Managing Urban Forests for Distributive, Procedural, and Recognition Justice

by

Timara Denae Crichlow

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Graduate Supervisory Committee:

Tyler DesRoches, Co-Chair
Paul Coseo, Co-Chair
Rob Melnick
Diane Pataki

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ABSTRACT

City governments have an opportunity to address historic environmental injustices through the management of their urban forests. When applying environmental justice to the management of urban trees, the common approach is to plant new trees in areas with high proportions of underserved residents and low tree canopy. This is the approach taken by many programs, such as the MillionTrees programs in Los Angeles and New York City. However, these initiatives do not always result in just outcomes and, in some cases, exacerbate existing inequities. This suggests the need for a model of urban tree canopy (UTC) justice that encapsulates distributive, procedural, and recognition justice. In this thesis, I suggest such a model of UTC justice that incorporates ecosystem services and disservices to understand resident satisfaction with neighborhood trees. I then apply the model to the case of the Phoenix, Arizona metropolitan area by assessing local UTC plans for mentions of environmental justice. Finally, I use multiple regression analysis to identify the relationship between neighborhood tree canopy percentage and resident satisfaction with neighborhood trees. Results indicate that tree canopy is a statistically insignificant determinant of resident satisfaction in 23 of 30 models. This supports my model of UTC justice in that it suggests that there is a confounding variable between UTC provisioning and resident satisfaction. This thesis culminates in recommendations for city governments, including the use of longitudinal socioecological surveys to evaluate the need for and success of UTC plans for environmental justice.

DEDICATION

In loving memory of Dorthy Jean Crichlow (1942 – 2024)

ACKNOWLEDGMENTS

I would like to acknowledge the mentorship and guidance given to me by my committee and other mentors throughout my program, without whom I would not have been able to learn, grow, and ultimately complete this project. Paul has been incredibly supportive and understanding and continues to be instrumental to my success. Tyler and Rob have guided me since my undergraduate program, seeing potential in me and encouraging me to advance my understanding of the world through this project. Diane's expertise has shaped my understanding of and my interest in urban forestry, and she continues to inspire my academic pursuits. Finally, I thank Connor Sheehan and Kelli Larson for their mentorship and generosity with their time.

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CHAPTER 1

INTRODUCTION

In the United States (US), over 80% of the population lives in urban areas (Hutt-Taylor & Ziter, 2022; Nascimento & Shandas, 2021). Rapid urbanization has led to the conversion of natural lands to built environments, resulting in higher air temperatures in cities than their surrounding areas – also known as the urban heat island (UHI) effect (Middel et al., 2016). While UHI may raise surface and air temperature in a given urban area, empirical evidence confirms that minority and low-income residents along with residents of formerly redlined neighborhoods are exposed to more extreme heat than residents who do not fall into those categories (Hoffman et al., 2020; Zhou et al., 2021). Some scholars argue that these disparities in the effects of UHI constitute an environmental injustice, one that is expected to become exacerbated over the next several decades due to climate change and urbanization processes (Zhou et al., 2021).

The history of the modern environmental justice movement in the United States began in 1982 in Warren County, North Carolina (Mohai et al., 2009). Civil rights activists famously organized against the dumping of 120 million pounds of contaminated soil in Warren County. As Warren County was the county with the highest proportion of Black residents in the state, the activists argued that the dumping was a case of environmental racism. Defined by Benjamin Chavis, former executive director of the Commission for Racial Justice of the United Church of Christ, environmental racism refers to "racial discrimination in environmental policy making, the enforcement of regulations and laws, the deliberate targeting of communities of color for toxic waste facilities, the official sanctioning of the life-threatening presence of poisons and pollutants in our communities, and the history of excluding people of color from leadership of the ecology movements" (Bullard, 2000, in Mohai et al., 2009, 406-7). Robert Bullard, commonly referred to as the father of the environmental justice movement, refers to environmental justice as the remedy for environmental racism, defining it as the principle that "all people and communities are entitled to equal protection of environmental and public health laws and regulations" (Bullard, 1996, in Mohai et al., 2009, 407). This definition has since been expanded upon, with contemporary environmental justice studies considering environmental features as a whole – not only the distribution of environmental "bads," but also the distribution of environmental "goods" (Boone, 2008).

Urban trees are an environmental feature that have recently received attention in the environmental justice literature. The term "urban trees," or "urban forests," refers to all of the trees within a given urban area, including individual trees on both private and public land, continuous tree canopy, and street trees. (Baumeister et al., 2022; Hutt-Taylor & Ziter, 2022). Air temperature regulation is one of many benefits provided by urban forests (Middel et al., 2016; Zhou et al., 2021). Other benefits include air quality regulation, stormwater retention, aesthetics, and recreation (Hutt-Taylor & Ziter, 2022; Middel et al., 2016). Despite these benefits, urban tree canopy (UTC) remains unequally distributed across US cities (Schwarz et al., 2015). With few exceptions (Berland et al., 2015), scholars have noted that certain socioeconomic and demographic characteristics, especially income and percent white population, are positively correlated with the provisioning of UTC (Berland et al., 2015; Gallego-Valadés et al., 2020; Nascimento & Shandas, 2021; Schwarz et al., 2015). For example, in an analysis of two North Carolina cities, Kolosna & Spurlock (2019) found a statistically significant negative association between UTC cover and percentage of non-white population. Additionally, in an analysis of nine U.S. cities, Schwarz et al. (2015) found a strong positive correlation between income and UTC cover, indicating an unequal distribution of urban trees.

This unequal distribution is not necessarily the product of present-day decisions, but often the result of structural injustices that accumulate over time. Redlining, the practice of racially segregating American neighborhoods in the 1930s, is one such structural injustice that has lasting effects on distribution of tree canopy (Burghardt et al., 2023; Locke et al., 2021). In an analysis of 37 metropolitan areas, Locke et al. (2021) found that tree canopy was consistently lower in formerly redlined neighborhoods. Burghardt et al. (2023) also found in Baltimore, MD that formerly redlined neighborhoods exhibited lower street tree diversity and significantly lower populations of old trees. Through the implementation of UTC plans, cities have an opportunity to address such historic injustices.

Many cities are including environmental justice as a consideration in their UTC plans, such as the Los Angeles and New York "MillionTrees" initiatives (Garrison, 2021; Grant et al., 2022). However, these two initiatives did not necessarily result in just outcomes, due in part to their failure to adequately operationalize UTC justice (Garrison, 2021). This suggests a need for a model of UTC justice which cities can use to identify opportunities for intervention. In this thesis, I review the literature on environmental justice theory and the heterogeneous effects of tree canopy to develop a model of urban tree canopy justice. Then, I use linear regression analysis to support the connections in the model. The sections that follow include the data and methods I use for analysis, the results of the analysis, a discussion of the implications of the results, and conclusions.

1.1 Environmental justice in theory

The environmental justice literature differentiates between distributive, procedural, and recognition justice. Built on the foundational work of John Rawls (1971), distributive justice is primarily concerned with the fairness of distribution of goods and social advantages. Rawls (1971) introduces the concept of a “veil of ignorance,” an imaginary barrier between reality and what he calls the “original position.” In the original position, all members of society are stripped of their social standing, unaware of their social advantages and disadvantages. Rawls argues that, tasked with deciding on the optimal organization of political rights and resources, all members of society will come to the consensus that everyone should enjoy equal political rights. Second, people in the original position will endorse the difference principle. Following this principle entails that, inequalities must benefit everyone, especially the least well-off. For example, given a suite of possible distributions of wealth, the just distribution is that which benefits the least well-off most, even if that distribution involves inequality. Distributive justice in the context of environmental justice is concerned with the unequal distribution of environmental amenities and, more commonly, environmental hazards. According to Rawls’ theory, environmental amenities and hazards should be distributed in a way that prioritizes benefits to the least well-off. Despite developments in contemporary justice theory, distributive justice remains the dominating paradigm in environmental justice literature (Grant et al., 2022; Schlosberg, 2007).

Procedural justice is a conception of justice related to the process by which distributional outcomes are determined, focused on fairness, access, and transparency in decision-making processes (Grant et al., 2022). The underlying assumption of procedural justice is that public engagement in the policy-making process results in better policy (Liao et al., 2019). For example, Mullenbach et al. (2022) argue that policy created with faulty assumptions due to lack of public participation in the planning process would be rendered irrelevant. However, Fainstein (2014) critiques the dominant discourse around participatory planning, stating that simply implementing a more democratic process "fails to confront adequately the initial discrepancy of power, offers few clues to overcoming co-optation or resistance to reform, does not sufficiently address some of the major weaknesses of democratic theory, and diverts discussion from the substance of policy" (24). Additionally, procedural justice assumes that people want to participate, which may not be the case (e.g. residents may lack trust in their local government's intentions (Riedman et al., 2022)). These shortcomings suggest a need for a conception of justice that recognizes the historical context of current injustices.

Recognition justice, according to Schlosberg (2007), is concerned with the underlying causes of maldistribution. Beginning with Iris Young's (1990) Justice and the Politics of Difference, and continuing with the works of Nancy Fraser (1997, 1998, 2000, 2001), recognition justice, unlike Rawls' original position, is grounded in real-world examples rather than an imagined state. The distributive lens, Young (1990) argues, fails to "thoroughly [examine] the social, cultural, symbolic, and institutional conditions underlying poor distributions in the first place" (Schlosberg, 2007, 14). The recognition lens, by contrast, aims to recognize and eliminate these institutional injustices.

Considering distributive, procedural, and recognition justice simultaneously forms the tripartite model of environmental justice.

Applying a distributive justice lens to UTC provisioning, the unequal distribution of UTC in cities appears to constitute an environmental injustice. The common response to this injustice is to locate neighborhoods with high proportions of low-income and minority residents and low UTC cover and plant trees in those neighborhoods (Roman et al., 2021). This approach, however, may not adequately address procedural and recognition justice. Failure to consult communities on their preferences before implementing a tree planting initiative would violate procedural justice. Additionally, recognition justice requires that marginalized individuals' diverse perspectives and preferences be prioritized in the decision-making process. The uncritical view that additional trees are inherently good for marginalized communities may lead to unintended consequences in neighborhoods (Roman et al., 2021). While it may be well-intentioned, a poorly considered plan may exacerbate the very inequities it aims to ameliorate.

1.2 Heterogeneous effects of UTC

One method for recognizing individuals' unique perspectives and preferences is considering their satisfaction with neighborhood trees. According to Coleman et al. (2023), satisfaction with neighborhood trees is dependent on the objective and subjective attributes of neighborhood trees. Subjective attributes of trees can be categorized as the benefits provided by trees, or ecosystem services, and the detriments of trees, or ecosystem disservices. In general, there is less research on ecosystem disservices than ecosystem services (Larson et al., 2019). Roman et al. (2021) summarized commonly noted ecosystem disservices created by trees into four categories: infrastructure; health and safety; cultural, aesthetic, and social issues; and environmental and energy issues. However, Baumeister et al. (2022) argue that this framework misses more anthropogenic disservices, such as garbage from park visitors and fear of crime. These ecosystem disservices have impacts on how residents view trees and ultimately whether they decide to plant trees on their own property or support public plantings, making ecosystem disservices an important consideration for UTC procedural justice (Coleman et al., 2023; Roman et al., 2021).

While useful for characterizing the heterogeneous effects of green space, the ecosystem dis/services dichotomy may not capture the complexity of residents' perceptions (Roman et al., 2021). Wilkerson et al. (2018) apply Maslow's (1943) widely adopted 'hierarchy of needs' to categorize ecosystem services in relation to socioeconomic status. They suggest that residents of lower socioeconomic status may have higher demand for ecosystem services that relate to basic needs, such as food provisioning, while residents of higher socioeconomic status may have higher demand for ecosystem services that relate to esteem and self-actualization, such as cultural and recreation services. Nesbitt et al. (2018) suggest that cultural background can also impact preferences for ecosystem services and disservices. For example, Western European residents prefer large trees and "natural" looking landscapes, residents with Mediterranean backgrounds prefer food-producing trees, and residents with middle-eastern backgrounds prefer manicured urban green spaces (Nesbitt et al., 2018). Therefore, it is one's preferences, often influenced by cultural background, that determine whether a given feature of a tree is an ecosystem service or disservice. The complexity of UTC justice suggests a need for a model which cities can apply to identify opportunities for intervention in the urban socioecological system.

1.3 Models of UTC justice

Several scholars have developed conceptual frameworks that can be synthesized to form a model of UTC justice. Wilkerson et al. (2018) put forth a model of the urban socioecological system, focusing on the supply, demand, and benefits of green space (Figure 2). Coleman et al. (2023) detail a model characterizing the relationship between tree attributes, resident satisfaction with trees, and participation in tree planting initiatives (Figure 3). Finally, Grant et al. (2022) developed a set of questions for evaluating whether an urban forestry plan incorporates the tripartite model of environmental justice (Figure 1). To synthesize these frameworks, I begin with Wilkerson et al. (2018) and expand the model to include satisfaction (Coleman et al., 2023) and ensure the model adequately addresses the questions asked by Grant et al. (2022).

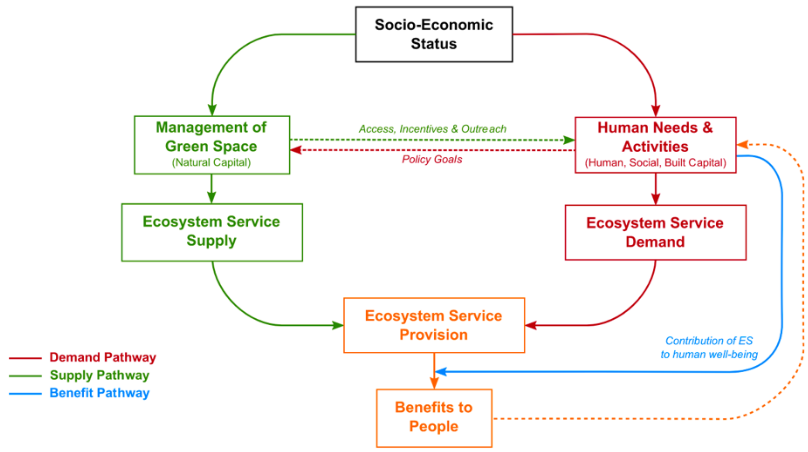

Figure 1: Wilkerson et al.'s (2018) model of the urban socioecological system

Wilkerson et al.'s (2018) model (Figure 1) is useful for analyzing the relationship between socioeconomic status and ecosystem services offered by green space within the urban socioecological system. The model consists of three pathways: supply, demand, and benefit. Socioeconomic status impacts the supply and demand pathways. Through the supply pathway, the management of green space determines the supply of green space. Through the demand pathway, human needs and activities determine demand for green space. The supply and demand pathways meet to form ecosystem service provisioning. Management of green space and human needs and activities interact via policy goals as well as access, incentives, and outreach. The benefit pathway, or the contribution of ecosystem services to human well-being, flows from human needs and activities and joins ecosystem service provisioning to result in benefits to people. While conceived for the management of green space in general, this model can be applied to the management of UTC to identify potential interventions for UTC justice.

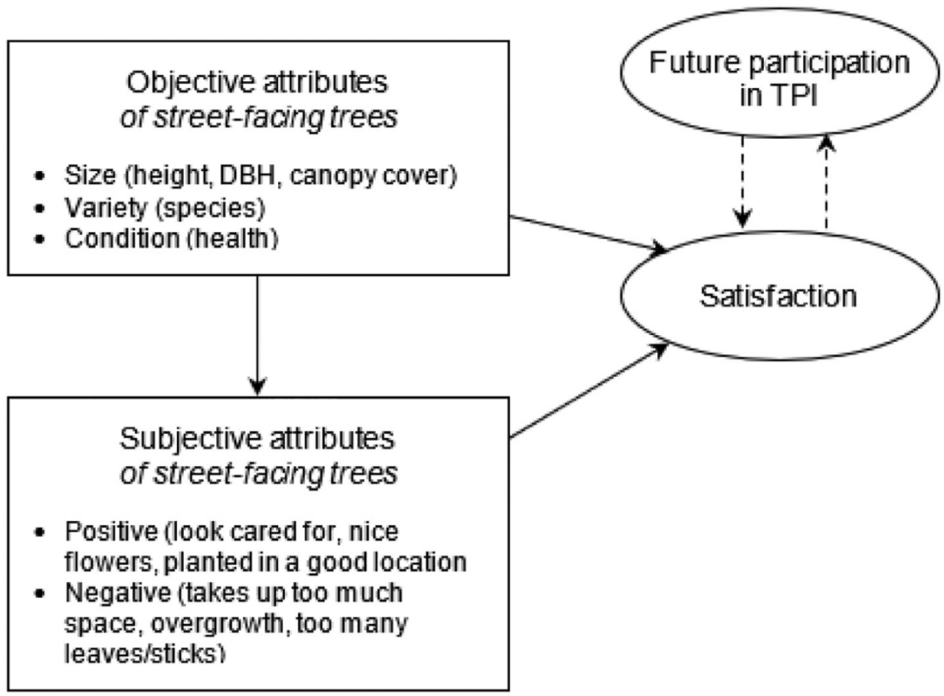

Figure 2: Coleman et al.'s (2023) model of resident satisfaction with street-facing trees

Coleman et al.'s (2023) model characterizes the relationship between satisfaction, urban tree attributes, and participation in tree planting initiatives. Objective attributes of trees determine subjective attributes of trees. Objective and subjective attributes of trees (both positive and negative) impact a resident's satisfaction with neighborhood trees. A resident's satisfaction impacts their future participation in tree planting initiatives and vice versa.

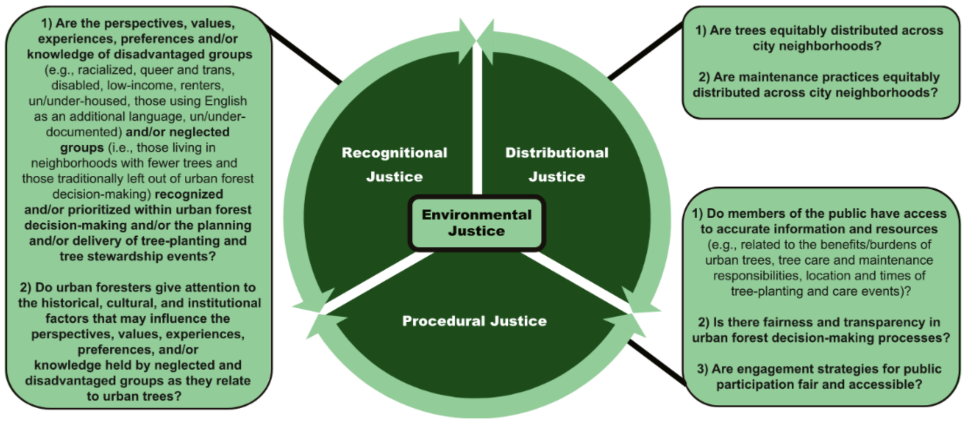

Figure 3: Grant et al.'s (2022) conceptual diagram of the three pillars of environmental justice when applied to urban tree canopy management

Grant et al. (2022) list the following questions for each dimension of environmental justice:

- Distributive justice:
  - (D1) Are trees equitably distributed across city neighborhoods?
  - (D2) Are maintenance practices equitably distributed across city neighborhoods?
- Procedural justice:
  - (P1) Do members of the public have access to accurate information and resources…?
  - (P2) Is there fairness and transparency in urban forest decision-making processes?
  - (P3) Are engagement strategies for public participation fair and accessible?
- Recognition justice:

- (R1) Are the perspectives, values, experiences, and/or knowledge of disadvantaged groups … and/or neglected groups … recognized and/or prioritized within urban forest decision-making and/or the planning and/or delivery of tree-planting and tree-stewardship events?
- (R2) Do urban foresters give attention to the historical, cultural, and institutional factors that may influence perspectives, values, experiences, preferences, and/or knowledge held by neglected and disadvantaged groups as they relate to urban trees?

Wilkerson et al.'s (2018) model does well to capture distributive and procedural justice. 'Ecosystem Service Supply' and 'Ecosystem Service Demand' meet to form 'Ecosystem Service Provision,' which can represent the distribution of tree canopy (D1). Additionally, maintenance practices and their distribution (D2) are already represented in this model through the 'Management of Green Space.' Access to information (P1), fairness and transparency in the decision-making process (P2), and fair and accessible engagement strategies (P3) are all represented by the 'Access, Incentives & Outreach' arrow that flows from 'Human Needs and Activities' to 'Management of Green Space.' However, the terms 'Ecosystem Service Supply/Demand/Provision' may oversimplify the unique perspectives, values, experiences, and knowledge held by disadvantaged groups (R1) as they do not adequately capture the heterogeneous impacts of UTC. Additionally, the term 'Socio-Economic Status' may not adequately address the historical, cultural, and institutional factors that impact an individual's socio-economic status (R2).

To adapt Wilkerson et al.'s (2018) model to the context of UTC, I replace the general ‘Management of Green Space’ with the specific ‘Management of UTC.’ Similarly, I replace the general ‘Ecosystem Service Supply’ and ‘Ecosystem Service Demand’ with the specific ‘UTC Supply’ and ‘UTC Demand,’ respectively. Due to the heterogeneous impacts of trees, provisioning of trees provides both ecosystem services and disservices to residents. Therefore, I replace ‘Ecosystem Service Provision’ with ‘Ecosystem Dis/Service Provision.” ‘Ecosystem Dis/Service Provision’ captures the objective and subjective attributes of trees from Coleman et al.'s (2023) model. To integrate operationalize ‘Benefits to People’ and integrate Coleman et al.’s (2023) model, I replace ‘Benefits to People’ with ‘Dis/Satisfaction.’ Since satisfaction impacts future participation in tree planting initiatives, I add an arrow from ‘Dis/Satisfaction’ to ‘Management of UTC.’ Finally, to address recognition justice, I add ‘Historical, Cultural, Institutional Context’ to the model, impacting ‘Socio-Economic Status.’ The resulting model (Figure 4) can be used to identify opportunities for intervention to maximize resident satisfaction with UTC.

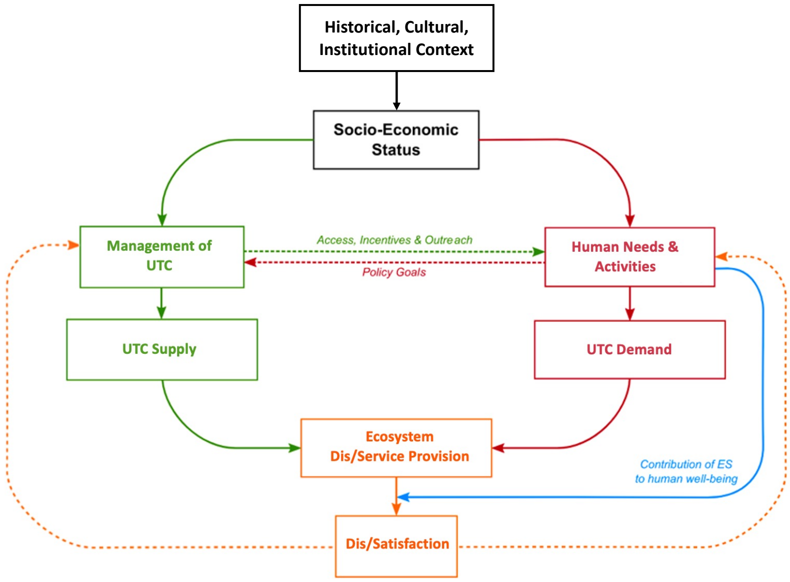

Figure 4: Conceptual model for this study, adapted from Wilkerson et al. (2018), Grant et al. (2022), and Coleman et al. (2023)

1.4 Research questions

In this thesis, I aim to apply my conceptual model (Figure 4) to the case of the Phoenix, Arizona metropolitan region. I begin applying the model by determining whether the study areas' UTC plans incorporate the tripartite model of environmental justice. Then, to test the connections in the model, I aim to determine whether actual tree canopy percentage is a sufficient measure of satisfaction with tree canopy. The research questions for this study are as follows:

RQ1: Do the study areas' UTC plans incorporate the tripartite model of environmental justice?

RQ2: Is percent tree canopy a statistically significant determinant of individual and neighborhood satisfaction with the amount of neighborhood trees when controlling for the sociodemographic factors income, race, educational attainment, and homeownership status?

CHAPTER 2

MATERIALS AND METHODS

To answer the research questions, I used a mixed-methods approach applying two complementary techniques: 1) qualitative content analysis of UTC plans and 2) quantitative statistical analysis of socioecological survey and tree canopy data. First, I review the data collection. Then, I provide a description of the measures. I finish by analyzing the data using linear regression analysis.

2.1 Data

Phoenix Tree Shade Master Plan, Tempe Urban Forestry Plan, and Gilbert Shade and Streetscape Master Plan Data

In this thesis, I compared the environmental justice mentions and explanations present in the study areas' urban forestry (or equivalent) plans. For Phoenix and Tempe, I used the data from Grant et al.'s (2022) analysis. For Gilbert, I used the methods employed by Grant et al. (2022) to analyze the Shade and Streetscape Master Plan. At the time of this writing, Scottsdale does not have an urban forestry plan.

Tree Canopy Data

I collected tree canopy data using iTree Canopy, an online tool for assessing tree canopy and land use. After specifying a boundary, the tool chooses a random point within the boundary. The user marks whether that point is a tree or not a tree. The tool then selects another point, and the process continues until the user reaches the desired number of data points. I collected 1000 data points for each of the 12 study neighborhoods.

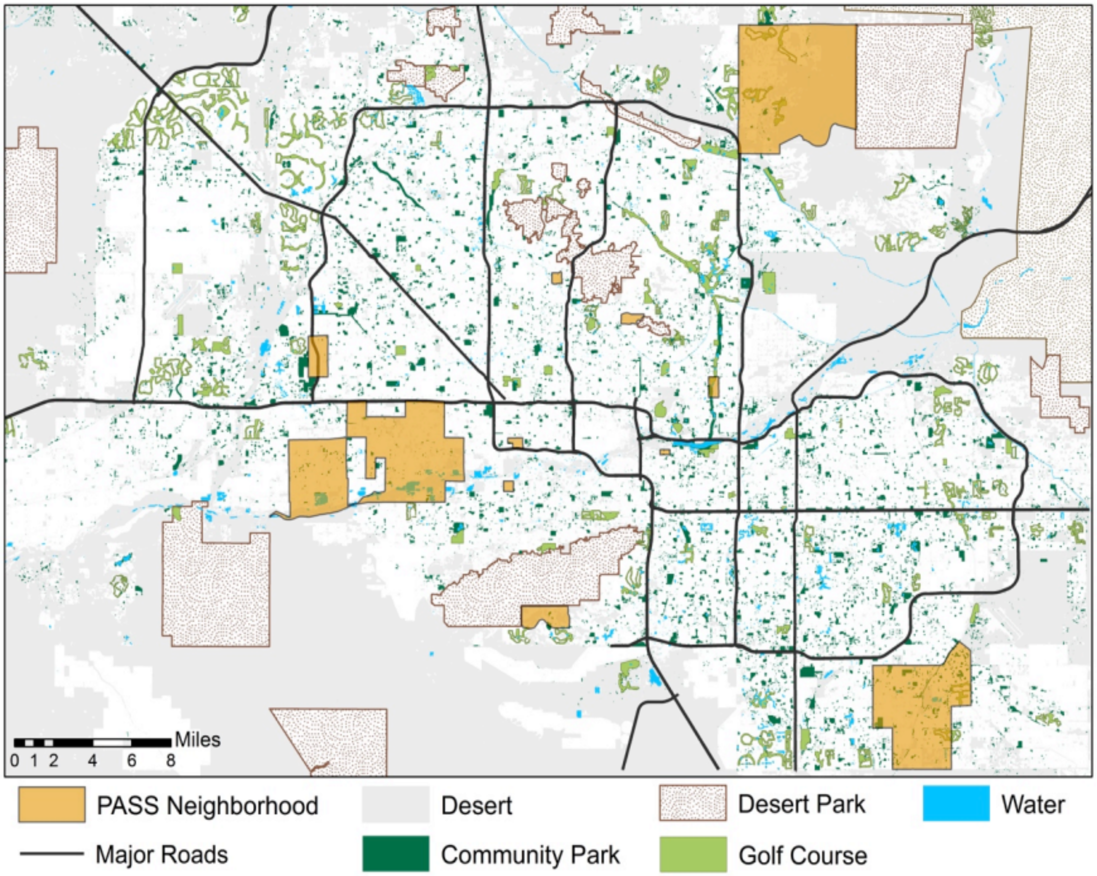

Figure 5: PASS study neighborhoods (Credit: Jeff Clark)

Phoenix Area Social Survey Data

This thesis uses data from the 2021 Phoenix Area Social Survey (PASS) (Larson et al., 2021). PASS is a two-decade-long longitudinal survey where data is collected approximately every 4 years. The PASS sampling design is a stratified, purposive, random sample approach. Twelve neighborhoods (Figure 5) were chosen for their diverse geographic locations (spread across four cities), demographic characteristics (low-to-high income and low-to-high proportion of Hispanic residents) and location within the region (urban core, suburban, and fringe neighborhoods). The total contacted sample included 1,549 addresses, made up of 496 addresses from the previous survey and 1,053 new addresses provided by the Marketing Systems Group (MSG). Addresses were randomly sampled from the MSG addresses. Five neighborhoods with low participation in the previous survey (711, Q15, R18, TRS, U18) were oversampled; the survey team drew 105 addresses for these neighborhoods as opposed to the 75 drawn from the other 7 neighborhoods. To replace duplicates with the previous sample, an additional 40 addresses were randomly drawn. Addresses with multiple residents (such as a boarding houses or fraternity houses), PO Boxes, and vacant residences were excluded from the sample.

The survey was conducted via mail and web, with five waves of mail contact beginning on May 10, 2021. The initial mailing included an informational postcard that included a unique URL to the online version, which was offered in English and Spanish. This was followed by a full packet of the printed survey with a $5 cash pre-incentive, mailed on May 26, 2021. On June 10, a reminder postcard was sent. A second mailing of the full packet was sent on June 25. A third full packet was sent on July 19. A final postcard reminder was sent to the six neighborhoods (711, IBW, R18, TRS, U18, X17) which had less than 40 responses. In addition to the prepaid incentive, $25 generic VISA gift cards were sent to respondents who completed the survey. The informed consent letters in each questionnaire included a phone number and email address where respondents could request the Spanish version of the questionnaire. Households with Hispanic surnames were sent English and Spanish versions of the survey in the third full packet. A total of 1549 households were sampled, and 509 eligible surveys were returned with a response rate of 35.6%. For more information on sampling design, see Larson et al. (2021).

2.2 Measures

Dependent variables

Satisfaction, the dependent variable, was sourced from the 2021 PASS data set. The survey question is worded as follows: "How dissatisfied or satisfied are you with each of the following features in and around your neighborhood?" The feature I measured is "the amount of trees." The possible answers include "Very dissatisfied," "Somewhat dissatisfied," "Neither dissatisfied nor satisfied," "Somewhat satisfied," and "Very satisfied." In the data "Very dissatisfied" is coded as 1, "Somewhat dissatisfied" as 2, "Neither dissatisfied nor satisfied" as 3, Somewhat satisfied" as 4, and "Very satisfied" as 5. For the analyses in which the dependent variable is individual satisfaction, I did not change the continuous variable. For the analyses in which the dependent variable is neighborhood satisfaction, I coded each individual's satisfaction as either satisfied ("Somewhat satisfied" or "Very satisfied") or not satisfied ("Neither dissatisfied nor satisfied," "Somewhat dissatisfied," or "Very dissatisfied"). Neighborhood tree satisfaction was represented by the percentage of respondents who were satisfied with neighborhood trees, according to the definition above.

Control variables

Annual household income was represented as a continuous variable, with 1 representing $20,000 and under and each 1-unit increase representing an additional $20,000, with the highest value representing more than $200,000, as self-reported in PASS. Neighborhood median income was reported as a continuous variable in the 2021 PASS Report and remained unchanged in my analysis. Respondent racial identity was coded as "white"/"non-white," as self-reported in PASS. Neighborhood racial makeup was represented by the percentage of non-white residents in each neighborhood as reported in the 2021 PASS Report. Respondent educational attainment was coded as “completed high school or less”/“completed college or more,” as self-reported in PASS. Neighborhood educational attainment was represented by the percentage of residents who have completed college or more, as reported in the 2021 PASS Report. Respondent homeownership was coded “renter”/”homeowner,” as self-reported in PASS. Neighborhood homeownership rate remained unchanged from the percentage reported in the 2021 PASS Report.

2.3 City UTC plan analyses

The study neighborhoods included in this thesis are located in Phoenix, Tempe, Scottsdale, and Gilbert, Arizona. Of these cities, Phoenix, Tempe, and Gilbert have UTC plans, while Scottsdale does not. In their review of 107 UTC plans, Grant et al. (2022) analyzed the City of Phoenix 2010 Tree Shade Master Plan and the City of Tempe 2017 Urban Forestry Master Plan. Using their methodology, I analyzed the Town of Gilbert Shade and Streetscape Master Plan. For this analysis I used NVivo 14, following Grant et al.’s (2022) use of NVivo 12. I conducted keyword searches to determine the frequency of environmental justice-related terms within the document. Following Grant et al. (2022),

> “The terms “access”, “distribution”, “equitable”, “lack of maintenance”, “lack of trees”, and “low canopy” were used when searching for potential distributional justice-related themes. When locating possible procedural justice themes, the terms “access”, “availability”, “campaigns”, “collaboration”, “information”,

"jargon", "outreach", "public participation", and "social media" were used. Finally, when identifying prospective recognitional justice themes, the terms "inclusion", "identity", "low-income", "people of color", "BIPOC", "minority", "historic", "race", "socio-economic", and "targeted outreach" were used. To ensure a comprehensive search was conducted stemmed words (e.g., equity/ equitable) and synonyms (e.g., lack of trees/fewer trees, people of color/ BIPOC) were used."

2.4 Linear regression – Neighborhood characteristics versus neighborhood satisfaction

I fit one bivariate model to determine the relationship between percent tree canopy and neighborhood satisfaction, characterized by the percent of residents who were satisfied or highly satisfied with the tree shade in their neighborhoods:

Bivariate percent tree canopy model: Percent satisfied = percent tree canopy

For each of the control variables, I fit three models. The first was a bivariate model, characterizing the relationship between the control variable and satisfaction:

Bivariate model: Percent satisfied = control variable

The second was a control model, characterizing the relationship between percent tree canopy and neighborhood satisfaction while controlling for the control variable:

Control model: Percent satisfied = percent tree canopy + control variable

The third was an interaction model, characterizing the relationship between percent tree canopy and neighborhood satisfaction while controlling for both the control variable and the interaction between the control variable and percent tree canopy:

Interaction model: Percent satisfied = percent tree canopy + control variable + interaction term

For example, the models for median income are detailed below, with similar models for percent non-white population, percent with college attainment or higher, and homeownership rate:

Bivariate percent tree canopy model: Percent satisfied = percent tree canopy

Bivariate median income model: Percent satisfied = median income

Control median income model: Percent satisfied = median income + percent tree canopy

Interaction median income model: Percent satisfied = median income + percent tree canopy + (median income x percent tree canopy)

2.5 Linear regression – Neighborhood characteristics versus individual satisfaction

I fit one bivariate model to determine the relationship between percent tree canopy and individual satisfaction, characterized by the percent change in satisfaction:

Bivariate percent tree canopy model: Satisfaction = percent tree canopy

For each of the control variables, I fit three models. The first was a bivariate model, characterizing the relationship between the control variable and satisfaction:

Bivariate model: Satisfaction = control variable

The second was a "control" model, characterizing the relationship between percent tree canopy and satisfaction while controlling for the control variable:

Control model: Satisfaction = percent tree canopy + control variable

The third was an interaction model, characterizing the relationship between percent tree canopy and neighborhood satisfaction while controlling for both the control variable and the interaction between the control variable and percent tree canopy:

Interaction model: Satisfaction = percent tree canopy + control variable + interaction term

For example, the models for median income are detailed below, with similar models for percent non-white population, percent with college attainment or higher, and homeownership rate:

Bivariate percent tree canopy model: Satisfaction = percent tree canopy

Bivariate median income model: Satisfaction = median income

Control median income model: Satisfaction = median income + percent tree canopy

Interaction median income model: Satisfaction = median income + percent tree canopy + (median income x percent tree canopy)

2.6 Linear regression – Individual characteristics versus individual satisfaction

For the models characterizing the relationship between individual characteristics and individual satisfaction, each control variable had a unique valid N, or number of responses. This is because a respondent may have answered one of the relevant survey questions but may have skipped the others. Therefore, I created a unique bivariate percent tree canopy bivariate model for each independent variable, using the valid responses for each variable:

Bivariate percent tree canopy model: Satisfaction = percent tree canopy

For each of the independent variables, I created three more linear models. The first was a bivariate model characterizing the relationship between the independent variable and satisfaction. The second was a control model, characterizing the relationship between the independent variable and satisfaction while controlling for percent tree canopy. The third and final model was an interaction model, characterizing the relationship between the independent variable and satisfaction, controlling for percent tree canopy and the interaction between the independent variable and percent tree canopy. The models for income are detailed below, with similar models for whether a respondent is white, college attainment, and homeownership:

Bivariate income model: Satisfaction = income

Control model: Satisfaction = income + percent tree canopy

Interaction model: Satisfaction = income + percent tree canopy + (income x percent tree canopy)

CHAPTER 3

RESULTS

3.1 City tree planting plan analysis

Table 1: Environmental justice mentions and explanations per 1000 words, categorized by distributive justice (DJ), procedural justice (PJ), and recognition justice (RJ)

	Mentions (M) and Explanations (E) per 1000 words								
City	Total EJ (M)	Total EJ (E)	DJ (M)	DJ (E)	PJ (M)	PJ (E)	RJ (M)	RJ (E)
Phoenix	1.78	0.11	0.00	0.00	0.80	0.11	0.00	0.00
Tempe	4.99	2.57	1.23	0.10	0.82	0.51	0.00	0.00
Gilbert	0.10	0.00	0.05	0.00	0.05	0.00	0.00	0.00

Phoenix and Tempe had 1.78 and 4.99 mentions of environmental justice per 1000 words, respectively, while Gilbert had 0.10 mentions per 1000 words. Phoenix and Tempe had 0.11 and 2.57 environmental justice explanations per 1000 words, respectively, while Gilbert had none. Gilbert had 1 distributive justice mention, which read, "Cooling stations across the Phoenix Metro have been set up for decades with simple water stations to provide equitable access to water through our unforgiving summers." Gilbert also had 1 procedural justice mention, which read, "Environmental Justice Grants – Urban Waters Small Grants – recognize that healthy and accessible urban waters can help grow local businesses and enhance educational, recreational, social, and employment opportunities in nearby communities. Environmental Justice Grant Programs- supports and empowers communities as they develop and implement solutions that significantly address environmental and/or public health issues at the local level."

3.2 Neighborhood characteristics and percent tree canopy

Table 2: Study neighborhood characteristics

ID	Median Income ($)	College attainment rate (%)	Homeownership rate (%)	Non-white (%)	Tree canopy (%)	Satisfied (%)
711	39,275	4.01	38.10	93	3.8 ± 0.60	27.78
R18	60,323	12.50	53.41	87	4.5 ± 0.66	38.71
X17	53,347	56.29	6.32	40	12.4 ± 1.04	41.94
U18	56,389	5.11	42.81	96	6.4 ± 0.77	43.48
V14	61,238	22.47	17.55	43	10.1 ± 0.95	44.12
Q15	84,090	19.20	65.58	83	2.6 ± 0.50	51.22
U21	153,601	65.31	95.71	25	4.7 ± 0.67	58.90
TRS	70,457	15.58	64.52	87	6.3 ± 0.77	64.00
AA9	155,712	63.45	86.34	13	5.6 ± 0.73	65.85
W15	179,204	74.01	88.40	7	18.6 ± 1.23	69.49
PWR	104,466	44.33	80.68	33	6.6 ± 0.79	78.13
IBW	71,742	54.23	51.62	25	8.5 ± 0.88	81.40

Table 2 summarizes the characteristics for each neighborhood as reported in the 2021 PASS Report with the percent tree canopy and percent satisfaction determined by this study, organized by percent satisfaction from low to high. Neighborhood median income ranged from $39,275 (711) to $179,204 (W15). The median income for the sampled neighborhoods was $90,483 (Larson et al., 2021). The neighborhood college attainment rate ranged from 4.01% (711) to 74.01% (W15). The neighborhood homeownership rate ranged from 6.32% (X17) to 95.71% (U21). The neighborhood percentage of the population that is non-white ranged from 7% (W15) to 96% (U18). Neighborhood percent tree canopy ranged from 2.6 ± 0.5 (Q15) to 18.6 ± 1.23 (W15). Percent satisfied ranged from 27.78 (711) to 81.40 (IBW).

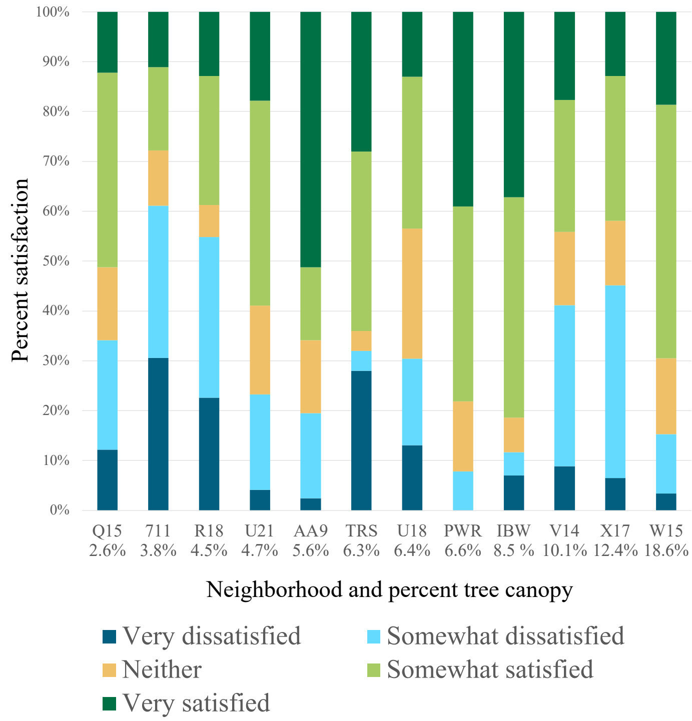

Figure 6: Bar chart showing percent of respondents who gave each answer to the question, "How dissatisfied or satisfied are you with each of the following features in and around your neighborhood?"

Figure 6 depicts the percentage of respondents who gave each answer to the PASS question, "How dissatisfied or satisfied are you with each of the following features in and around your neighborhood?" Blue represents dissatisfied responses, green represents satisfied responses, and yellow represents neutral responses. The neighborhood with the most satisfied respondents was IBW, with 16 respondents reporting "Very satisfied" and 19 respondents reporting "Satisfied." The neighborhood with the most dissatisfied respondents was 711, with 11 respondents reporting "Very dissatisfied" and 11 respondents reporting "Dissatisfied."

Table 3: Matrix depicting neighborhood satisfaction based on neighborhood median income versus percent tree canopy.

	Neighborhood Satisfaction (%)		
	Lowest Median Income ($30,000 - $60,000)	Middle Median Income ($60,001 - $90,000)	Highest Median Income (>$90,001)
Lowest % tree canopy (0% - 4.9%)	711 – 27.78%	R18 – 38.71% Q15 – 51.22%	U21 – 58.90%
Middle % tree canopy (5% - 9.9%)	U18 – 43.48%	TRS – 64.00% IBW – 81.40%	PWR – 78.13% AA9 – 65.85
Highest % tree canopy (>10%)	X17 – 41.94%	V14 – 44.12%	W15 – 69.49%

Table 3 depicts the relationship between percent tree canopy, neighborhood median income, and neighborhood satisfaction. The neighborhoods with the highest neighborhood satisfaction rate, IBW (81.40%) and PWR (78.13%), were both in the middle tree canopy category, but varied in median income. The neighborhoods with the lowest neighborhood satisfaction rate, 711 (27.78%) and R18 (38.71%), were both in the lowest tree canopy category, but also varied in income. Within percent tree canopy categorizations, satisfaction was consistently higher in neighborhoods with higher median income, with the exception of neighborhood IBW. Within median income categorizations, tree canopy was not consistently associated with satisfaction. This indicates that median income is a more significant indicator of satisfaction than percent tree canopy.

Table 4: Matrix depicting neighborhood satisfaction based on percent non-white residents versus percent tree canopy.

	Neighborhood Satisfaction (%)	
	Lowest % Non-white Residents (0% - 49%)	Highest % Non-white Residents (50% - 100%)
Lowest % tree canopy (0% - 4.9%)	U21 – 58.90%	Q15 – 51.22% R18 – 38.71% 711 – 27.78%
Middle % tree canopy (5% - 9.9%)	AA9 – 65.85% PWR – 78.13% IBW – 81.40 %	TRS – 64.00% U18 – 43.48%
Highest % tree canopy (>10%)	W15 – 69.49% V14 – 44.12% X17 – 41.94%	

Table 4 depicts the relationship between percent tree canopy, percent non-white residents, and neighborhood satisfaction. The neighborhoods with the highest neighborhood satisfaction rate, IBW (81.40%) and PWR (78.13%) were both in the category with the lowest percentage of non-white residents and the middle percentage of tree canopy. The neighborhoods with the lowest neighborhoods satisfaction rate, 711 (27.78%) and R18 (38.71%), were both in the category with the lowest percentage of tree canopy and highest percentage of non-white residents. Within percent tree canopy categorizations, satisfaction was consistently higher in neighborhoods with lower percentages of non-white residents. However, within percent non-white residents categorizations, satisfaction was not consistently associated with percent tree canopy. This indicates that percentage of non-white residents is a more significant indicator of satisfaction than percent tree canopy.

Table 5: Matrix depicting neighborhood satisfaction based on percent residents with college attainment or higher versus percent tree canopy.

	Neighborhood Satisfaction (%)	
	Lowest % College Attainment (0% - 25%)	Highest % College Attainment (>25%)
Lowest % tree canopy (0% - 4.9%)	711 – 27.78% R18 – 38.71% Q15 – 51.22%	U21 – 58.90%
Middle % tree canopy (5% - 9.9%)	U18 – 43.48% TRS – 64.00%	PWR – 78.13% IBW – 81.40% AA9 – 65.85%
Highest % tree canopy (>10%)	V14 – 44.12%	X17 – 41.94% W15 – 69.49%

Table 5 depicts the relationship between percent tree canopy, percent of residents with college attainment or higher, and neighborhood satisfaction. The neighborhoods with the highest satisfaction rate, IBW (81.40%) and PWR (78.13%), were both in the category with the highest percentage of college attainment and the middle percentage of tree canopy. The neighborhoods with the lowest neighborhoods satisfaction rate, 711 (27.78%) and R18 (38.71%), were both in the category with the lowest percentage of tree canopy and the lowest percentage of residents with college attainment or higher. Within percent tree canopy categorizations, satisfaction was consistently higher in neighborhoods with higher percentages of residents with college attainment or higher, with the exception of neighborhood V14. However, within percentage of residents with college attainment or higher categorizations, satisfaction was not consistently associated with percent tree canopy. This indicates that percentage of residents with college attainment or higher is a more significant indicator of satisfaction than percent tree canopy.

Table 6: Matrix depicting neighborhood satisfaction based on homeownership versus percent tree canopy.

	Neighborhood Satisfaction (%)		
	Lowest homeownership (<40%)	Middle homeownership (41% - 80%)	Highest homeownership (>80%)
Lowest % tree canopy (0% - 4.9%)	711 – 27.78%	R18 – 38.71% Q15 – 51.22%	U21 – 58.90%
Middle % tree canopy (5% - 9.9%)		U18 – 43.48% IBW – 81.40% TRS – 64.00%	AA9 – 65.49% PWR – 78.13%
Highest % tree canopy (>10%)	X17 – 41.94% V14 – 44.12%		W15 – 69.49%

Table 6 depicts the relationship between percent tree canopy, neighborhood homeownership rate, and neighborhood satisfaction. The neighborhoods with the highest satisfaction rate, IBW (81.40%) and PWR (78.13%), were both in the category with the middle percentage of tree canopy but differed in homeownership rate. The neighborhoods with the lowest neighborhood satisfaction rate, 711 (27.78%) and R18 (38.71%), were both in the category with the lowest percentage of tree canopy, but also differed in homeownership rate. Within percent tree canopy categorizations, satisfaction was consistently higher in neighborhoods with higher homeownership rates, with the exception of neighborhood IBW. Within homeownership rate categorizations, satisfaction was consistently higher in neighborhoods with higher percentages of tree canopy, with the exceptions of neighborhoods IBW and PWR. This indicates that neither homeownership rate nor percent tree canopy are a better indicator of satisfaction than the other.

3.3 Linear regression results

Variables were considered statistically significant if they had a p-value below 0.05. The tables below detail the coefficients, statistical significance, number of observations (N), R^2, and adjusted R^2 of each model, followed by summary tables that detail the statistical significance of all models.

3.3.1 Tree canopy versus neighborhood satisfaction controlling for neighborhood characteristics

Table 7: Percent tree canopy versus percent satisfied controlling for neighborhood median income

	% Satisfied			
	Bivariate (% Tree Canopy)	Bivariate (Median income)	Control	Interaction
% Tree canopy	0.990		0.272	2.184
Interaction				-0.148
Median Income ($10k)		2.112	2.025	3.343
Constant	47.425*	35.676*	34.423*	19.165
Observations	12	12	12	12
R^2	0.065	0.327	0.331	0.372
Adjusted R^2	-0.029	0.259	0.182	0.136
Note:				* $p<0.05$

There was no statistically significant relationship between percent tree canopy and percent neighborhood satisfaction in any of the models. There was no statistically significant relationship between median income and neighborhood satisfaction in any of the models. The interaction term was not statistically significant in the interaction model.

Table 8: Percent tree canopy versus percent satisfied controlling for percent non-white population

	% Satisfied			
	Bivariate (% Tree Canopy)	Bivariate (% Non-white)	Control	Interaction
% Tree canopy	0.990		-0.678	-0.573
Interaction				-0.005
% Non-white		-0.333*	-0.384*	-0.358
Constant	47.425*	72.410*	80.165*	79.553*
Observations	12	12	12	12
R^2	0.065	0.427	0.448	0.448
Adjusted R^2	-0.029	0.370	0.325	0.242
Note:				*p<0.05

There was no statistically significant relationship between percent tree canopy and percent satisfaction in any of the models. Percent non-white population was statistically significant in the bivariate and control models, but not the interaction model. The interaction term was not statistically significant in the interaction model.

Table 9: Percent tree canopy versus percent satisfied controlling for percent population with college attainment or higher

	% Satisfied			
	Bivariate (% Tree Canopy)	Bivariate (% College attainment)	Control	Interaction
% Tree canopy	0.990		-0.538	0.582
Interaction				-0.018
% College attainment		0.427*	0.478*	0.589
Constant	47.425*	39.334*	41.511*	35.162
Observations	12	12	12	12
R^2	0.065	0.404	0.417	0.427
Adjusted R^2	-0.029	0.345	0.288	0.212
Note:				*p<0.05

There was no statistically significant relationship between percent tree canopy and percent satisfaction in any of the models. Percent population with college attainment or higher was statistically significant in the bivariate and control models, but not in the interaction model. The interaction term was not statistically significant in the interaction model.

Table 10: Percent tree canopy versus percent satisfied controlling for percent homeownership

	% Satisfied			
	Bivariate (% Tree Canopy)	Bivariate (% Homeowner)	Control	Interaction
% Tree canopy	0.990		1.257	4.603
Interaction				-0.047
% Homeowner		0.369*	0.391*	0.858
Constant	47.425*	33.587*	22.929	-9.381
Observations	12	12	12	12
R^2	0.065	0.364	0.467	0.553
Adjusted R^2	-0.029	0.301	0.349	0.386
Note:				*p<0.05

There was no statistically significant relationship between percent tree canopy and percent satisfaction in any of the models. Percent homeownership was statistically significant in the bivariate and control models, but not the interaction model. The interaction term was not statistically significant in the interaction model.

3.3.2 Tree canopy versus individual satisfaction controlling for neighborhood characteristics

Table 11: Percent tree canopy versus satisfaction controlling for neighborhood median income

	Satisfaction			
	Bivariate (% Tree Canopy)	Bivariate (Median income)	Control	Interaction
% Tree canopy	0.025*		0.003	0.100*
Interaction				-0.007*
Median income ($10k)		0.059*	0.058*	0.117*
Constant	3.256*	2.839*	2.828*	2.076*
Observations	501	501	501	501
R^2	0.008	0.047	0.048	0.061
Adjusted R^2	0.006	0.046	0.044	0.056
Note:				*p<0.05

There was a statistically significant relationship between percent tree canopy and satisfaction in the bivariate and interaction models, but not the control model. Median income was statistically significant in all models. The interaction term was statistically significant in the interaction model.

Table 12: Percent tree canopy versus satisfaction controlling for percent white population

	Satisfaction			
	Bivariate (% Tree Canopy)	Bivariate (% White Population)	Control	Interaction
% Tree canopy	0.025*		-0.026	-0.016
Interaction				-0.0001
% White population		0.012*	0.014*	0.015*
Constant	3.256*	2.800*	2.884*	2.834*
Observations	501	501	501	501
R^2	0.008	0.081	0.087	0.087
Adjusted R^2	0.006	0.079	0.084	0.082
Note:				*p<0.05

There was a statistically significant relationship between percent tree canopy and satisfaction in the bivariate model, but not the control nor interaction model. Percent white population was statistically significant in all models. The interaction term was not statistically significant in the interaction model.

Table 13: Percent tree canopy versus satisfaction controlling for percent population with college attainment or higher

	Satisfaction			
	Bivariate (% Tree Canopy)	Bivariate (% College attainment)	Control	Interaction
% Tree canopy	0.025*		-0.016	0.050
Interaction				-0.001
% College attainment		0.014*	0.015*	0.021*
Constant	3.256*	2.872*	2.929*	2.565*
Observations	501	501	501	501
R^2	0.008	0.066	0.068	0.073
Adjusted R^2	0.006	0.064	0.064	0.067
Note:				*p<0.05

There was a statistically significant relationship between percent tree canopy and satisfaction in the bivariate model, but not the control nor interaction models. Percent college attainment was statistically significant in all models. The interaction term was not statistically significant in the interaction model.

Table 14: Percent tree canopy versus satisfaction controlling for percent homeownership

	Satisfaction			
	Bivariate (% Tree Canopy)	Bivariate (% Homeownership)	Control	Interaction
% Tree canopy	0.025*		0.027*	0.151*
Interaction				-0.002*
% Homeownership		0.010*	0.011*	0.026*
Constant	3.256*	2.774*	2.557*	1.407*
Observations	501	501	501	501
R^2	0.008	0.049	0.058	0.075
Adjusted R^2	0.006	0.047	0.054	0.069
Note:				*$p<0.05$

There was a statistically significant relationship between percent tree canopy and satisfaction in all models. Percent homeownership was statistically significant in all models. The interaction term was statistically significant in the interaction model.

3.3.3 Tree canopy versus individual satisfaction controlling for individual characteristics

Table 15: Percent tree canopy versus satisfaction controlling for household income

	Satisfaction			
	Bivariate (% Tree Canopy)	Bivariate (Income)	Control	Interaction
% Tree canopy	0.025*		0.018	0.080*
Interaction				-0.008*
Income ($10K)		0.047*	0.041*	0.106*
Constant	3.244*	3.159*	3.058*	2.600*
Observations	477	477	477	477
R^2	0.008	0.015	0.019	0.029
Adjusted R^2	0.006	0.013	0.015	0.023
Note:				*p<0.05

Percent tree canopy was statistically significant in the bivariate and interaction models, but not the control model. Income was statistically significant in all models. The interaction term was statistically significant in the interaction model.

Table 16: Percent tree canopy versus satisfaction controlling for whether a respondent was white

	Satisfaction			
	Bivariate (% Tree Canopy)	Bivariate (Income)	Control	Interaction
% Tree canopy	0.019		0.015	0.104
Interaction				-0.093
White		0.282	0.232	0.734
Constant	3.381*	3.304*	3.228*	2.757*
Observations	405	405	405	405
R^2	0.006	0.007	0.010	0.015
Adjusted R^2	0.003	0.005	0.005	0.007
Note:				*$p<0.05$

Percent tree canopy was not statistically significant in any of the models. Whether a respondent was white was not statistically significant in any of the models. The interaction term was not statistically significant in the interaction model.

Table 17: Percent tree canopy versus satisfaction controlling for college attainment

	Satisfaction			
	Bivariate (% Tree Canopy)	Bivariate (College attainment)	Control	Interaction
% Tree canopy	0.026*		0.023	0.053
Interaction				-0.037
College attainment		0.142	0.092	0.346
Constant	3.253*	3.365*	3.213*	3.023*
Observations	491	491	491	491
R^2	0.009	0.003	0.010	0.013
Adjusted R^2	0.007	0.001	0.006	0.007
Note:				*p<0.05

Tree canopy was statistically significant in the bivariate model, but not the control nor interaction model. College attainment was not statistically significant in any of the models. The interaction term was not statistically significant in the interaction model.

Table 18: Percent tree canopy versus satisfaction controlling for rentership

	Satisfaction			
	Bivariate (% Tree Canopy)	Bivariate (Rentership)	Control	Interaction
% Tree canopy	0.024		0.024	0.023
Interaction				0.002
Rentership		-0.311*	-0.304*	-0.319
Constant	3.282*	3.532*	3.348*	3.350*
Observations	480	480	480	480
R^2	0.008	0.009	0.017	0.017
Adjusted R^2	0.006	0.007	0.013	0.011
Note:	*p<0.05			

Percent tree canopy was not statistically significant in any of the models. Rentership was statistically significant in the bivariate and control models, but not the interaction model. The interaction term was not statistically significant in the interaction model.

3.3.4 Summary of statistical significance

Table 19: Statistical significance for percent tree canopy in linear models characterizing the relationship between percent tree canopy and neighborhood satisfaction, controlling for neighborhood characteristics.

Control Variable	Bivariate (% Tree canopy) Model	Control Model	Interaction Model
Median income	Insignificant	Insignificant	Insignificant
% White population		Insignificant	Insignificant
% College attainment		Insignificant	Insignificant
% Homeowners		Insignificant	Insignificant

Percent tree canopy was statistically insignificant in the bivariate model and all of the control/interaction models characterizing the relationship between percent tree canopy and neighborhood satisfaction controlling for neighborhood characteristics.

Table 20: Statistical significance for percent tree canopy in linear models characterizing the relationship between percent tree canopy and individual satisfaction, controlling for neighborhood characteristics.

Control Variable	Bivariate (% Tree canopy) Model	Control Model	Interaction Model
Median income ($10k)	**Significant**	Insignificant	**Significant**
% White population		Insignificant	Insignificant
% College attainment		Insignificant	Insignificant
% Homeowners		**Significant**	**Significant**

Percent tree canopy was statistically significant in 3 of the 12 models characterizing the relationship between percent tree canopy and individual satisfaction controlling for neighborhood characteristics.

Table 21: Statistical significance for percent tree canopy in linear models characterizing the relationship between individual characteristics and individual satisfaction.

Control Variable	Bivariate (% Tree canopy) Model	Control Model	Interaction Model
Income	**Significant**	Insignificant	**Significant**
White	Insignificant	Insignificant	Insignificant
College attainment	**Significant**	Insignificant	Insignificant
Renter	Insignificant	Insignificant	Insignificant

Percent tree canopy was statistically significant in 2 of 4 bivariate models and 1 of 8 control/interaction models characterizing the relationship between percent tree canopy and individual satisfaction controlling for individual characteristics. Overall, tree canopy was statistically significant in 7 of 30 linear models.

CHAPTER 4

DISCUSSION

4.1 City tree planting plans

In Grant et al.'s (2022) analysis of 107 UTC plans, the average number of mentions of environmental justice was 2.2 mentions per 1000 words, while the average number of explanations was 0.7 per 1000 words. Phoenix falls below both averages, with 1.78 mentions and 0.11 explanations per 1000 words. Tempe, by contrast, exceeds both averages, with 4.99 mentions and 2.57 explanations per 1000 words. Gilbert falls far below both averages, with 0.10 mentions and 0 explanations per 1000 words. The Town of Gilbert had 2 total mentions, which included 1 mention of distributive justice and 1 mention of procedural justice. However, the distributive justice mention does not reference the distribution of trees or shade. Rather, it references the equitable distribution of water. Similarly, the mention of procedural justice relates to "empowering communities," but does not explicitly state which communities it aims to support.

Eight of the 12 PASS study neighborhoods were in Phoenix, 2 in Scottsdale, 1 in Tempe, and 1 in Gilbert. Therefore, it is difficult to determine a statistically significant correlation between municipality and neighborhood satisfaction using this data. However, the descriptive statistics offer insights into this relationship. Neighborhood X17, located in Tempe, had the second highest percentage of tree canopy (12.4%). However, this neighborhood exhibited the third lowest percentage of satisfied residents (41.94%). Neighborhood PWR, located in Gilbert, had the fifth highest percentage of tree canopy (6.6%) and the second highest percentage of satisfied residents (78.13%). Since Tempe had more EJ mentions/explanations than Gilbert, this indicates an inverse relationship between environmental justice mentions and explanations and percentage of satisfied residents. This relationship is further supported by neighborhood IBW which has the highest percentage of satisfied residents (81.40%), yet is located in Scottsdale, which has no UTC plan. The inverse relationship between EJ mentions/explanations and percent satisfaction with neighborhood trees may indicate that cities with lower satisfaction – whether they have formally measured resident satisfaction or not – are more likely to recognize disparities in neighborhood tree canopy through their UTC plans. Conversely, cities with generally high satisfaction may not prioritize tree equity as the problem of low satisfaction in particular neighborhoods is not apparent.

4.2 Determinants of individual satisfaction

In the linear models characterizing the relationship between percent tree canopy and individual satisfaction, controlling for neighborhood characteristics, percent tree canopy was statistically significant in 1 of 4 control models and 2 of 4 interaction models (Table 20). Percent tree canopy was statistically significant in the bivariate model characterizing the relationship between percent tree canopy and individual satisfaction (Table 20). The insignificance of tree canopy in most of the models indicates that the spatial distribution of trees is an inadequate measure of individual satisfaction with neighborhood trees when controlling for neighborhood characteristics.

In these models controlling for neighborhood characteristics, homeownership had a different effect on the models than the other control variables. Tree canopy was statistically significant in the models controlling for homeownership, indicating that homeownership rate does not have the same impact on individual satisfaction as the other control variables. In other words, two individuals with differing UTC coverage will be expected to have differing satisfaction levels, whether their neighborhoods differ in homeownership rate or not. This implies that homeownership rate is a less reliable variable for consideration of which individuals to target for tree planting.

In the models in which individual characteristics were the control variables, percent tree canopy was statistically significant in 2 of 4 bivariate models, 0 of 4 control models, and 1 of 4 interaction models. Similarly to the models controlling for neighborhood characteristics, this indicates that the spatial distribution of trees is an inadequate measure of individual satisfaction.

4.3 Determinants of neighborhood satisfaction

Tree canopy was not a statistically significant determinant of neighborhood tree satisfaction in the bivariate model nor any of the control or interaction models characterizing the relationship between tree canopy and neighborhood satisfaction (Table 4). This indicates that the spatial distribution of trees is an inadequate indicator of neighborhood satisfaction, and therefore an inadequate indicator of the tripartite EJ implications of UTC distribution at the neighborhood level.

In all 4 bivariate models and 3 of 4 control models charactering the relationships between the control variables and neighborhood tree satisfaction, the control variables were statistically significant determinants of neighborhood tree satisfaction. However, when controlling for the interactions between the control variables and percent tree canopy, none of the control variables were statistically significant. In the case of percent white population, this means that two neighborhoods with similar racial makeup will be expected to have similar levels of satisfaction regardless of their actual percentage of tree canopy, while two neighborhoods of differing racial makeup will be expected to have different levels of satisfaction (Table 4). One example of this relationship is neighborhoods W15 and AA9. Both neighborhoods have a low percentage of non-white residents (7% and 13%, respectively), but have differing levels of tree canopy (18.6% and 5.6%, respectively). Yet, both neighborhoods have similar percentages of satisfied residents (69.49% and 65.85%, respectively). Conversely, neighborhoods U18 and PWR have similar levels of tree canopy (6.4% and 6.6% respectively) and differing percentages of non-white residents (96% and 33%, respectively). As expected, these neighborhoods have differing levels of satisfaction (43.48% and 78.13%, respectively).

Neighborhoods Q15 and U18 offer an example of how traditional methods of prioritizing planting locations may contradict actual satisfaction levels. Choosing a neighborhood for planting based on low percentage of tree canopy and high percentage of non-white residents would suggest choosing neighborhood Q15 before U18. However, neighborhood Q15 has a 7.74% higher satisfaction rate, indicating that Q15 is a lower priority neighborhood.

4.4 Prioritization of Phoenix PASS Neighborhoods

Since eight of the twelve PASS neighborhoods are located in Phoenix and urban forestry decisions are largely made at the city level, this section of the analysis will focus on the prioritization of the Phoenix PASS neighborhoods. There are 4 Phoenix neighborhoods with satisfaction rates below 50%: 711, R18, U18, and V14. Using the method outlined in this thesis, these neighborhoods would be the highest priority neighborhoods for tree planting. Neighborhood 711 was the only neighborhood with low median income, high percentage of non-white residents, low college attainment rate, and low homeownership rate. This would make Neighborhood 711 a high-priority planting location according to traditional prioritization frameworks that prioritize actual percent tree canopy and sociodemographic vulnerability. Neighborhood 711 is also the neighborhood with the lowest satisfaction rate, making it a high-priority planting location according to the method outlined in this thesis.

Homeownership is one variable that complicates prioritization. The majority of UTC is on privately owned and managed land, making homeowners a key stakeholder in the urban forest system (Nguyen et al., 2017). There is a positive correlation between homeownership and individual satisfaction, indicating that prioritizing neighborhoods with low homeownership rates would increase satisfaction. However, while renters have shown stronger opinions regarding UTC management than homeowners (Baur et al., 2016), they may lack authority in yard management and landlords may not be incentivized to plant trees (Nguyen et al., 2017). Further, homeowners see the benefits of planting trees through increased property values and ecosystem services. Schwarz et al. (2015) note that there is a positive relationship between UTC cover and property values, and residents in areas with low UTC cover may have less incentive to increase property values because they are renters or on fixed incomes. This is a feedback loop that may reinforce existing inequalities over time. While targeting neighborhoods with low homeownership may be better for increasing satisfaction, targeting neighborhoods with high homeownership rates may be more feasible as residents have greater control over their own lawns. For example, Neighborhood U18 has low median income ($56,389), relatively low satisfaction (43.48%), the highest percentage of non-white residents (96%), and a mid-level homeownership rate (42.81%). This makes Neighborhood U18 a strong choice for a planting program in terms of increasing satisfaction, improving equity, and feasibility.

4.5 Comparisons to other prioritization methods

One tool readily available for measuring the distribution of trees in the Phoenix region is Tree Equity Score (TES) and the accompanying Tree Equity Score Analyzer (TESA). Using Census Block Groups as neighborhood boundaries, TES employs a 4-step methodology for assessing how equitably a city distributes their tree canopy cover. The first step involves determining a canopy goal for each neighborhood based on location and population density. In the second step, existing tree canopy is subtracted from the goal to determine the “gap” between existing and ideal UTC cover. Priority planting locations are determined in the third step using the following equally weighted characteristics: income, employment, race, age, climate, and health. Finally, the TES is calculated by multiplying the gap by the priority index. Census block groups are ranked 1-100, with 1 representing high-priority areas and 100 representing low-priority areas. Using TES has the potential to encourage cities to increase canopy in areas with low tree canopy and high populations of vulnerable residents. However, by assuming that a lack of trees equates to demand for trees, it perpetuates the idea that planting trees is inherently good, without considering ecosystem disservices.

Table 22: Tree Equity Scores and neighborhood satisfaction rates for PASS neighborhoods located in Phoenix.

Neighborhood ID	Satisfaction (%)	Tree Equity Score
711	27.78	67
R18	38.71	64*
U18	43.48	92
V14	44.12	96
Q15	51.22	80**
U21	58.90	86**
TRS	64.00	64*
W15	69.49	100

* These neighborhoods do not align well with current census tracts, so the closest distinction possible was chosen.
** These neighborhoods contained multiple census tracts, so the scores were averaged.

Table 22 demonstrates that TES does not accurately represent satisfaction in the Phoenix PASS neighborhoods. For example, Neighborhood U18, previously identified as a high priority neighborhood for planting, has a TES of 92. It is notable that TES lists Neighborhood U18 as a low-priority census tract as it has 12% canopy cover according to their measurement, while I measured the neighborhood at 6.4% canopy cover using iTree.

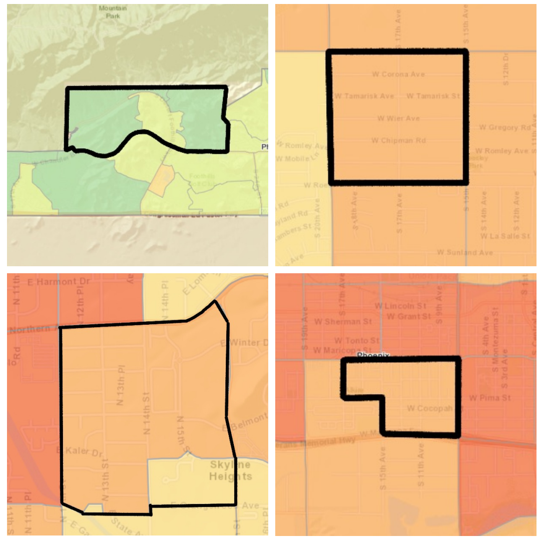

Figure 7: Neighborhoods U21 (top left), U18 (top right), V14 (bottom left), and 711 (bottom right), as represented in the 2017 Shade Tree Planting Prioritization map

Another tool for prioritizing planting in the Phoenix Region is the 2017 Shade Tree Planting Prioritization map produced by the Arizona Department of Forestry and Fire Management. The map uses colors to show planting prioritization, with dark red representing high priority census block groups and bright green representing low priority census block groups. Using this map, the lowest priority PASS neighborhood in Phoenix is U21 (Figure 5, top left), which has a satisfaction rate of 51.22% and a TES of 86. The highest priority neighborhoods according to the map are U18 (Figure 5, top right), V14 (Figure 5, bottom left), and 711 (Figure 5, bottom right). Neighborhoods U18 and V14 are similar in satisfaction rate (43.48% and 44.12%, respectively) and TES (92 and 96, respectively). Neighborhood 711, by contrast, has a considerably lower satisfaction rate (27.78%) and TES (67). Despite their varying demographic characteristics, satisfaction rates, and TES, these 3 neighborhoods are ranked the same according to the 2017 Shade Tree Planting Prioritization map.

In summary, the highest priority neighborhoods by satisfaction are 711, R18, U18, and V14. The highest priority neighborhoods according to TES are R18, 711, and TRS (which is one of the lowest priorities by satisfaction). Finally, the highest priority neighborhoods by the 2017 Shade Tree Planting Prioritization map are Neighborhoods U18, V14, and 711. 711, consistently identified as a high-priority neighborhood, is an obvious choice for planting. Neighborhoods U18 and V14 may be overlooked when using TES, while neighborhood R18 may be overlooked when using the 2017 Shade Tree Planting Prioritization map.

Tree Equity Score and the 2017 Shade Tree Planting Prioritization map are both free, easy to use, and accessible to the public, making them powerful tools for prioritizing planting locations. However, by assuming that areas with low tree canopy and high proportions of underserved populations are inherently high priorities for planting, these methods fail to account for the heterogeneous impacts of tree planting and the unique needs and preferences of individuals. By collecting and analyzing satisfaction data, city governments can better identify where tree planting is most needed and wanted.

4.6 Tradeoffs

According to Grant et al. (2022), recognition justice for UTC planning requires the prioritization of marginalized groups' perspectives, values, and/or knowledge in the UTC decision-making process. However, this requirement may present tradeoffs between recognition justice and city goals. City governments have obligations to allocate funding to achieve goals stated in their plans. For example, U.S. cities are obligated to spend a portion of certain federal funding in underserved neighborhoods, according to the White House Justice40 initiative (*Justice40 Initiative*). However, as discussed throughout this thesis, some residents (including some residents in underserved neighborhoods) may not want additional trees planted in their neighborhoods for a variety of reasons. Mullenbach et al. (2022) note that decision-makers should be prepared for the possibility that communities may refuse conservation initiatives when power is shifted toward communities, and recognition justice requires accepting that outcome. Cities may also have goals relating to the environmental benefits trees provide to the urban ecosystem, such as increased habitat for wildlife (Ordóñez et al., 2023). However, there may be tradeoffs between environmental and social outcomes. While some tree species are ideal for biodiversity, these species may not meet the preferences of neighborhood residents. The existence of these tradeoffs implies that city governments should take care in making decisions about where, when, and how to plant urban trees.

4.7 Returning to the tripartite model of UTC justice

One goal of this study was to develop a model of UTC justice and determine whether actual UTC coverage is an adequate measure of satisfaction with UTC, or whether the model should include another determinant. Since percent tree canopy was shown to be a statistically insignificant determinant of satisfaction, these results support the claim that provisioning of UTC does not inherently translate to increased benefits. The ecosystem dis/services paradigm offers a possible explanation for the disconnect between UTC provisioning and dis/satisfaction. Residents who have more trees in their neighborhood but are less satisfied may be experiencing ecosystem disservices or may simply want less trees. It is also possible, however, that these residents have many trees and still want more, leading to their dissatisfaction. One way of determining why residents are dis/satisfied is to implement targeted questions in future socioecological surveys. The 2021 PASS asks questions about ecosystem dis/services provided by trees – one area for future research.

4.8 Recommendations for city governments

City governments have limited funds dedicated for reaching their UTC goals, creating a need for prioritization of fund allocation. However, as demonstrated by these results, general UTC cover goals are not sufficient for achieving environmental justice. For example, The City of Tempe has a goal of achieving 25% UTC cover throughout the city, with a minimum of 10% in the neighborhoods with the lowest coverage. It is arguable whether this is a just outcome.

From a distributive lens, while the least well-off would see increased benefits, tree canopy would still be inequitably distributed as the least well-off neighborhoods would still have the least amount of tree canopy. From a procedural lens, the outcome would only be just if there was meaningful participation in the planning process. Finally, through a recognition lens, the outcome would only be just if individuals' needs and preferences are met. Since none of these conditions are explicitly stated in the goal, the goal is insufficient for an environmentally just outcome. A just UTC plan would go beyond a canopy goal and seek to maximize satisfaction for underserved communities.

Planting new trees may be one method of improving UTC equity, but these results indicate that there are other factors involved. For distributive justice, cities should ensure that maintenance practices are equitably distributed among neighborhoods (Grant et al., 2022). It is possible that neighborhoods with high percent UTC cover and low satisfaction may suffer from poor management of existing trees. Furthermore, recognition justice requires that individuals' preferences are accommodated (Grant et al., 2022). For cities, this may mean ensuring that trees provided in planting programs include fruit trees, indigenous trees, drought-tolerant trees, and/or ornamental trees to ensure that a variety of preferences can be met. Nguyen et al. (2017) suggest that continuous monitoring after a tree planting program is essential to the sustainability of the program. I suggest that cities do so through repeated social-ecological surveys to determine changes in satisfaction over time. This would allow cities to confirm that planting and maintenance efforts lead to increased satisfaction.

4.9 Limitations

In this thesis, I used a mixed-methods approach, combining survey data, qualitative content analysis, and spatial tree canopy data to answer my research questions. While the research questions were answered, there were limitations to the research that should be considered when interpreting the results.

Survey research

In this study, I use socioecological survey data and suggest the use of surveys for future research. However, survey research has limitations. Surveys are prone to error, including coverage, sampling, nonresponse, and measurement error (Dillman et al., 2014). This thesis is particularly limited by its small sample size. With 24 - 74 responses in each neighborhood, I did not make any claims about the patterns within neighborhoods. Additionally, the section of this thesis focused on neighborhood satisfaction has a sample size of N = 12, making statistical significance difficult to achieve. Future research should survey more neighborhoods to better elucidate the relationships between neighborhood characteristics and neighborhood satisfaction.

UTC plan analysis

In this analysis, I compared the environmental justice mentions and explanations between Phoenix, Tempe, and Gilbert, Arizona. While I collected the data for Gilbert, the data for Phoenix and Tempe were collected by Grant et al. (2022). Without intercoder reliability analysis, it is possible that my coding standards differed from those of the previous researchers.

UTC cover data collection

This study uses iTree Canopy for UTC cover data collection as it is a free, easy-to-use, online tool that requires minimal training to operate, making it an accessible means of collecting tree canopy data for nonprofits, students, and community members who may not have access to expensive high resolution tree canopy data. However, Ucar et al. (2016) found that using Google Earth imagery produced significantly different results than imagery from the U.S. National Agricultural Imagery Program in one of their two study cities, indicating that the method of collecting UTC data can have an impact on the resulting data. This is evidenced by the difference between the UTC measured in this study using iTree Canopy versus the UTC measured by Tree Equity Score for Neighborhood U18.

Statistical analysis

In this study, I use bivariate and multivariate regression analysis to identify correlations between tree canopy and resident satisfaction while controlling for the variables income, race, educational attainment, and homeownership. However, there are myriad factors that may influence resident satisfaction that were not measured, such as environmental attitudes and features of the built environment. Future socioecological surveys coupled with more detailed spatial analysis could better elucidate the factors that influence resident satisfaction.

Although these limitations exist, the results and discussion presented in this thesis have implications for urban forest management. This thesis presents many opportunities for future research, which would benefit from addressing these limitations.

CHAPTER 5

CONCLUSION

When implementing UTC plans, city governments have an opportunity to address the historic injustices that have led to the unequal distribution of tree canopy within their city. Many cities have implemented UTC plans with the intention of advancing environmental justice. However, these plans often fall short of their goals or, in some cases, exacerbate existing inequities. This suggests the need for a model of UTC justice that cities can use to identify opportunities for intervention. The first goal of this research was to develop a model of UTC justice in the urban socioecological system that addresses distributive, procedural, and recognition justice. The second goal was to apply the model to the case of the Phoenix, Arizona metropolitan area. Finally, the third goal was to determine whether actual UTC cover is a sufficient measure of satisfaction with UTC to test the model I developed.

Synthesizing a model of the urban socioecological system, a model of resident satisfaction with urban trees, and a framework for assessing UTC plans for distributive, procedural, and recognition justice, I developed a model of UTC justice for use by city governments in their urban forestry planning. To apply this model to the Phoenix, Arizona metropolitan area, I assessed the UTC plans for the cities of Phoenix, Tempe, and Gilbert for mentions and explanations of environmental justice. I found that Tempe had above average mentions and explanations, while Phoenix and Gilbert had below average mentions and explanations. Scottsdale does not have a UTC plan at the time of this writing. The neighborhoods with the highest satisfaction rate were located in Gilbert and Scottsdale, indicating that cities with more satisfied residents may be less prone to recognizing environmental justice in their UTC plan, if they have one at all.

While the spatial distribution of tree canopy is the prominent measure within the UTC literature, I took the novel approach of measuring satisfaction with UTC to gain a better understanding of UTC justice, as this measure captures individuals' preferences for and experiences with urban trees. To determine whether the spatial distribution of trees is a sufficient indicator of satisfaction with neighborhood trees, I used multivariate linear regression with interactions to assess the statistical significance of neighborhood tree canopy in a model of tree satisfaction. I determined that, within the 12 study neighborhoods, percent tree canopy is a statistically significant indicator of UTC satisfaction in 7 of 30 models when controlling for income, race, homeownership status, and college attainment. This supports my model of UTC justice in that there is a confounding variable between actual UTC distribution and UTC satisfaction.

While this study examines correlations within the same region, it does not compare correlations within individual cities. Future research should survey more neighborhoods in each city, allowing for more robust comparisons across cities. Additionally, there are other PASS questions that allow for better understanding of neighborhood satisfaction. For example, one question asks about satisfaction with maintenance practices, an important consideration for distributive justice.

This research is applicable for city governments interested in improving environmental justice through urban forestry. My first recommendation for city governments is to meaningfully explain environmental justice in their urban forestry plans, including measurable targets. These targets should address distributive, procedural, and recognition justice. My second recommendation is to implement surveys in target neighborhoods to identify existing satisfaction levels and the underlying reasons for those satisfaction levels. Finally, my third recommendation is to aim to maximize satisfaction in underserved neighborhoods. This should be one of the primary targets in their urban forestry plans.

City governments have obligations to meet tree canopy goals that are stated in their UTC plans as well and goals mandated by their state and federal governments. As such, environmental justice may not be a priority for UTC planning. However, an environmental justice lens – and especially a satisfaction lens – may make for goals that are more feasible. For example, the most satisfied neighborhoods in this study, IBW and PWR, had actual canopy cover that were far lower than the common goals of 25-30%. This indicates that achieving a just outcome based on satisfaction may require less tree canopy than cities are currently aiming for, allowing city governments to focus urban forestry spending elsewhere. I suggest that instead of focusing primarily on tree planting, city governments focus on allocating funding to the entire urban forest system, which can include removing existing nuisance trees, providing water credits, and city-funded-and-facilitated urban forest maintenance. Additionally, urban forestry plans should include neighborhood surveys to assess residents' perceptions of and preference for neighborhood trees. Ongoing analysis of longitudinal neighborhood surveys may allow cities to implement future UTC plans that address Distributive, Procedural, and Recognition justice.

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