: Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

The South of Market neighborhood ranked the lowest when both tree canopy and average temperature were taken into consideration. In terms of tree canopy cover, South of Market was ranked the second lowest neighborhood in the City. South of Market has a tree canopy that only covers approximately 4.11% of the neighborhood area. This neighborhood did score better when it came to average temperature, ranking as the eighth lowest neighborhood in terms of heat, with an average temperature of approximately 30.2 degrees Celsius. Figure 15 displays an LST map zoomed into the South of Market neighborhood, with the tree canopy shown in black for better contrast with the LST raster.

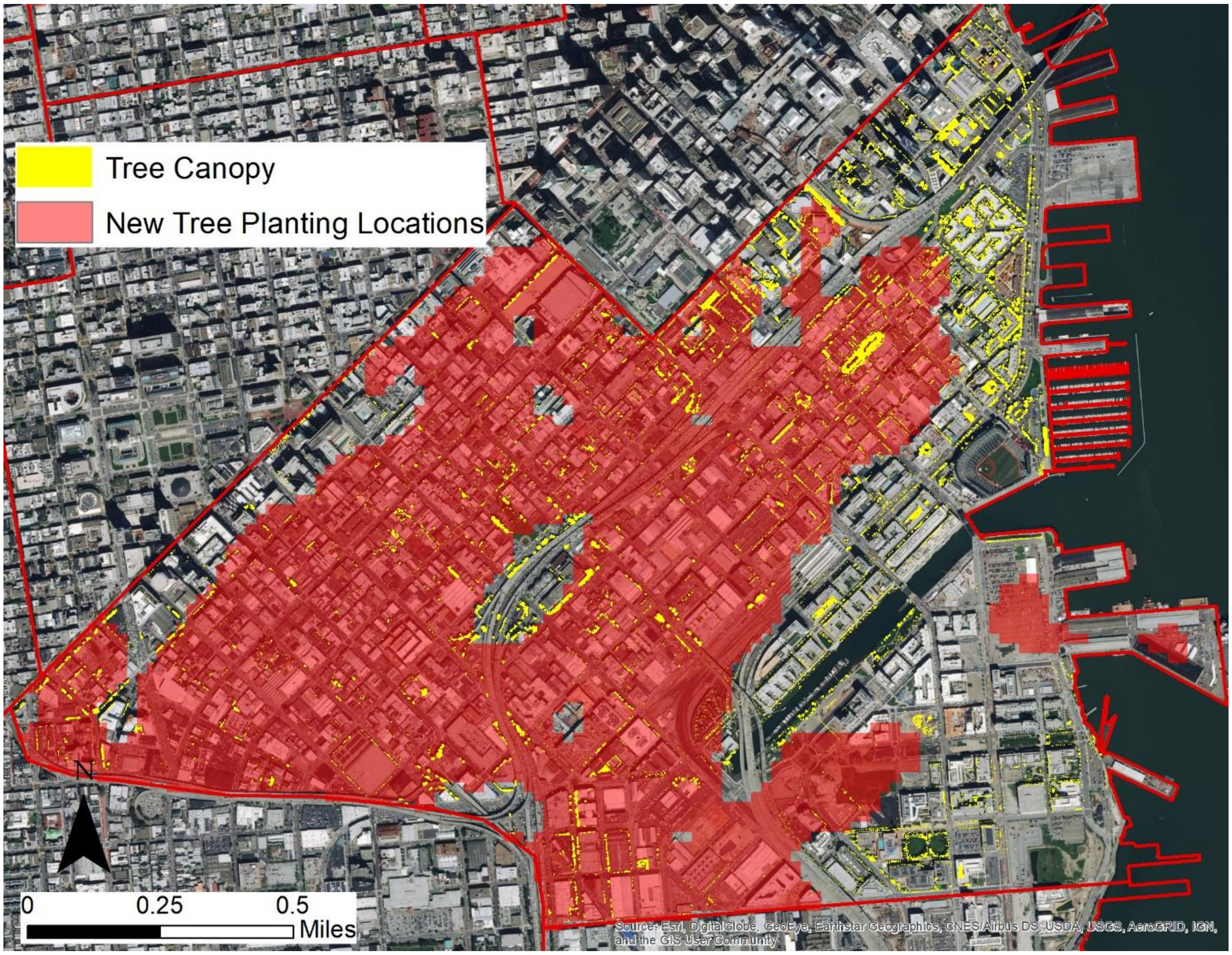

Figure 16: South of Market Neighborhood Possible Tree Planting Locations. Source: Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

Figure 16 above shows the South of Market neighborhood as well as an area highlighted in red representing the part of the neighborhood with above the average temperature of that neighborhood, which is 30.2 degrees Celsius. The image also displays the tree canopy for the neighborhood, shown in yellow. From Figure 16, it is evident that a significant portion of the neighborhood is above the mean temperature. It is also easy to see that much of the tree canopy is located outside of the red area. In order to determine which areas were above the average temperature for the neighborhood, the Raster Calculator tool was used where (Figure 17):

$$LST>30.2$$

LST is the raster produced in Section 3.1.3 and 30.2 is the average temperature for South of Market derived from Figure *12*. The resulting image was then clipped by the extent of the neighborhood. From this image, we can deduce that the red area is the location where tree planting should be focused to achieve the greatest reduction in temperature for the neighborhood.

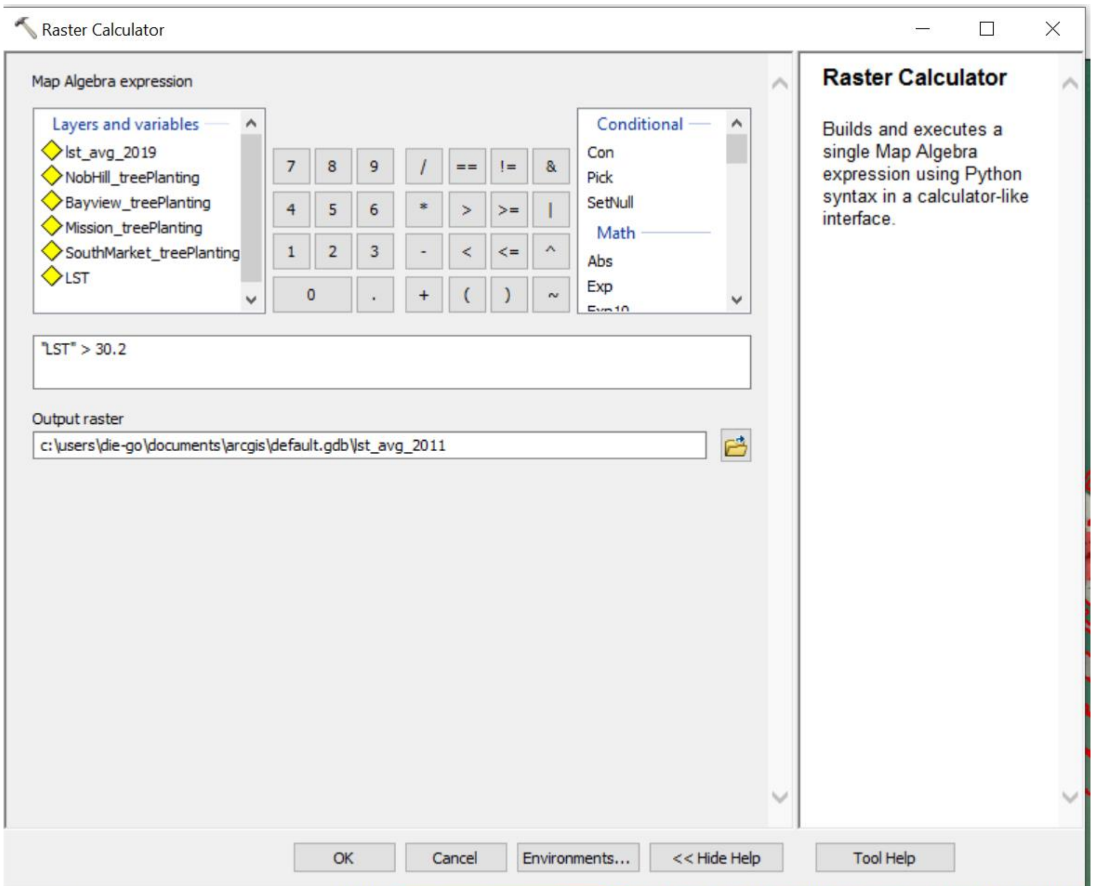

Figure 17: Raster Calculator Tool Used to Determine areas Above the Average Temperature of the South of Market Neighborhood. Source: Image created by author.

3.2.2 Mission Neighborhood

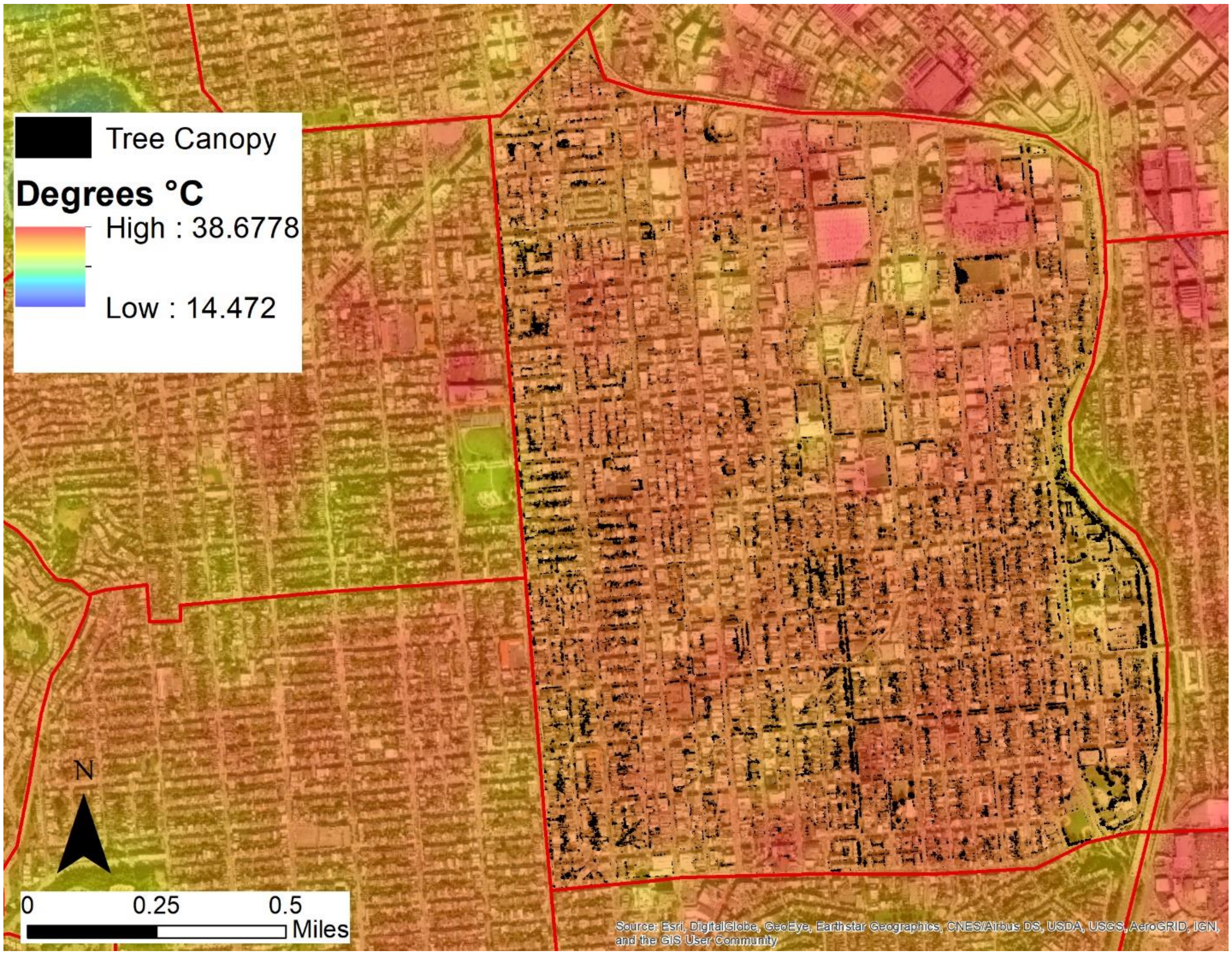

Figure 18: Mission Neighborhood LST Map. Source: Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

The Mission neighborhood was ranked the second lowest, after the South of Market neighborhood, when both tree canopy and average temperature were examined. The Mission neighborhood did not rank too poorly when it came to tree canopy, as it was ranked the tenth lowest overall with a tree canopy that covers approximately 7.51% of the neighborhood. In terms of temperature, this neighborhood was ranked the lowest out of all the neighborhoods with a temperature of 31.5 degrees Celsius.

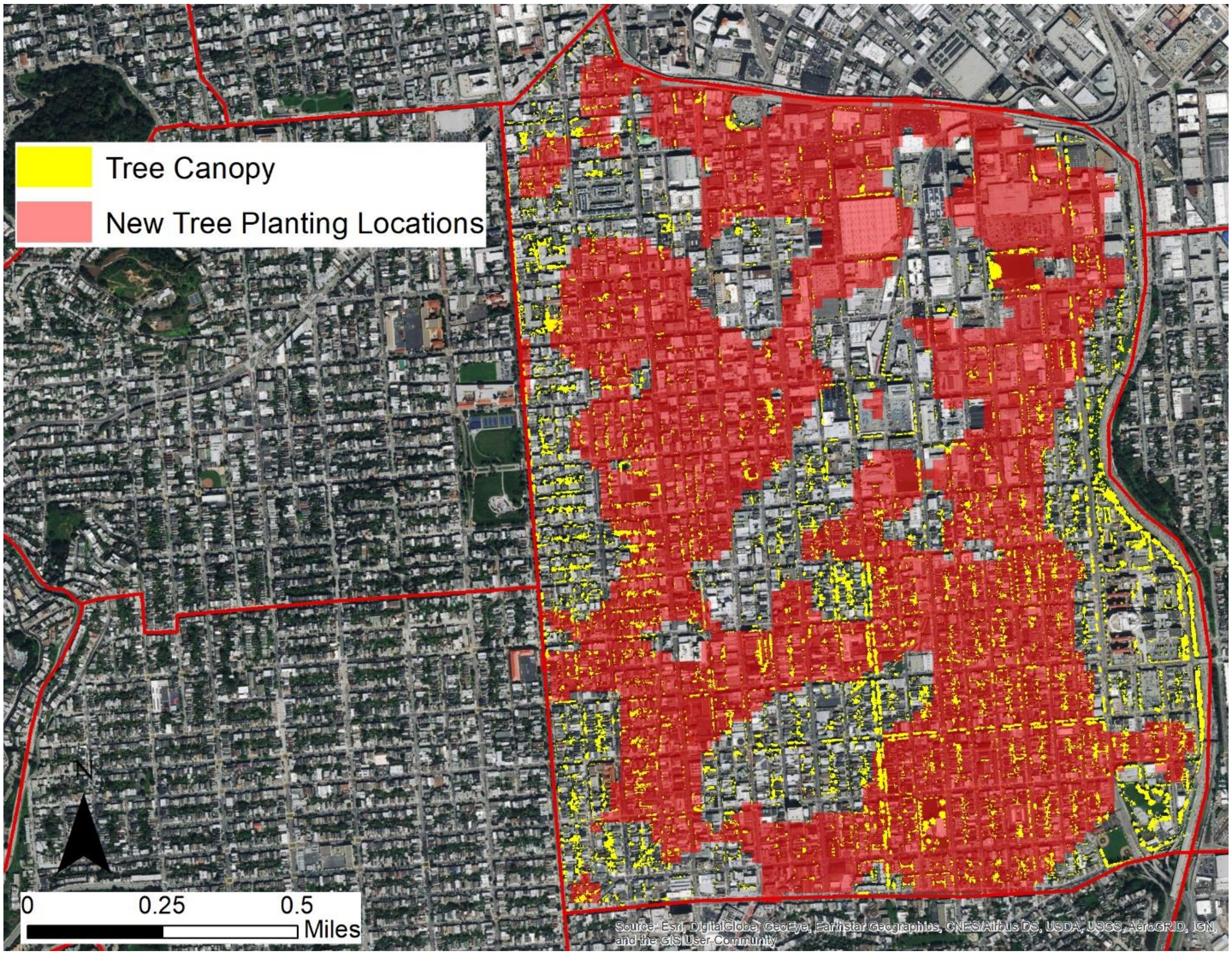

Figure 19: Mission Neighborhood Possible Tree Planting Locations. Source: Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

Figure 19 above displays the Mission neighborhood along with its tree canopy, represented in yellow. The area in red signifies the locations in the neighborhood that are above the mean temperature, 31.5 degrees Celsius, for that neighborhood. In order to determine this area for this neighborhood, the Raster Calculator tool was utilized where (Figure 20):

$$LST>31.5$$

LST is the raster produced in Section 3.1.3 and 31.5 is the average temperature for the Mission neighborhood derived from Figure 12, the resulting image was then clipped by the extent of the neighborhood. The area in red represents those location that could be considered for new tree plantings to reduce surface temperatures within the neighborhood. Upon examination of Figure

19, it appears that a majority of the canopy seems to be located in the southern portion of the neighborhood, yet the locations that see the highest temperatures are distributed throughout the neighborhood. Examining Figures 18 and 19, one can see that there is a street that is lined with trees on both sides, in the southern portion of the neighborhood. If the trees on this street were to be extended all the way to the north of the neighborhood, it could act as a connected pathway for the neighborhoods to the north and the south, like what was mentioned in the Sacramento Urban Forest Master Plan.[159]

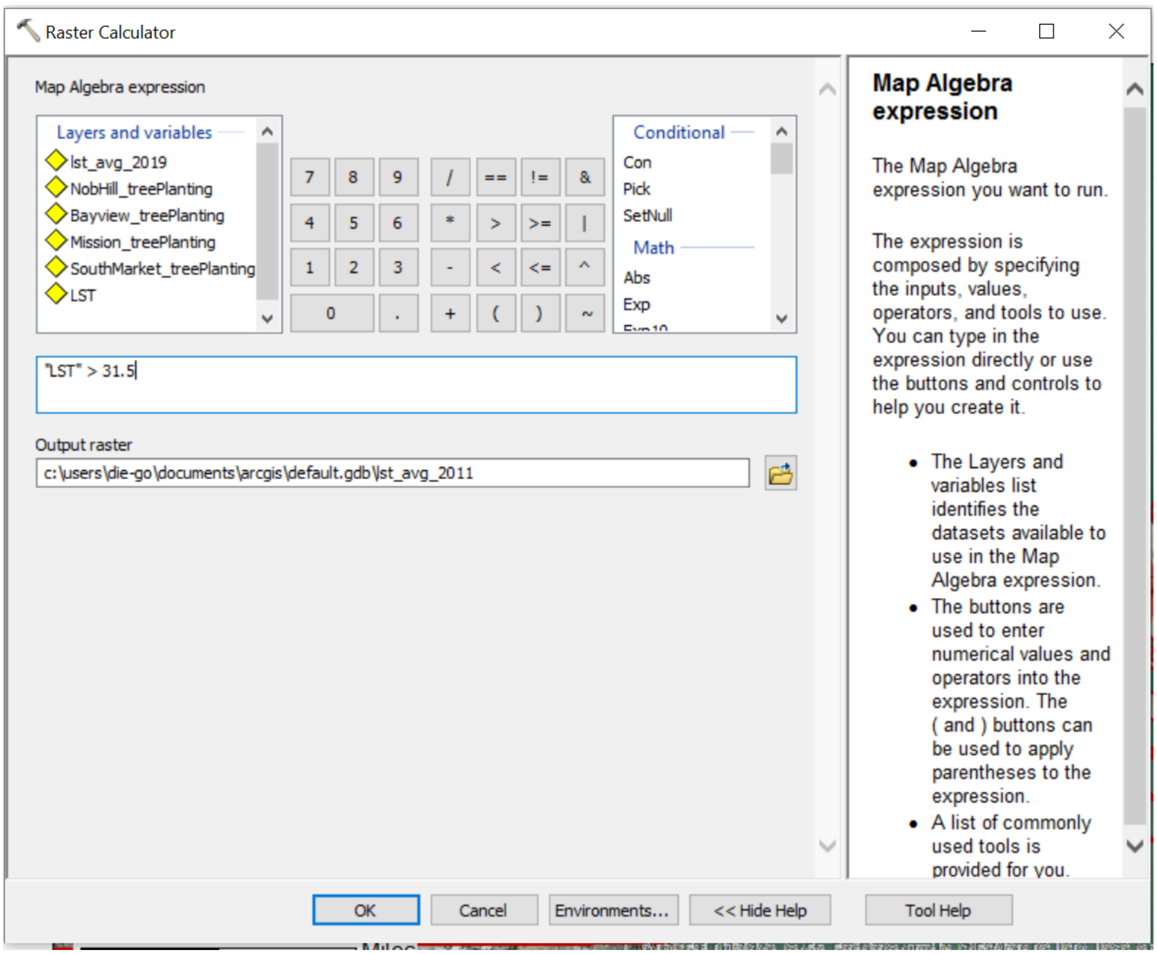

Figure 20: Raster Calculator Tool Used to Determine areas Above the Average Temperature of the Mission Neighborhood. Source: Image created by author.

[159] City of Sacramento, "2035 General Plan," 2015.

3.2.3 Bayview Neighborhood

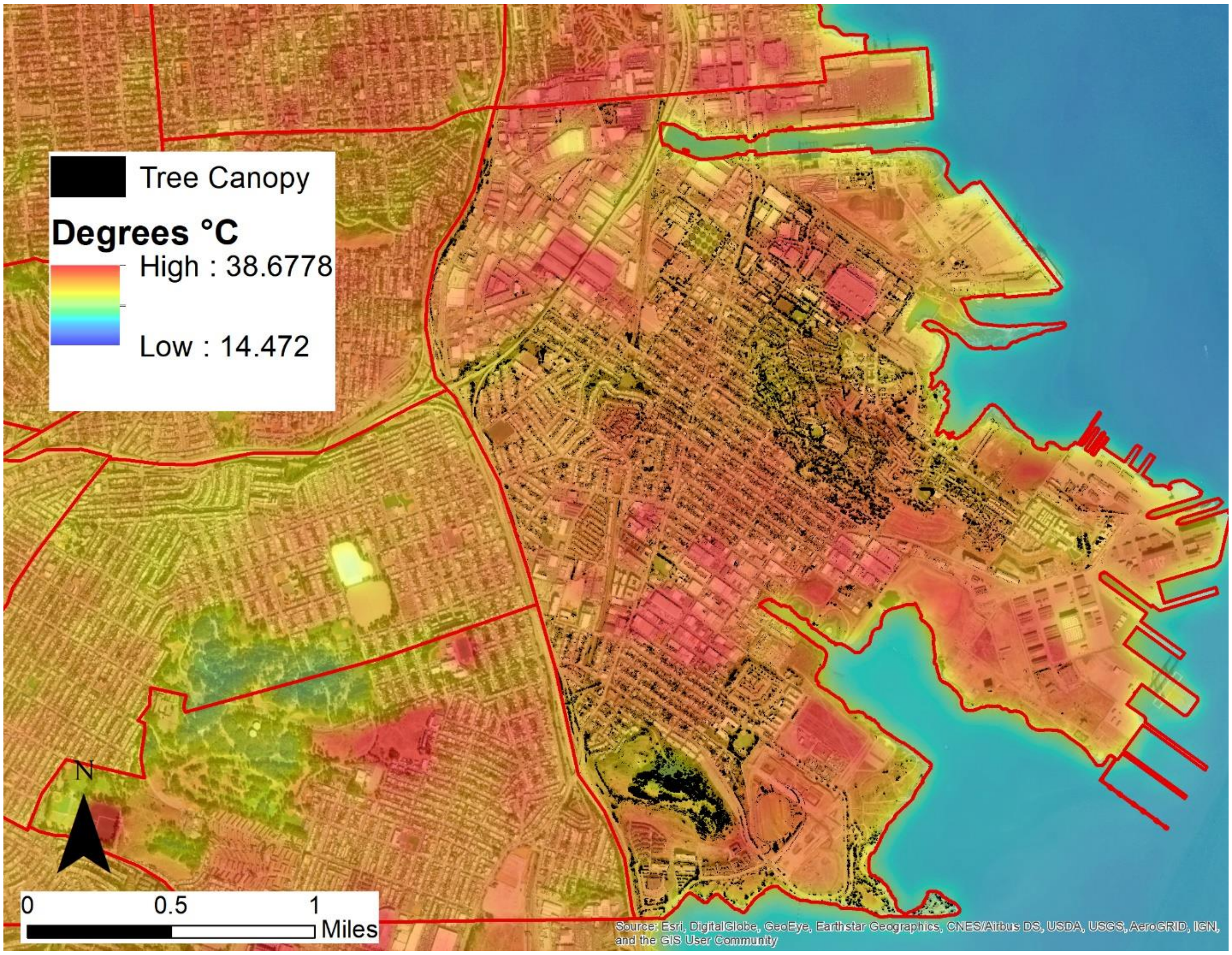

Figure 21: Bayview Neighborhood LST Map. Source: Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

The Bayview neighborhood ranked the ninth worst when it came to tree canopy cover. This did not come as a surprise as this neighborhood has a tree canopy that only covers 6.75% of the neighborhood. In regard to temperature, the Bayview neighborhood ranked the third worst, with an average temperature for the neighborhood of 30.8 degrees Celsius. When both categories were combined, the Bayview neighborhood was tied for the third worst neighborhood overall.

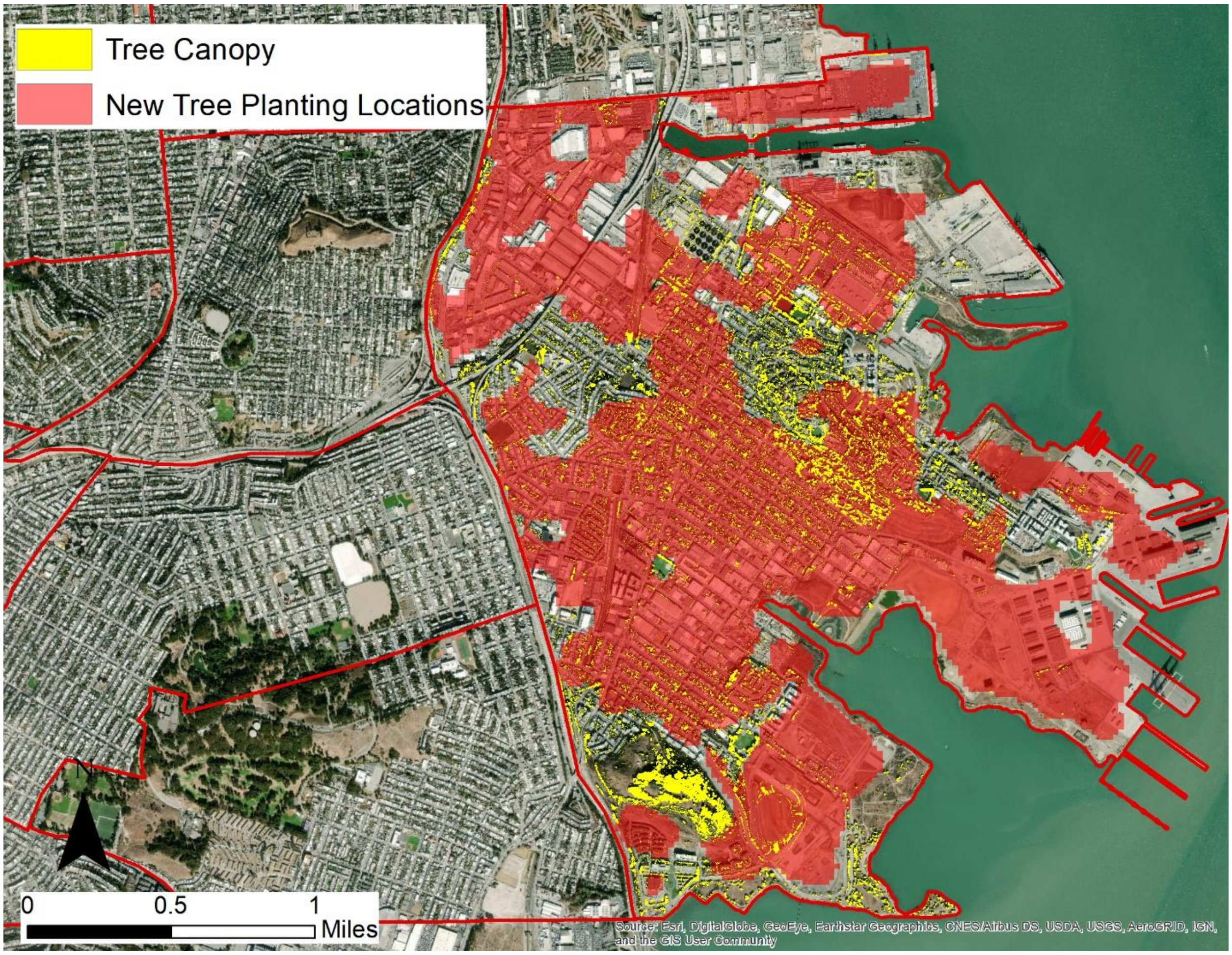

Figure 22: Bayview Neighborhood Possible Tree Planting Locations. Source: Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

Figure 22 above displays the Bayview neighborhood along with its tree canopy represented in yellow. The area in red represents the location where new tree plantings could take place to reduce surface temperatures within the neighborhood. This area represents the locations in the Bayview which are above the mean temperature, 30.8 degrees Celsius, for this neighborhood. In order to determine this area for the neighborhood, the Raster Calculator tool was used where (Figure 23):

$$LST>30.8$$

LST is the raster produced in Section 3.1.3 and 30.8 is the average temperature for the Bayview neighborhood derived from Figure 12, the resulting image was then clipped by the extent of the neighborhood. Examination of Figure 22 shows that the majority of the canopy seems to be in the center of the neighborhood. It also appears that most of the neighborhood sees temperatures which are above the mean.

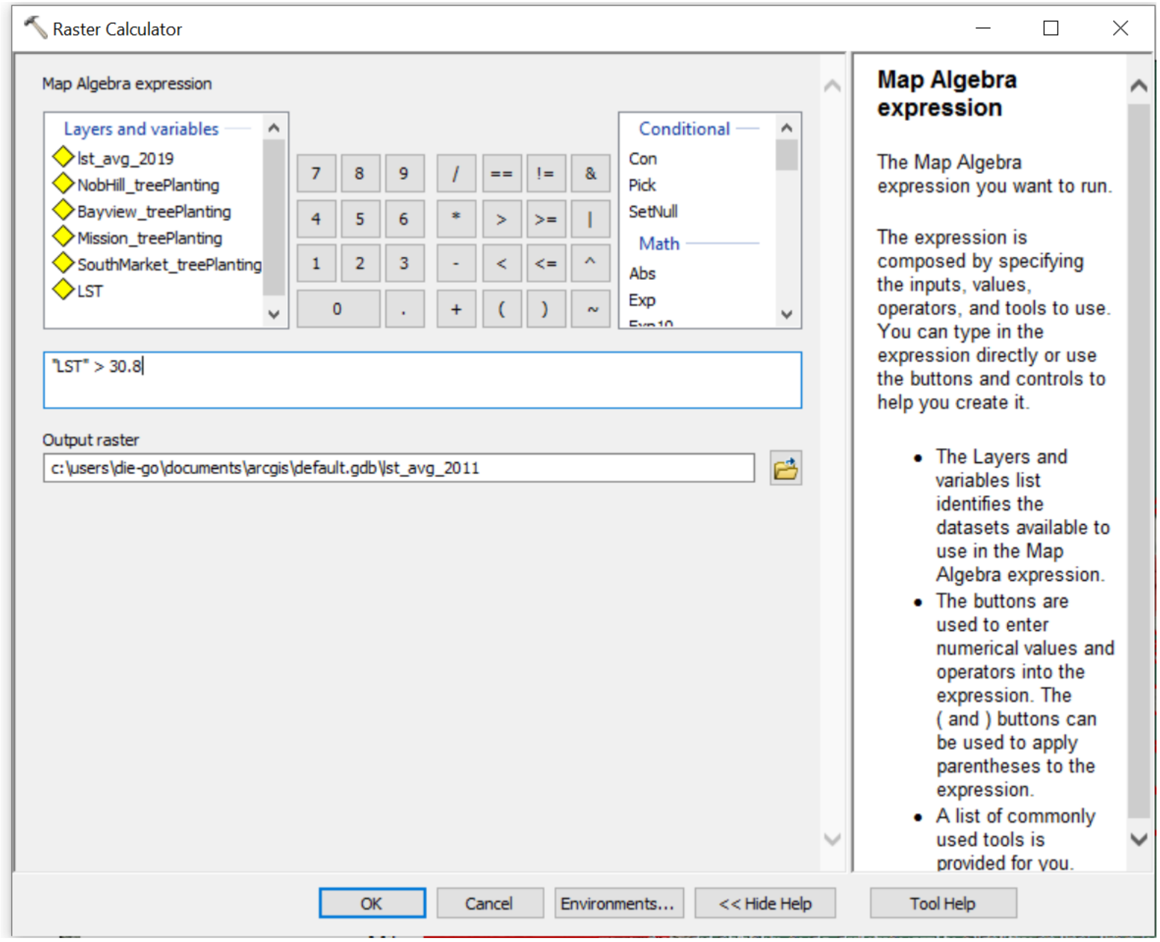

Figure 23: Raster Calculator Tool Used to Determine areas Above the Average Temperature of the Bayview Neighborhood. Source: Image created by author.

3.2.4 Nob Hill Neighborhood

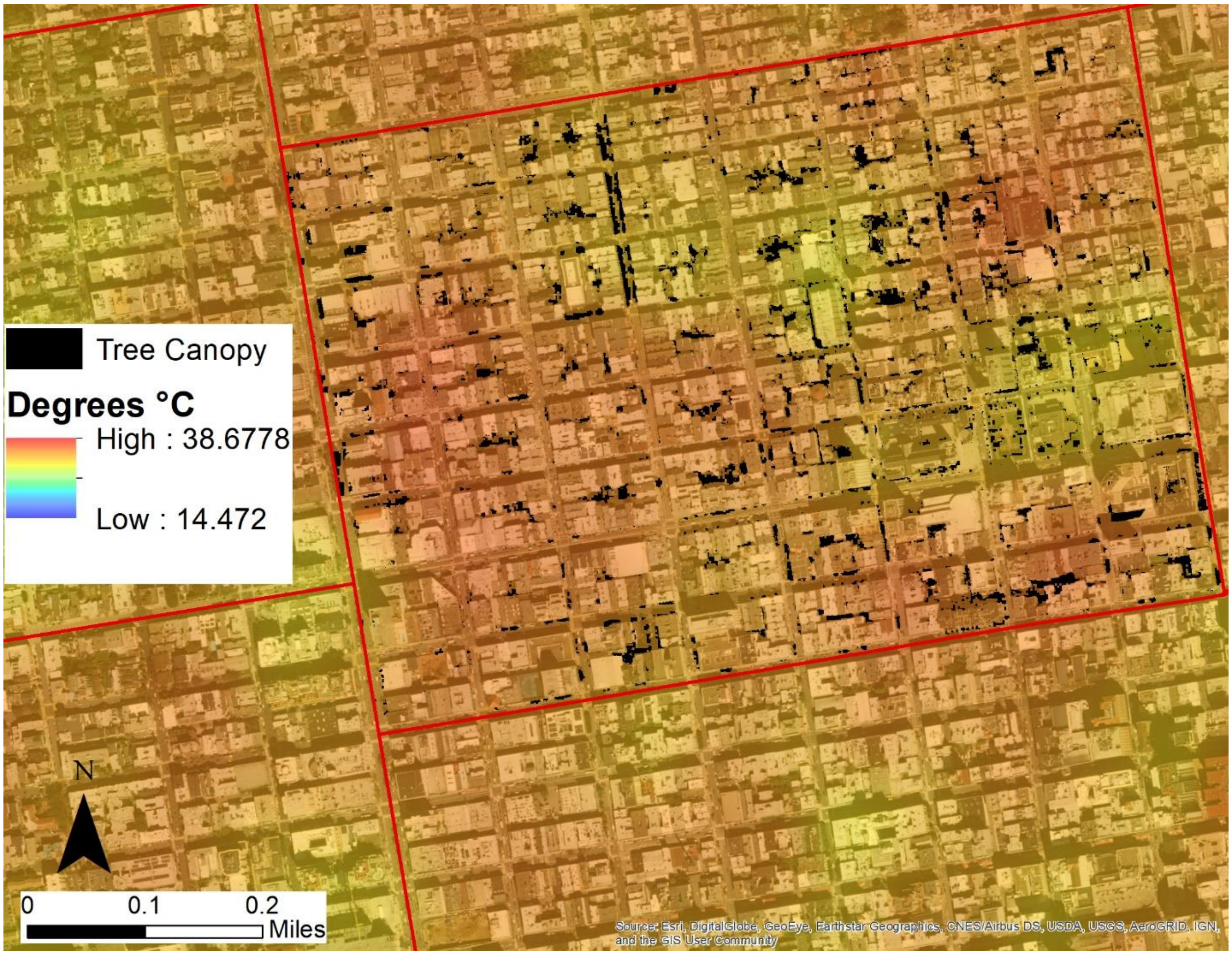

Figure 24: Nob Hill Neighborhood LST Map. Source: Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

The Nob Hill neighborhood was tied for the third worst neighborhood overall. This neighborhood ranked similarly to Bayview, except it was the inverse of how Bayview ranked for tree canopy and average temperature. For tree canopy, the Nob Hill ranked the third worst, with a tree canopy that only covers 4.99% of the neighborhood. However, in regard to temperature, the Nob Hill ranked the ninth worst, with an average temperature of 30.2 degrees Celsius. Figure 24 highlights the different temperatures the neighborhood experiences as well as the tree canopy represented in black.

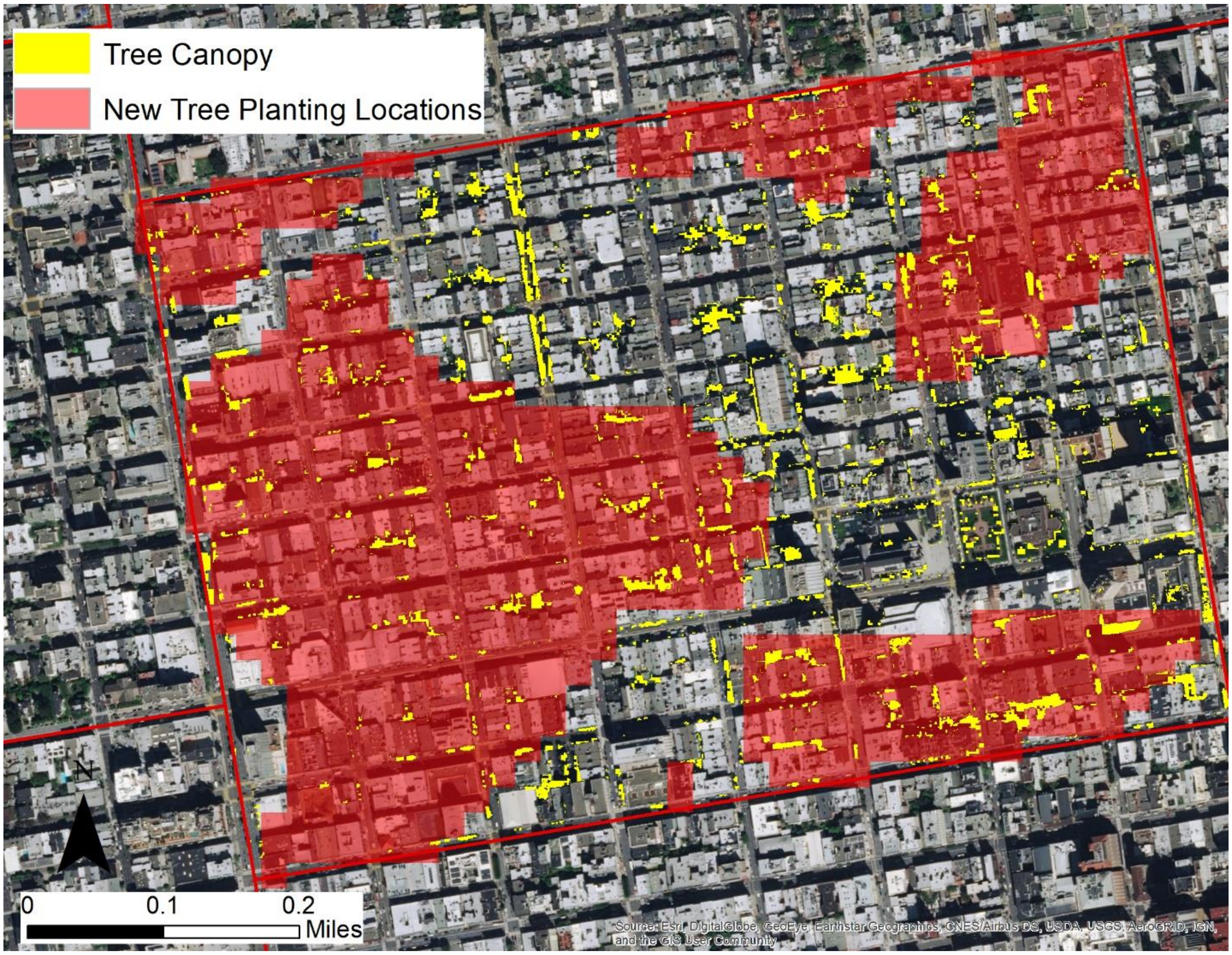

Figure 25: Bay View Neighborhood Possible Tree Planting Locations. Source: Map created by Author Using Basemap Layers from Esri; Data obtained from USGS.

Figure 25 above shows the Nob Hill neighborhood as well as an area highlighted in red, which represents the part of the neighborhood that is above the average temperature of 30.2 degrees Celsius. The image also displays the tree canopy for the neighborhood, shown in yellow. Figure 25 highlights that a portion of the neighborhood is above the mean and that much of the tree canopy is located outside of the red area. In order to identify this area for the neighborhood, the Raster Calculator tool was used where (Figure 26):

$$LST>30.2$$

LST is the raster produced in Section 3.1.3 and 30.2 is the average temperature for the Nob Hill Neighborhood derived from Figure 25, the resulting image was then clipped by the extent of the neighborhood. This red area represents the location where tree planting should be focused to achieve the greatest reduction in temperature for the neighborhood. In the northern portion of Figure 25 there is a street that is continuously lined with trees for about two and half blocks, this could be extended all the way to the south of the neighborhood, it could then act as a connected pathway for the neighborhoods to the north and the south, like what was mentioned in the Sacramento Urban Forest Master Plan.[160]

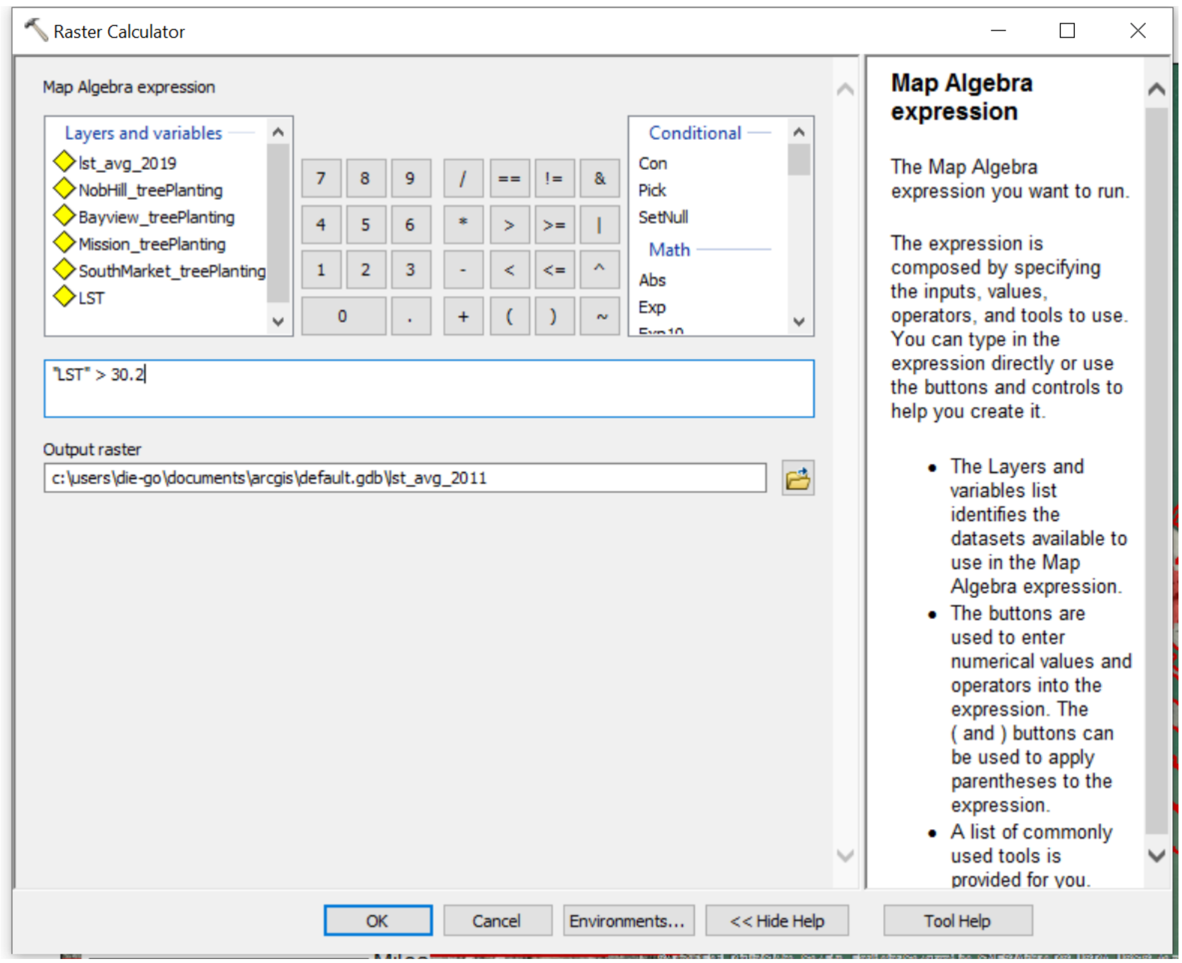

Figure 26: Raster Calculator Tool Used to Determine areas Above the Average Temperature of the Nob Hill Neighborhood. Source: Image created by author.

[160] City of Sacramento, "2035 General Plan," 2015.

3.3 Discussion of Findings

It appears from the data collected and analyzed in this chapter, that the neighborhoods which experience higher temperatures also tend to have less tree canopy, and vice versa. The average temperature for the entire city was found to be 28.43 degrees Celsius during the summer of 2019, meaning that 23 neighborhoods experience higher temperatures than the city-wide average. The research found that there were multiple neighborhoods with average temperatures higher than 30 degrees Celsius for the summer of 2019. There were also multiple instances where parts of the City experienced temperatures over 37 degrees Celsius. Looking at Figure 12, it is no surprise that the eastern portion of the City experiences higher temperatures while the western portion of the City experiences cooler temperatures. This is probably due to the more intense land uses on the east, as well as the cooling effect the Pacific Ocean has on the west. An interesting finding was that the Nob Hill neighborhood did not have much tree coverage, even though it is an affluent neighborhood with half of the households earning more than $100,000 per year.[161] Although Figure 14 shows that temperatures have been decreasing over time in San Francisco, unfortunately the data used was so intermittent, that was not possible to draw any definitive conclusions.

Now that the neighborhoods which should be prioritized for increased tree plantings have been identified, it is necessary to examine current policies as well as new initiatives the City of San Francisco should consider to accomplish the goal of increasing its tree canopy.

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[161] US Census Bureau. *San Francisco city*. n.d. https://www.census.gov/quickfacts/fact/table/sanfranciscocitycalifornia,US/PST045218 (accessed April 22, 2019)

Chapter 4: An Analysis of Tree Planting Policy Tools

4.1 Overview

Although there are many strategies and policies that could be applied to the City of San Francisco to increase its tree canopy, many of these policies might be redundant in that they aim to accomplish the same goal. In an ideal world, there would be no dilemma as to which policies to implement because one could implement them all. However, this is not possible and there are many factors that need to be examined when making these decisions. This chapter aims to group some of the policies from the cities mentioned in Chapter 2 of this report to form a set of alternatives, and then evaluate those alternatives based on the following criteria:

1. **Technical Feasibility**: whether a policy or program is effective or not at achieving its purpose. This is necessary because if a program will not help increase tree canopy, there is no need to even examine it.
2. **Economic Possibility:** compares the costs against the benefits. If a programs costs outweigh its potential benefits, it will never be an effective program.
3. **Political Desirability**: the impact on relevant decision makers and stakeholders. This looks at how willing or adverse those in decision making roles are to the program.
4. **Administrative Operability**. How possible is it to implement the program within an administrative, political, and social context? If the administrative capability to implement the program is not sufficient, the program will fail.
5. **Equity**. How is the program going to affect people with differing demographic characteristics?

4.2 Alternatives

4.2.1 Cost-Effective Alternative

The Cost-Effective Alternative aims to increase tree canopy while taking costs into consideration. One policy that would be straightforward to implement would be to encourage developers in the planning stage to avoid taking out trees whenever feasible. When trees are required to be removed, there should be a tree ordinance in place in which the developers are required to at least replace the tree on a one to one basis.[162] An important aspect that is not always considered is the need to have a suitable location to plant trees in the first place. Criteria should be developed to determine a site's ability to facilitate new tree plantings and to protect them accordingly.[163] Part of this criteria should be to examine which neighborhoods have the least amount of trees, like what was done in section 3.1 of this report, and to prioritize the planting locations which fall within the area that experiences the highest temperatures, like those in section 3.2.

Since this alternative's goal is to increase canopy while being the most cost effective, the City should prioritize trees that provide the most canopy which would improve the environmental health and livability of the City.[164] Many times when new tree plantings occur, there is no certified or trained arborist on staff. Consulting with an arborist early ~~on~~ in the process can greatly increase the tree survival and welfare of the tree.[165] Also, a management plan is needed which outlines how the trees will be maintained and pruned and it is recommended that this plan should be revised every five years.[166] An important factor for the longevity of the urban forest is to get community buy-in; a concerted effort should be made to sell the public on the idea that San Francisco is a city of trees.[167] In order to help educate the public on the importance of the City's urban forest, it is first necessary to enhance the understanding of the ecosystem services that are provided by the City's urban forest. This can

[162] City of Sacramento, "Sacramento Urban Forest Management Plan," 1994.
[163] City of Palo Alto, "Palo Alto Urban Forest Master Plan," 2019.
[164] City of Sacramento, "Sacramento Urban Forest Management Plan," 1994.
[165] CRTI, "Chicago Region Trees Initiative Master Plan," 2019.
[166] City of Sacramento, "Sacramento Urban Forest Management Plan," 1994.
[167] Ibid.

be accomplished by having the City's Public Works Department submit annual reports on the total number of trees, new tree plantings, trees removed, and the number of trees pruned.[168] Once the ecosystem services that are provided by the City's urban forest are better understood, an outreach program should be developed which firsts targets the neighborhoods listed in section 3.2. This outreach program should help foster a sense of ownership between the residents of these neighborhoods and the trees.

4.2.2 Largest Impact Alternative

The Largest Impact Alternative aims to achieve the greatest increases in tree canopy without worrying about budgetary constraints as much. This alternative builds on the previous two alternatives and recommends additional policies. Under this alternative, every public tree in the City should be inspected once a year as part of a risk management program.[169] This will allow the City to track the health of the urban forest on a year by year basis. The City should implement a rotational replacement strategy where the City removes and replaces 0.5 percent of its trees annually.[170] This will allow the City the opportunity to ensure that the urban forest has certain levels of species diversity while mitigating the risk of catastrophic loss.

San Francisco's Urban Forest Plan calls for the creation of a new division within the Public Works Department, which is already in charge of all oversight of the urban forest. Going a step further, the City could also create a new department whose sole purpose is to ensure the City has enough baseline information so that changes in the urban forest can be monitored.[171] Whenever a street is going be worked on or redesigned, the City should maximize parkways and tree wells to enhance the street tree grow space.[172] The City should also implement a tree giveaway program where it provides residents with free fruit or native trees and it should also introduce climate adaptive trees.[173] This program should only be offered to those who live within one of the neighborhoods identified in section 3.2, or at the very least those residents

[168] City of Santa Monica, "Santa Monica's Urban Forest Master Plan," 2017.
[169] City of Santa Monica, "Santa Monica's Urban Forest Master Plan," 2017.
[170] City of Sacramento, "Sacramento Urban Forest Management Plan," 1994.
[171] City of Palo Alto, "Palo Alto Urban Forest Master Plan," 2019.
[172] City of Santa Monica, "Santa Monica's Urban Forest Master Plan," 2017.
[173] City of Palo Alto, "Palo Alto Urban Forest Master Plan," 2019.

should be given priority. This will not only increase the number of trees within the City, but it will also encourage residents to take ownership of these trees and become more invested in the longevity of the urban forest as well as increasing tree canopy in neighborhoods that are currently underrepresented.

4.2.3 Balanced Approach Alternative

The Balanced Approach Alternative aims to be the middle ground between the Cost-Effective Alternative and the Largest Impact Alternative. Under this approach, one the first things that should be accomplished is to establish a database that keeps track of each tree's species, location, age, health, and the last time it was pruned.[174] The City should also aim to maintain their trees on a 3-5 year cycle depending on the species of that tree.[175] Each year, the Public Works Department should publish a work plan detailing the tree pruning and planting schedule for the next 12 months.[176] Each time new trees are maintained, this information should be added to the database, thus continually expanding that database. Additionally, the management of pests and diseases should be more proactive instead of reactive because it is less costly, results in lower catastrophic loss, and can help improve the value and services an urban forest provides.[177]

The City should make connected pathways between neighborhoods that are completely lined with trees.[178] These pathways will create something like an urban highway of trees allowing people to cross the City while always being shaded by trees. The Nob Hill and Mission neighborhoods already have a street that is lined with trees, these streets could be further built out so that they can serve as a starting point to develop this tree highway. Anytime there are construction-related activities, tree protection measures should be mandatory, reducing the number of trees that could die due to the shock of construction.[179] Furthermore, the City should develop a master tree planting list that not only takes a tree's canopy size into

[174] City of Sacramento, "Sacramento Urban Forest Management Plan," 1994.
[175] Ibid.
[176] City of Santa Monica, "Santa Monica's Urban Forest Master Plan," 2017.
[177] CRTI, "Chicago Region Trees Initiative Master Plan," 2019.
[178] City of Sacramento, "Sacramento Urban Forest Management Plan," 1994.
[179] City of Santa Monica, "Santa Monica's Urban Forest Master Plan," 2017.

consideration, but also the habitat value they provide for birds, butterflies and pollinators as well as their carbon sequestration potential, energy use reduction potential, and their potential to provide healthy, local food to residents.[180] In order to protect trees legally, the City should require a permit to plant, remove, or maintain any tree that is in the public right of way, and those trees should only be removed if the trees are dead or dying and cannot be saved, or the trees present a structural failure risk.[181]

4.2.4 Do Nothing

This alternative assumes that no new policy action is taken, and conditions continue as they are today. This would mean that public trees are still maintained by the City, but there would be no way to track any of the changes, thus making it difficult to determine if tree canopy is increasing or decreasing.

4.3 Analysis of Alternatives

In order to evaluate the different alternatives of this report, the following analytical method was used:

Nondominated-Alternatives Model (Table 3): This model examines each alternative and ranks them against the evaluation criteria outlined in Section 4.1. The alternatives are ranked with 1st being the best option and 4th being the lowest rank. Alternatives that rank 1st will be highlighted in green, 2nd will be highlighted in orange, and the lowest ranking option will be highlight in red.

[180] City of Palo Alto, “Palo Alto Urban Forest Master Plan,” 2019.
[181] City of Santa Monica, "Santa Monica’s Urban Forest Master Plan," 2017

Table 3. Non-dominated Analysis of Alternatives

Criteria:	Cost-Effective	Balanced Approach	Largest Impact	Do Nothing
Technical Feasibility	3rd. Tree canopy will be maintained so any increase will be more effective, but tracking will be difficult.	2nd. Tracking will be more effective. Maintenance will be more proactive instead of reactive.	1st. This alternative would be the most likely to see the greatest increases in tree canopy.	4th. Conditions will stay similar as they are today.
Economic Possibility	2nd. Cheapest option. makes new plantings more effective	3rd. A balance between the Cost-Effective and Largest Impact alternatives.	4th. Most expensive option. Maintenance occurs yearly. Infrastructure improvement.	1st. Doing nothing will add no new direct costs.
Political Desirability	2nd. Less regulation changes already in line with how the city operates.	1st. not as expensive to implement while still help achieve the city's goals.	4th. Very expensive to implement with many projects going over budget and long construction times.	3rd. tree canopy still increase but more difficult to track.
Administrative Operability	2nd. Simple to implement not much administrative effort needed might need possible zoning changes.	3rd. Administrative effort for expansion of system in place.	4th. Creating new agency would require significant administrative effort.	1st. Doing nothing would require no new administrative work.
Equity	3rd. New tree plantings occur but not to the level of the other alternatives.	2nd. New tree walkways to connect different areas of the city.	1st. Brings the greatest increase of trees as well as giving tree directly to residents.	4th. Conditions stay the same where some neighborhoods have more tree canopy than others.

4.4 Conclusion

While all three alternatives would protect the current tree canopy and at the same time increase it, some would be more effective than others. Out of the four alternatives that were proposed, the Balanced Approach alternative scored the best. The second highest scoring alternative was the Cost-Effective alternative, followed by the Do Nothing alternative, and the

Largest Impact alternative scored the lowest. It was to be expected that the Balanced Approach alternative scored the highest because it was the alternative that aimed to be the most realistic and easy to implement. What was surprising was that the Largest Impact alternative scored the worst. The reason for this is that the costs associated with its implementation would probably make it difficult to convince people that it is money well spent.

Chapter 5: Conclusions and Recommendations for San Francisco

5.1 Discussion of Findings

Although it is true that San Francisco has a fairly temperate climate and the urban heat island effect may not be as significant of a concern when compared to other cities, it is still something worth considering as the effect can impact temperatures within the City in the future. Because San Francisco does not normally experience very high temperatures, it is even more likely that when an extreme temperature event does occur, it can catch people off guard and unprepared. For these reasons, just like with tree maintenance, it is better to be proactive to get ahead of a problem before it is in front of us and it becomes more difficult to control.

Many neighborhoods within San Francisco lack any significant tree canopy cover, to the extent that only a handful of the neighborhoods have more tree canopy than the city-wide average of 22 percent. Chapter 1 assumed that neighborhoods that had less canopy cover would experience higher temperatures. Since temperature is highly influenced by geography, this assumption was shown to be true most of the time. The neighborhoods that experienced high temperatures while still having high tree canopy cover tended to be located in the parts of the City that experienced higher temperatures. Research also revealed that much of the tree canopy was located in a concentrated portion of the neighborhood, leaving the rest of the neighborhood without any significant canopy cover.

The four neighborhoods that experienced the highest temperatures for the summer of 2019 had the least amount of tree canopy cover: South of Market, Mission, Bayview, and the Nob Hill. This was similar to the initial hypothesis which speculated that the Bayview, Mission, and the Financial District neighborhoods would be likely candidates. Chapter 3 makes recommendations of areas to focus tree plantings in order to have the greatest reduction of temperatures within those neighborhoods. Chapters 2 and 4 examined policies already in place and policies which could be implemented in the City of San Francisco to increase tree canopy and reduce the heat island effect. After a review of the policies and the three different alternatives proposed, it was found that the Balanced Approach alternative scored the highest.

This was not unexpected, as it was the alternative that aimed to be the most realistic and easy to implement.

5.2 Limitations of Study

The study revealed a great deal of information, but it was confronted with a few limitations. One limitation was the type of data available. While the tree canopy data used for the geospatial analysis of this study contained most of the tree canopy within the City, it did not contain the full tree canopy in existence today. San Francisco conducted its tree canopy assessment in 2013, so any trees planted after this would not be reflected in the dataset. Although the results would probably not change drastically, it is something to take into consideration in future research. Some Ideas for future research could be how tree canopy coverage correlates to neighborhood income, property values, and other demographic variables.

Another challenge the study encountered relates to the LandSat 8 images that were used to derive the temperature. These images are only available in 16-day increments, meaning that one could only calculate temperature readings twice per month at most. Unfortunately, this does not allow for the most accurate representation. An added drawback encountered was that there are many instances where significant portions of San Francisco were covered by clouds, making many of the images unusable.

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