Influence of Tree Planting Program Characteristics on Environmental Justice Outcomes

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(ABSTRACT)

Urban trees provide a variety of benefits to human physical and mental health. However, prior research has shown that urban tree canopy is unevenly distributed; areas with lower household incomes or higher proportions of racial or ethnic minorities tend to have less canopy. Urban tree benefits are largely spatially-dependent, so this disparity has a disproportionate impact on these communities, which are additionally subject to higher rates of health problems. Planting programs are a common way that municipal and nonprofit urban forest organizations attempt to increase canopy in cities. Increasing canopy in underserved communities is a commonly desired outcome, but which of the wide range of programmatic strategies currently employed are more likely to result in success? This research uses interviews with planting program administrators, spatially referenced planting data, and demographic data for six U.S. cities in order to connect planting program design elements to equity outcomes. I developed a planting program taxonomy to provide a framework for classifying and comparing programs based on their operational characteristics, and used it along with planting location data to identify programs that had the greatest reach into low-income and minority area. I found that highly integrated partnerships between nonprofit and municipal entities, reduced planting responsibility for property owners, and concentrated plantings that utilize public property locations to a high degree are likely to improve program penetration into low-income and minority areas. These findings provide urban forestry practitioners with guidance on how to more successfully align planting program design with equity outcomes.

❧ *For my parents, John and Karen Goodin.* ❧

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Abbreviations

ACS	American Community Survey
AOI	Area of Interest
DBH	Diameter at Breast Height
EJ	Environmental Justice
MHI	Median Household Income
PIV	Planting Index Value
PM	Particulate Matter
SES	Socioeconomic Status
UHI	Urban Heat Island
UFORE	Urban Forest Effects Model
UTC	Urban Tree Canopy
ROW	Right of Way
STF	Sacramento Tree Foundation
SMUD	Sacramento Municipal Utility District
VOC	Volatile Organic Compound

CHAPTER 1

Introduction

We live in an urban world. The UN Department of Economic and Social Affairs estimates that 54% of the global population lived in urban areas in 2014; they expect that rate to reach 66% by 2050 (United Nations Department of Economic and Social Affairs, Population Division, 2014). Rapidly increasing urbanization brings greater density to population centers and extends the sphere of urban influence into surrounding areas. This heightens pressures on the local ecosystem, degrading its ability to moderate the adverse environmental effects of this expansion. Municipal governments increasingly face the challenge and the necessity of developing policies and practices to protect the urban environment and the ecosystem services that it provides in order to ease demands on built infrastructure while creating a sustainable, healthy, and livable environment for their citizens.

Trees, a major component of the urban environmental landscape with well-established benefits, are a sustainable, cost-effective tool that city governments use as one way to meet this challenge. As an element of municipal green infrastructure, urban forests provide many environmental benefits for both cities and the people living in them. However, these benefits are not equally available to all citizens. Research on the distribution of urban trees shows that canopy is commonly linked to neighborhood income levels (Iverson & Cook, 2000; Schwarz et al., 2015) and concentrations of racial or ethnic minorities (Flocks, Escobedo, Wade, Varela, & Wald, 2011; Landry & Chakraborty, 2009); in most localities, wealthier areas have higher levels of tree canopy coverage than poorer areas, and in several cities higher concentrations of racial or ethnic minorities have been associated with lower levels of tree canopy. The proportion of land area covered by trees, their branches, and their leaves, known as urban tree canopy (UTC), is a common measure of distribution, which can be used to compare cities, neighborhoods, or land use types, and is frequently used as a reference point for municipal greening initiatives. As urban tree benefits are highly spatially-dependent—accruing primarily to citizens in their immediate vicinity—UTC can serve as a proxy for the level of ecosystem service benefits available to the surrounding community (M. C. Dwyer & Miller, 1999). When UTC disparities exist in areas heavily populated by historically disadvantaged groups it presents not only an ethical issue to cities and urban forestry organizations, but also a difficult technical challenge in order to overcome this inequality. Inequities in tree distribution might be at least partially addressed through focused efforts to increase UTC in underserved areas, using community outreach and prudent planting and cultivation. Municipal and nonprofit tree planting programs are opportunities to reduce the gap between high-canopy and low-canopy neighborhoods.

Much of the early research in urban forestry was focused on identifying and quantifying the ecosystem services provided by UTC (Nowak & Dwyer, 2007). And, while researchers continue to refine and expand upon this work, attention has increasingly been paid to the spatial distribution of UTC and the equity issues that arise as a result of disparities (Iverson & Cook, 2000; Perkins, Heynen, & Wilson, 2004; Flocks et al., 2011; Schwarz et al., 2015). The question has expanded beyond *what* urban trees do to include *where* they are located and *who* benefits from this distribution.

In the 1980s and 90s, while the nascent urban forestry field was concerned with establishing the function and value of urban trees, the environmental justice movement was focused on the harm that inequitable distribution of environmental hazards and disservices inflicted on poor and minority communities (Mohai & Bryant, 1992). In this century, interest in the distributional patterns of urban forests has grown, particularly as they relate to the allocation of urban forest benefits. Similarly, environmental justice literature has expanded to include equitable *access* to environmental assets (Jennings, Gaither, & Gragg, 2012) such as parks and other urban green spaces. The two disciplines converge around this issue of equitable UTC distribution; just as the negative health effects resulting from preferentially siting hazardous toxins in low-income and minority communities created an unjust burden on these populations, so do the negative health effects resulting from unequal access to the community asset of urban trees (Reid et al., 2009, 11; D. R. Williams & Collins, 1995).

While urban forest researchers increasingly understand UTC distribution patterns and their association with demographic characteristics, little work has been done to provide decision support to municipal and nonprofit organizations that wish to use tree planting to decrease inequity in tree canopy and the allocation of its benefits. Tree planting organizations operate within a set of constraints—specific to their locality—that encompass varying funding levels, management authority, political and citizen preferences, and climate, all of which influence the strategies and tactics used in tree planting programs. Complicating the effort to improve tree distribution is the fact that, though equity is often a desired outcome, it is rarely the primary goal of planting programs. Given local constraints, tree planting organizations often focus on a particular ecosystem service (such as stormwater abatement or energy conservation), general UTC expansion, or community engagement.

Municipal and nonprofit urban forestry organizations are generally aware of equity problems, and often attempt to incorporate tactics to address them into their planting programs (e.g. free or reduced price trees for low-income neighborhoods) despite the above constraints. However, to date there has been limited research on the effectiveness of these tactics with which to guide planting program development. Usually groups rely on organizational experience or anecdotal evidence to craft a more equitable canopy.

This research seeks to address this gap by providing analysis of existing planting programs in six U.S. cities, describing their strategies and tactics, and relating them to tree planting outcomes in areas with historically disadvantaged populations. My aim is to provide previously unavailable information on tactics that have been successful at placing trees in underserved areas, which can then be used by planting program administrators to create or modify their programs to better meet environmental justice goals and the needs of all communities in their city.

We gathered three types of data for this research: telephone interviews conducted with planting program administrators, locational data for trees planted through the programs, and demographic data for each city. Spatially associating the planting data with U.S. census block groups allowed us to characterize each tree planting location with neighborhood household income and racial and ethnic composition. The proportion of trees that were planted by each program in low-income or high-minority areas could then be quantified and normalized by program size and the extent of the area in which it operates, allowing comparison between programs. Descriptive data from the interviews were aggregated into a taxonomy of planting program strategies and tactics that could then be correlated with effectiveness at reaching underserved populations.

Chapter 2 is a review of the relevant literature, which presents current research on the influence of urban trees on human health, provides evidence that urban trees are inequitably distributed, gives background relating the environmental justice movement to issues of UTC access, and offers support for the idea that tree planting programs are a way to alleviate disparities. Chapters 3 and 4, presented in manuscript form, give the results of my research into current planting programs. Chapter 3 provides detailed descriptive information on planting program strategies and tactics based on interviews with thirteen program administrators in six cities. The multiplicity of program tactics were generalized and classified into taxonomic categories and used to examine how outcome goals and local constraints influence program design and subsequent equity outcomes. Chapter 4 is an analysis of which specific strategies and tactics described in Chapter 3 result in greater planting program effectiveness in reaching underserved populations, applying a geospatial analysis approach to planting data from thirteen programs in six cities. Finally, Chapter 5 discusses on the relevance of the results of this study, highlights potential applications by municipal and nonprofit forestry organizations, describes the limitations of the study, and offers possibilities for further research.

1.1 Research Objectives

1. Describe municipal and nonprofit tree planting programs in six major U.S. cities in terms of their goals, programmatic strategies, and administrators' perceptions of local characteristics.

2. Identify practices in cities with well-developed urban forestry infrastructure that are more effective or less effective at placing trees in low-income and predominantly minority areas.

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CHAPTER 2

Literature Review

2.1 Introduction

Urban forests have been recognized for the benefits and services they provide beyond simply beautifying a streetscape or ornamenting a yard (Lawrence, 1995; Ricard, 2005). Three decades of research have shown that urban trees contribute a broad range of environmental, social, and economic benefits to cities (Bolund & Hunhammar, 1999; Nowak & Dwyer, 2007; S. Roy, Byrne, & Pickering, 2012), and firmly established them as essential components of urban green infrastructure (e.g. Schwab, 2009; Seamans, 2013). Urban trees add economic value to municipalities and their citizens by providing ecosystem services and assisting and extending the capabilities of built infrastructure (McPherson, Simpson, Peper, & Xiao, 1999; Payton, Lindsey, Wilson, Ottensmann, & Man, 2008; B. Zhang, Xie, Zhang, & Zhang, 2012).

In addition to well-established capabilities for energy conservation through shading and windbreaks (Akbari, Pomerantz, & Taha, 2001; Donovan & Butry, 2009); stormwater management and treatment through interception, infiltration, and filtering (Armson, Stringer, & Ennos, 2013; B. Zhang et al., 2012); and economic benefits for property owners and businesses (Payton et al., 2008; Tyrväinen & Miettinen, 2000; Wolf, 2003); urban forests contribute to the vitality (W. C. Sullivan, Kuo, & Depooter, 2004), safety (Donovan & Prestemon, 2012; Dumbaugh & Gattis, 2005; Kuo & Sullivan, 2001), and neighborhood social ties (Coley, Sullivan, & Kuo, 1997; Holtan, Dieterlen, & Sullivan, 2014) that promote a high quality of life in urban areas. Urban trees have also been shown to promote human physical and mental health (Beyer et al., 2014; Donovan et al., 2013; Jiang, Li, Larsen, & Sullivan, 2014), particularly by mitigating some undesirable effects of urbanization such as air pollution (Nowak, Hirabayashi, Bodine, & Greenfield, 2014) and the urban heat island (UHI) effect (Hart & Sailor, 2009).

It is however, important to note that tree canopy is not distributed evenly across urban areas. At a broad scale, spatial heterogeneity in urban forest structure results from a combination of ecological and anthropogenic factors and processes: the natural ecosystem (Nowak et al., 1996; Sanders, 1984), terrain (Berland, Schwarz, Herrmann, & Hopton, 2015; Jim, 1989), urban land use patterns (Jim, 1989; Rowntree, 1984), and management intervention (Nowak et al., 1996; Sanders, 1984). At finer scales, there is evidence that more nuanced factors such as neighborhood age (Lowry, Baker, & Ramsey, 2012; Martin, Warren, & Kinzig, 2004; Grove et al., 2006), housing vacancy, and population density (Troy, Grove, O'Neil-Dunne, Pickett, & Cadenasso, 2007) can influence tree canopy distribution. There is also evidence that social drivers have an effect; lower canopy levels are often associated with lower income areas (Iverson & Cook, 2000; Landry & Chakraborty, 2009; Pedlowski, Da Silva, Adell, & Heynen, 2002; Pham, Apparicio, Séguin, Landry, & Gagnon, 2012; Schwarz et al., 2015; Tooke, Klinkenber, & Coops, 2010) and racial or ethnic minority status (Flocks et al., 2011; Heynen, Perkins, & Roy, 2006; Landry & Chakraborty, 2009). Given that trees have a variety of positive physical and mental health effects (Bell, Wilson, & Liu, 2008; Beyer et al., 2014; Donovan, Michael, Butry, Sullivan, & Chase, 2011; Donovan et al., 2013; Jiang et al., 2014; Kuo, 2001; Lovasi, Quinn, Neckerman, Perzanowski, & Rundle, 2008; Markevych et al., 2014; Takano, Nakamura, & Watanabe, 2002), when there is evidence of inequitable distribution on lines of economic class or on race, environmental justice concerns emerge.

This review begins with a summary of urban forest benefits, with a particular focus on their influence on human health outcomes. It examines the evidence that urban forest benefits are unequally distributed with regards to race, ethnicity, and socioeconomic status (SES), placing it within the context of environmental justice. It concludes with what is known of the effectiveness of tree planting programs as a management technique to alleviate these conditions, presents the practical implications for urban forestry professionals, and identifies areas for future research.

2.2 Health Benefits of Urban Forests

Numerous health benefits of urban forests have been identified. For urban residents in developed countries, the primary environmental sources of negative health effects are air pollution (in the form of ozone (O_3), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM)) (Brunekreef &

Holgate, 2002; Harlan & Ruddell, 2011); as well as heat stress related to the UHI effect (Basu & Samet, 2002; Curriero et al., 2002). Therefore, I will focus on urban forest impacts in these two areas, with a more limited review of mental health and other benefits. The locations that are most vulnerable to air pollution and heat-related health risks are most often those that are low income or that have a high proportion of minority residents (Basu, 2009; Curriero et al., 2002; Grineski, Bolin, & Boone, 2007; Jesdale, Morello-Frosch, & Cushing, 2013; Jenerette, Harlan, Stefanov, & Martin, 2011). These areas are often afflicted by a lack of economic and political resources, segregation, and discrimination (Brulle & Pellow, 2006), which limit the choice of housing locations and the availability of cooling resources such as vegetation and air conditioning (Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006), and restrict the ability to successfully oppose undesirable land uses (Bolin, Grineski, & Collins, 2005).

The uneven spatial distribution of these hazards places historically disadvantaged groups, who have borne a disproportionate burden of negative effects from exposure to toxic environmental conditions (Bullard, Mohai, Saha, & Wright, 2007), into greater danger from global climate change (Meehl & Tebaldi, 2004; Congressional Black Caucus Foundation, 2004). Trees can act as a mitigating force, influencing both air pollution and urban heat intensity (Harlan & Ruddell, 2011), so their inequitable distribution has important implications for the future health of these vulnerable populations.

2.2.1 Pollutant Removal

Trees can filter gaseous pollutants from the air through stomatal uptake, while airborne PM is generally reduced through deposition onto leaves and other plant surfaces. Nowak, Crane, and Stevens (2006) found that urban trees remove an estimated $711,000$t of pollutants per year across the coterminous United States, though a later study placed the amount at $651,000$t (Nowak et al., 2014). At the city scale, pollution removal research has been synthesized into a component of the Urban Forest Effects Model (UFORE), developed by the USDA Forest Service (Nowak & Crane, 2000), which has been used to quantify air pollution removal for many cities worldwide (for example, London (Tallis, Taylor, Sinnett, & Freer-Smith, 2011), Beijing (Yang, McBride, Zhou, & Sun, 2005), and Washington, D.C. (Nowak, Hoehn, Crane, Stevens, & Walton, 2006)). Within individual cities, the amount of pollutants removed can be highly varied, dependent upon pollution concentrations and urban forest distribution (Escobedo & Nowak, 2009; M. Rao, George, Rosenstiel, Shandas, & Dinno, 2014). Pollution removal rates by urban trees have been found to be higher in low income and minority communities (Flocks et al., 2011), though it has been suggested that this is due to the higher overall concentrations of pollutants in these areas (Escobedo & Nowak, 2009; Grineski et al., 2007; Pastor, Morello-Frosch, & Sadd, 2005).

Positive health effects from pollutant removal can be substantial. Using BenMAP (EPA software that estimates air pollution's health and economic effects), Nowak et al. (2014) estimated that air pollution removal by urban trees resulted in the avoidance of 670,000 incidences of acute respiratory symptoms, 430,000 incidences of asthma exacerbation, and 850 incidences of mortality. A similar study in Portland, Oregon (M. Rao et al., 2014) estimated that annual NO_2 removal by trees was responsible for 21,000 fewer incidences of asthma exacerbation in children, 54 fewer emergency room visits, and 46 fewer hospitalizations, with an economic value of \$7 million (2013 USD).

Trees also can also degrade air quality, however, due to emissions of pollen and volatile organic compounds (VOCs), a precursor to O_3 (Chameides, Lindsay, Richardson, & Kiang, 1988). Seasonal tree pollen emissions have been linked to increases in asthma and wheeze-related emergency department visits in Atlanta (Darrow et al., 2012) and New York (Jariwala et al., 2011). Trees are generally thought to have a net positive effect on asthma and other respiratory problems due to removal of PM and their overall positive effect on O_3 (Escobedo et al., 2008; Nowak et al., 2000); however, research into this area has been mixed. A 2008 study by Lovasi et al. found that street trees were associated with lower asthma rates in children, though a more rigorous follow up study found no association between UTC and asthma prevalence and slightly higher rates of allergic sensitization to tree pollen (Lovasi et al., 2013). The interactions between local species mix, air pollution levels, and climate have an complex influence on the amount of pollution removal and the emissions of pollen and VOCs; therefore, more research is needed to determine the precise effects of trees on specific air pollution-related conditions. The balance of the literature supports the position that trees have a positive effect on air quality, though the effects of VOCs and pollen should be taken into account when planning future planting or other modifications to urban forest structure.

2.2.2 Urban Heat Island Mitigation

Heat stress is a particular concern in urban areas due to the urban heat island effect. This refers to elevated surface temperatures present in cities compared to their rural surroundings. The UHI effect is a result of solar radiation being first stored as heat in paved surfaces, buildings, and other components of the built environment, and then re-radiated back into the atmosphere. The presence of additional heat sources in urban areas, such as internal combustion engines, and reduced cooling from evapotransipration due to the relative lack of vegetation also contribute to the UHI. This effect is particularly pronounced at night.

As with pollution, UHI-related temperature increases are variable within cities and tied closely to land use (Aniello, Morgan, Busbey, & Newland, 1995; Cui & De Foy, 2012; Hart & Sailor, 2009). Trees and other forms of urban vegetation have been shown to be correlated with reduced UHI effects (Aniello et al., 1995; Feyisa, Dons, & Meilby, 2014; Hart & Sailor, 2009; Yu & Hien, 2006), as they shade surfaces that store solar energy and cool the air around them through evapotransipration.

The health effects of elevated temperatures are clear: increased risk of death from cardiovascular, respiratory, and related disease (Basu, 2009). Heat-related mortality follows a J-shaped curve; when the initial temperature is high, a relatively small increase in heat results in a large increase in mortality risk (Curriero et al., 2002).

Not all populations in a city are equally at risk. In Phoenix, Harlan et al. (2006) found that heat stress exposure was correlated with the percentage of poor and minority residents and that the disparity became larger during heat wave events. This was attributed to the lower levels of vegetation and open space and denser development patterns prevalent in low income and minority communities. Similarly, a national study of U.S. urban areas by Reid et al. (2009, 11) found that the locations most susceptible to elevated heat levels were concentrated in city centers and that social and environmental factors such as education levels, poverty, percent minority, and amount of green space explained much of the variability in heat vulnerability. Another national study by Jesdale et al. (2013) found that racial and ethnic minorities were more likely to live in landscapes with higher heat risk (i.e. low vegetation cover and high impervious cover) even after controlling for poverty and local segregation levels.

Compounding these disparities, climate change models predict more frequent and severe heat events in North America (Meehl & Tebaldi, 2004), which may magnify the negative health impacts in vulnerable communities (Patz, Campbell-Lendrum, Holloway, & Foley, 2005). Climate change is also expected to have a negative impact on urban air quality as O_3 levels are tied to temperature (Jacob & Winner, 2009). Many cities are currently adopting climate change adaptation policies in anticipation of these future conditions. Urban forests may be used as a mitigation strategy within these larger climate change plans, as they reduce atmospheric CO_2 by reducing energy consumption and by acting as carbon sinks (C. Liu & Li, 2012; Nowak, 1994).

2.2.3 Other Health Benefits

In addition to mitigating the negative physical health effects of pollution and extreme heat, urban forests and urban green spaces have also been shown to be associated with greater longevity for senior citizens (Takano et al., 2002), reduced risk of poor birth outcomes (Donovan et al., 2011; Kihal-Talantikite et al., 2013), and improved recovery times for surgery patients (Ulrich, 1984). In children, they are associated with lower blood pressure (Markevych et al., 2014) and lower body mass indices (Bell et al., 2008). A recent study in Toronto found that higher street tree density was associated with better perceptions of personal health and reduced cardiometabolic conditions (e.g. diabetes, hypertension, and stroke) (Kardan et al., 2015).

Urban trees and green spaces have also been shown to contribute to positive mental health effects. Natural scenes, trees, and green space have long been associated with improved stress recovery (Hartig, Mang, & Evans, 1991; Ulrich et al., 1991), and a recent study by Jiang et al. (2014) showed a linear relationship between street tree density and stress recovery, suggesting that additional urban trees would assist urban residents' abilities to respond to stressful events. Urban children have been shown to exhibit improved self-discipline and attention-deficit disorder symptoms with increased exposure to natural elements in the environment (Kuo & Taylor, 2004; A. F. Taylor, Kuo, & Sullivan, 2002). A similar influence on attention and coping ability has also been found with adults (Kuo, 2001). A statewide study in Wisconsin by Beyer et al. (2014) found that higher vegetation levels were associated with lower levels of depression, anxiety, and stress. It also found higher initial levels of these symptoms in areas with more residential racial segregation, and that those with the lowest income were more likely to live in areas with less than 10% tree canopy (Beyer et al., 2014).

Though the mechanisms are not well understood, it appears that regular exposure to natural elements such as trees can have physical and mental heath benefits that go beyond air quality and heat island mitigation, leading to improved quality of life for urban residents.

2.3 Environmental Justice & Urban Forests

The environmental justice (EJ) movement is a social movement dedicated to addressing the inequitable distribution of environmental liabilities and benefits based on race and class. Though fair access to the full range of environmental amenities and services was identified early on as an important aspect of the movement—being noted as a key issue in the defining document, "Principles of Environmental Justice" (1991) (as noted in D. E. Taylor, 2000)—early EJ literature and grassroots action was focused primarily on the environmental *hazards* that disproportionately affected socially disadvantaged groups (Bryant & Mohai, 1992; Bullard, 2000; Bullard et al., 2007; C. Lee, 1994; Mohai & Bryant, 1992). However, in this century, the movement has broadened in scope, placing more emphasis on the importance of access to urban environmental amenities and services such as parks (Joassart-Marcelli, 2010), recreational facilities (Dahmann, Wolch, Joassart-Marcelli, Reynolds, & Jerrett, 2010), and green space (Jennings et al., 2012)—including tree canopy (Flocks et al., 2011).

Urban forest research matured in parallel to the increased interest in the distribution of environmental services in EJ literature, leading to more well-defined quantification of UTC benefits. At the same time, high-resolution, remotely sensed imagery became cheaper and easier to obtain, and less technically challenging to process, leading to a greater ability to visualize and quantify UTC distribution across a city and to compare this to demographic and socioeconomic data. As a result, the study of the distribution of urban forest benefits from an EJ perspective has become more frequent in both the EJ and urban forestry fields.

In the context of tree canopy distribution, there is ample evidence that UTC is not distributed equally with regard to SES, though there seems to be considerable local variation. This section describes the results of this EJ-aware research into UTC distribution, concluding that low income and minority areas often suffer from reduced UTC, with a corresponding reduction in environmental service benefits. As the importance of natural elements in the urban landscape become better understood, decisions regarding the location of greenery and other environmental elements take on an increasing importance (Altschuler, Somkin, & Adler, 2004; Jackson, 2003).

2.3.1 Income Level and Tree Cover

The evidence that unequal UTC distribution is related to income is generally consistent, finding lower levels of canopy in lower income neighborhoods. In addition to UHI studies that have found less canopy and vegetation in low income areas (Harlan et al., 2006; Reid et al., 2009, 11), there have been a number of studies that specifically examine UTC distribution patterns in relation to socioeconomic indicators. An influential study by Iverson and Cook (2000) merged household data and land cover classification in the Chicago area, and found a strong positive relationship between household income and tree cover, with the highest cover occurring in areas with household incomes three to four times higher than the region average. Similar analyses in Montreal (Pham et al., 2012), Tampa (Landry & Chakraborty, 2009), and Campos dos Goytacazes, Brazil (Pedlowski et al., 2002) found the same general effect. A Boston study looking at the possibility of using planting to achieve equity, also found that median household income (MHI) was positively correlated with percent canopy cover (Danford et al., 2014). However, a modeling study of urban areas in Indiana (excluding both the smallest municipalities and Indianapolis, the largest) conducted by Heynen and Lindsey (2003) did not find a significant correlation MHI and canopy cover. Rather, housing age, slope, and education were found to be significant. A study in just Indianapolis, though, found that MHI significantly explained changes to tree canopy over time (Heynen, 2002); perhaps the size and history of the municipality had an influence that was not present in surrounding communities, or perhaps there was more variation in income or more concentrated low-income areas in Indianapolis. Income-related disparities in public and private tree abundance were also seen in Brisbane, Australia (Shanahan, Lin, Gaston, Bush, & Fuller, 2014), though the effect was less pronounced for trees on public parkland than trees on private property, suggesting the role that public management can play in reducing disparities. Kendal, Williams, and Williams (2012) in Ballarat, Australia and Pham et al. (2012) in Montreal, however, found the opposite: greater inequality in tree cover in public streetscapes than in private gardens. They also found that income was not related to canopy, though they suggest that it was due to the particular local circumstances of their study areas. A recent multi-city study by Schwarz et al. (2015) found a strong correlation between UTC and MHI across all seven cities they investigated, while a similar study in Australia found that the amount of green space and level of access was correlated with income across five cities, though there was considerable variation in green space availability between cities (Astell-Burt, Feng, Mavoa, Badland, & Giles-Corti, 2014). Income was also found to be associated with vegetation abundance across three Canadian cities (Tooke et al., 2010).

Recent work using market research techniques has questioned the extensive use of social stratification variables such as income in the literature, and proposes greater emphasis on lifestyle preferences in neighborhoods (Grove et al., 2006). A study by Grove et al. (2006) used the PRIZM market classification scheme, and found that social stratification variables explained the *possibility* of vegetation in Baltimore—that is, the space available for planting—but did not explain variation in *realized* vegetation cover. By additionally including other lifestyle factors and housing age, they were able to improve their prediction of the variation in vegetation cover. These findings were echoed by Troy et al. (2007). Though adding additional market segmentation factors may provide a more nuanced picture, there is evidence that in large cities, income alone is often a reliable indicator for urban forest distribution, though local factors can play a role in the magnitude of the disparity.

2.3.2 Race & Ethnicity and Trees

Several case studies have confirmed that race and ethnicity can be locally significant factors in UTC cover. In Tampa, Florida, Landry and Chakraborty (2009) found significant UTC differences between White and African-American neighborhoods, and Flocks et al. (2011) found that White areas in Miami-Dade County had more tree cover and greater tree species diversity than African-American and Hispanic areas despite similar levels of impervious cover. Heynen et al. (2006) found significant disparities in UTC between White and Hispanic neighborhoods in Milwaukee, though the same relationship was not found between White and African-American residents. A qualitative difference was noted, however, in that much of the canopy in predominantly African-American neighborhoods consisted of unplanted and undesirable trees growing along rear fences, which was not the case in White neighborhoods. Pham et al. (2012) found that visible minority status was associated with lower levels of vegetation in Montreal, but that the factor was minor compared to income.

On the other hand, Danford et al. (2014) and Duncan et al. (2014) found that minority neighborhoods were weakly correlated with *increased* tree canopy in Boston. Danford et al. (2014) speculate that this may be due to the fact that in Boston high minority neighborhoods are located further from the dense, low-UTC urban center, and that volunteer trees in vacant lots may contribute to higher UTC levels in minority communities. Local terrain was found to play an overwhelming role in determining canopy cover in Cincinnati, Ohio (Berland et al., 2015). Historical segregation patterns consigning Black and poor residents to a particular hilly area were cited as a reason that percent Black was a significant positive predictor of canopy cover on residential land. Heynen and Lindsey (2003) also found slope to be a significant variable in explaining UTC distribution. This is consistent with early studies showing the effect of physical environmental factors on vegetation abundance and structure (Rowntree, 1984; Sanders, 1984; Jim, 1989). While Schwarz et al. (2015) found that income was significant in all cities they studied, they found that the association with race was inconsistent, with some cities showing negative correlations between minority concentration and UTC and others showing weak positive correlations. They propose that climate may account for this: areas where the association was negative were more arid, meaning that greater investment was required for trees to grow; where the correlation was not significant or positive, the native ecosystems allow for urban forest regeneration with little or no human intervention.

Race and ethnicity have been found to be a factor in UTC distribution in some cities, but there is evidence that local factors such as climate, terrain, and patterns of neighborhood change may be more important drivers of distribution in some cases, leading to considerable variation between cities. Race and ethnicity are not as strong a predictor of UTC as income, though the disparity is quite real in many cities. As the conditions that led to environmental inequality formation are similar for both low income and minority residents (Brulle & Pellow, 2006), we would expect the outcome in terms of UTC distribution to be similar as well, yet that does not seem to be the case. Why does the link between income and UTC appear stronger and more resistant to local conditions such as climate and terrain than the link between race and ethnicity and UTC? Future research could explore cities where income and minority status show divergent effects on canopy to determine the local factors that may account for this seemingly counterintuitive outcome.

2.3.3 Urban Forest Quality

In addition to UTC distribution, socioeconomic factors may affect measures of urban forest quality such as biodiversity and level of maintenance. Species diversity has been shown to increase the mental health benefits of urban green spaces (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007; Van Dillen, de Vries, Groenewegen, & Spreeuwenberg, 2012). Biodiversity can be relatively high in urban areas compared to surrounding unpopulated areas (for a review, see Alvey, 2006); however, the level of diversity has been shown to vary with family income and housing age in Central Arizona (Hope et al., 2003; Kinzig, Warren, Martin, Hope, & Katti, 2005; Martin et al., 2004) and Campos dos Goytacazes, Brazil (Pedlowski et al., 2002). These studies suggest that socioeconomics has an impact on the distribution of urban plant diversity, though much more research is needed to see if their results hold for cities in different ecoregions or with different landscape traditions.

The frequency of maintenance activities such as pruning affects tree condition (Hauer, Vogt, & Fischer, 2015), which in turn impacts growth rates and the level of ecosystem services provided (McPherson & Peper, 2012). As mentioned above, Heynen et al. (2006) found that a large number of urban trees in predominantly African-American neighborhoods in Milwaukee were unplanted, unmaintained trees along fence lines and on divested private property. Interviews revealed that these trees caused conflicts and damage to built infrastructure, and were viewed by many residents as disamenities

(Heynen et al., 2006). Though they provide ecosystem services, it is presumably at a lower rate than well-maintained and intentionally placed trees, and they can become financial liabilities when conflicts or hazards to property necessitates their removal. This sentiment was echoed by Schwarz et al. (2015), speculating that the higher levels of vegetation in African-American neighborhoods in Baltimore may be a function of the large amount of land left vacant through divestment.

Unfortunately, there has been much less research on the relationship between socioeconomic indicators and disparities in urban forest quality compared to those studying disparities in distribution. Most studies employ a top-down remote sensing approach, which has the advantage of being able to efficiently cover large areas, but can only measure the spatial distribution of trees and other vegetation, not quality (Kenney, van Wassenaer, & Satel, 2011). Tree inventories can provide insight into tree species composition and condition, but these do not typically include trees on private property, which constitute a substantial portion of the urban forest (Kenney et al., 2011; Rowntree, 1984). More research is needed to determine what effect socioeconomic factors have on the quality of the urban forest and that effect on the allotting of ecosystem service benefits.

2.3.4 Connections to Other UTC Influences

While examining UTC distribution through the lens of income, race, and ethnicity is important, there are other factors that influence canopy, many of which cannot be neatly separated from EJ variables. For example, socioeconomic variables such as lower educational attainment (Heynen & Lindsey, 2003) and higher proportions of renters (Heynen et al., 2006; Landry & Chakraborty, 2009) have been linked to lower UTC. However, since these conditions have also been shown to track closely with income and minority status (Gyourko, Linneman, & Wachter, 1999; Kao & Thompson, 2003; Sirin, 2005), they may be exhibiting the same pattern. The interrelationship between the proportion of owner-occupied housing and race can be seen as the product of complex histories of housing discrimination, unequal economic opportunity, racism, market pressures, preferential government assistance, and so on. And, while there may be some similarities between cities, the spatial and historical morphologies of individual cities complicates comparative efforts. These tightly interwoven connections, make it difficult to precisely determine the effect of one particular variable. It is important, though, to be aware of these interrelationships when trying to determine the causes of present UTC distribution.

Additionally, neighborhood-level characteristics such as socioeconomic variables, physical attributes, and local actors such as neighborhood civic organizations may foster inequalities. For example, Conway, Shakeel, and Atallah (2011) found that Toronto neighborhoods where home values and the percentage of owner-occupied homes were high had resident associations that were more likely to be involved in urban forestry activities than those in less affluent areas, possibly contributing to greater inequity. Locke and Grove (2014) found that recruitment for programs that planted trees on private property was most successful in more affluent areas of Washington, DC and Baltimore where the need was least.

Along with biogeophysical factors such as terrain and climate, the most common correlate of urban tree canopy in the literature is housing age (Heynen & Lindsey, 2003; Pham et al., 2012; Schwarz et al., 2015, to list a few examples). This makes intuitive sense; since trees take many years to achieve their mature canopy, substantial UTC levels are unlikely to be found in recently developed areas. However, housing stocks tends to filter from high-income occupancy to low-income occupancy as they age, neighborhoods homogenize, and income and racial groups become segregated (Bond & Coulson, 1989; Brueckner, 1977). As such, the current vegetation patterns in a neighborhood may be considered a reflection of the preferences and stewardship of past residents. More research is needed to tease out the complex interrelationships between housing turnover, segregation, and vegetation structure.

Some inequities are heavily influenced by physical characteristics of urban structure such as building density and the presence and size of planting strips along roadways, which limits the availability of planting space and the size of trees that may be planted. Higher canopy is easier to attain in areas with more space to plant, and in most cities, lot sizes tend to increase with income. A recent study projected the expected canopy for a variety of planting scenarios for Boston's "Grow Boston Greener" planting initiative, and found that even if trees were preferentially planted in environmental justice communities, true equity was difficult to attain due to the lack of available planting space in underserved areas (Danford et al., 2014).

Cultural preferences for the amount and type of vegetation may also play a role. Variation in preferences for the arrangement and, to a lesser extent, amount of vegetation has been shown between racial, ethnic, and cultural groups (Buijs, Elands, & Langers, 2009; Kaplan & Talbot, 1988; Fraser & Kenney, 2000). There are economic disincentives as well. For example, renters are less likely to experience the benefits of a planted tree, and have little incentive to invest in planting and maintenance on property that is not their own (Heynen et al., 2006). Avoidance of the costs resulting from tree maintenance and removal, and reducing the risk of costly damage to property may also be a factor, particularly in low-income communities.

There are many mechanisms affecting the present distribution of UTC, each of which may have more or less influence depending on the particular human and environmental conditions in a city. Some of these mechanisms, such as terrain, are resistant to human influence, but many can be affected, either positively or negatively, through management practices and public policy. For example, a municipal urban forestry program may be able to partially overcome the effect of a hot, arid climate by irrigating plantings or choosing drought-tolerant trees. Or it may exacerbate the influence of climate by selecting incompatible trees for planting and providing minimal maintenance. Though the management interventions may not be as straightforward, the factors that drive conditions of environmental inequity in UTC may be similarly influenced for better or worse by management and policy. Perhaps planning and outreach efforts may be modified to prioritize vulnerable communities, economic barriers addressed through subsidized planting and maintenance costs, or public space planting increased in areas with a greater proportion of renters. At this point, there is little research which would recommend one strategy over another, though the principle that management and policy inputs affect the quality and distribution of the urban forest is well accepted.

2.4 Impacts of Unequal UTC Distribution

The negative health effects of lower UTC in low-SES or predominately minority communities disproportionately impact groups that suffer worse health in general (Powell, Slater, & Chaloupka, 2004; D. R. Williams & Collins, 1995), are more likely to live in environmentally degraded areas (Grineski et al., 2007; Jennings et al., 2012), have less access to active recreation infrastructure (Dahmann et al., 2010), and are more prone to chronic stressors such as poverty and crime (Altschuler et al., 2004). As shown earlier, these groups are more vulnerable to the negative consequences of climate change, heat stress, and air pollution (Congressional Black Caucus Foundation, 2004; Harlan et al., 2006; Jesdale et al., 2013). The additive impacts of these vulnerabilities may have a compounding effect, amplifying the negative effects of low UTC (Jennings et al., 2012).

Unequal canopy may also have an effect on the economic well-being of individuals and communities. Customers perceive businesses on treed streets to be of higher quality, express a willingness to pay more, and patronize these businesses more frequently and for longer durations (Wolf, 2003). Thus businesses in low income and minority communities with low UTC may be placed at a disadvantage relative to businesses in areas with more trees. Personal wealth too may be affected. Since nearby trees add substantial value to property (Payton et al., 2008; Tyrväinen & Miettinen, 2000), homeowners in areas with low UTC may have less opportunity to build wealth. Productivity and work time lost to health problems can also negatively impact personal and community economic potential (Mitchell & Bates, 2011).

The presence of trees can have a positive effect on social networks, creating opportunities for interaction, and increasing neighborhood social capital (Coley et al., 1997; Holtan et al., 2014). Unequal access to tree canopy means that affected neighborhoods are less able to develop the social ties that improve neighborhood political influence and efficacy and community resilience.

Since urban trees can help ameliorate these negative environmental conditions, and since the environmental services associated with UTC are largely spatially-dependent, unequal UTC distribution along lines of class and race constitutes an environmental justice condition. As citizens in these areas often have less direct control over their environments and less means to purchase and maintain trees, municipal and nonprofit involvement and investment become more essential (Flocks et al., 2011).

2.5 Management Implications

Given the interrelationship between urban design and human health and well-being, Agyeman, Bullard, and Evans (2002) have suggested that governments embed the principles of environmental justice into their sustainability planning and join forces with nonprofits to achieve these goals. Indeed, municipalities working hand-in-hand with nonprofit urban forestry groups is not uncommon. Both groups have access to resources, experience, and planting space that may be inaccessible to the other. Municipalities commonly have authority over trees in the public right of way (ROW) and in parks, and are mandated to maintain these trees for the public good, while mitigating tree conflicts and risk. They typically have access to equipment and well-established contractor relationships, which, with appropriate funding, allows them to plant and maintain many more trees than a nonprofit entity. On the other hand, nonprofits can focus on planting on private property, which is the bulk of plantable land, and have volunteer networks available to them. They can take an active role in urban forest education and outreach, improving public perception of trees and urban forestry programs. By working in tandem to achieve urban forestry goals, municipalities and nonprofits are able to leverage each other's strengths to expand the reach of their programs. However, while much has been learned about the drivers of urban forest distribution, planting program administrators have little guidance as to which strategies should be employed in order to achieve a more equitable UTC (Perkins et al., 2004).

Planting programs vary widely in primary outcome goals (e.g. UHI reduction, stormwater management, beautification) and in sub-goals (e.g. equity, community engagement, education). The methods by which they attempt to achieve those goals are equally varied, developed with different funding sources, levels of volunteer involvement, outreach tactics, partnership arrangements, and other characteristics. While planting organizations may have institutional or anecdotal evidence that particular tactics are more effective at meeting their desired outcomes, there is limited research comparing the effectiveness of one tactic over another.

Though program administrators may intend to improve planting program participation in underserved communities, the evidence suggests that program outcomes may instead reinforce the unjust condition. Planting programs in Washington, D.C. and Baltimore were found to have the most participation where the need was least and efforts to minimize the cost of trees to participants in less affluent areas were unsuccessful at increasing participation (Locke & Grove, 2014). They note that existing marketing tactics were highly appealing to the programs' existing audiences, but much less salient to other groups, and suggest using market research strategies that more effectively tailor their appeals to targeted communities (Locke & Grove, 2014). Donovan and Mills (2014) also found that a tree planting program in Portland was more successful at recruiting participants where more trees were already present and less successful at recruiting low SES participants.

Differing cultural perspectives should be taken into account when planning vegetation in public and private spaces in order to create neighborhoods that reflect the aesthetic and landscape use preferences of their residents (Gobster, 2002; Rishbeth, 2001). For individual projects, engaging the targeted community, determining their goals, and involving them in the planning and execution of the project can be an effective way to improve the landscape while empowering the community (Westphal, 2003). However, these outcomes are not inevitable. Westphal (2003) studied successful and unsuccessful greening projects in Chicago, and offers suggestions on selecting projects, finding appropriate partnerships, and avoiding common pitfalls.

Any engagement strategy should recognize that low SES and minority neighborhoods may have reasonable and rational reasons to oppose trees. Wolch, Byrne, and Newell (2014) note that greening activities often have the effect of attracting higher income residents, driving gentrification. They suggest finding a "just right" level of vegetation that improves the neighborhood's ecological function, while minimizing gentrification. Fear that trees may provide cover for crime is another common concern. While some studies have shown that vegetation is associated with reduced crime (Kuo & Sullivan, 2001), it is also associated with a decreased sense of personal safety (Maruthaveeran & van den Bosch, 2014; Nasar, Fisher, & Grannis, 1993). Donovan and Prestemon (2012) found that trees' effects on crime seems to be related to their stature: shorter, view-blocking vegetation was associated with more crime, while tall shade trees were associated with less. A combination of selecting large stature trees and planting them in locations that minimize view obstruction, along with routine maintenance that emphasizes clear sight lines could be a strategy to increases canopy while being sensitive to community concerns about crime.

UTC is a convenient measure of urban forest extent, but does not provide a complete picture. It can be used as a benchmark to measure progress towards canopy goals and, when analyzed with other spatial datasets, can be used to compare canopy levels across, for example, land use types, neighborhoods, or watersheds. The easy availability of high spatial resolution imagery, U.S. Census demographic data, and improved analysis techniques for urban areas has made determining the location and magnitude of local distributional inequities cheaper and easier. This knowledge can be used as a starting place for planning. However, UTC is only one facet of urban forest structure. As noted by Kenney et al. (2011), it does not provide any information about the health or diversity of the urban forest, factors which influence urban forest function and the provisioning of benefits. They build upon seminal work by Clark, Matheny, Cross, and Wake (1997), proposing a more holistic set of criteria and indicators for urban forest management that can be used to guide and measure the performance of a municipal urban forestry program (Kenney et al., 2011). Although this approach addresses many measures of urban forest quality, community involvement, and management, it does not include criteria and indicators for equity. However, this could be incorporated into the overall framework for a municipality with an environmental justice goal.

Addressing environmental justice conditions with regard to tree canopy is not an easily attained goal. Planting programs often seem to reinforce disparities even when equity is a desired outcome. Higher income residents are more receptive to typical recruitment appeals and lack some of the barriers present in environmental justice communities, such as smaller lot sizes, higher numbers of renters, and less resources available for maintenance. There may also be differences in cultural preferences or language barriers. Standard planting program design may not be up to the task of meeting environmental justice goals. If UTC equity is a desired outcome, urban foresters may have to take a concentrated approach, increasing outreach and community engagement activities, and recognizing that—at least for a while—they will have to accept lower levels of tree planting for higher levels of work.

2.6 Conclusions

Urban forests provide a number of benefits for urban residents, especially for those in close proximity to the resource. Of particular concern are their positive influences on human health. However, canopy is often disproportionately lower in low income and minority communities. The unequal allocation of UTC-derived benefits along lines of race and class creates an environmental justice condition that must be addressed. However, there is a gap in knowledge: much is known about the patterns, causes, and consequences of unequal tree canopy distribution, while relatively little is known about how to remedy that condition. This lack of information presents a barrier to municipal and nonprofit urban forestry organizations that wish to shape a more equitable canopy.

Although these sorts of disparities are well known within the urban forestry profession, there is considerable variation between cities in the magnitude of the inequity and in the groups affected. While UTC assessments and i-Tree (an urban forestry software suite) analyses have proven to be quite effective at quantifying forest structure, function, and value, communities should go further to uncover the particular patterns of inequity in their cities and the processes that led to the situation. The basis for any remediation program should be reliable local information. There is an additional gap in knowledge regarding the relationship between SES indicators and urban forest quality. While more difficult to obtain, this information is an important aspect of urban forest function and value, and can influence community perceptions of trees.

Planting programs are an obvious strategy for increasing canopy, however, as commonly constructed, they may actually contribute to inequity (Donovan & Mills, 2014). Even if the overall outcome goal is a specific environmental service, such as UHI reduction or air quality, efforts should focus on the most vulnerable populations (Harlan et al., 2006; Jesdale et al., 2013).

As research into planting programs is at present underrepresented in the literature, future work should address how organizations currently operate planting programs—what is the range of strategies, tactics, and goals—and evaluate their effectiveness at addressing environmental disparities. Decision support information is sorely needed.

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CHAPTER 3

A New Taxonomy of Urban Tree Planting Programs: A Tool for Analysis

3.1 Introduction

Urban forests provide a wide variety of benefits for residents and municipalities (Bolund & Hunhammar, 1999; Nowak & Dwyer, 2007; S. Roy et al., 2012). These benefits are generally described as being environmental, social, or economic, and include such things as stormwater control (Armson et al., 2013), air pollution reduction (Nowak et al., 2006), energy savings (Akbari et al., 2001), and improved human health (Donovan et al., 2013; Jiang et al., 2014). However, distribution of urban trees is not uniform across cities (Flocks et al., 2011; Iverson & Cook, 2000; Nowak et al., 1996; Sanders, 1984), which has important consequences for city residents (Escobedo & Nowak, 2009; Harlan et al., 2006; Reid et al., 2009, 11). One significant way that urban foresters can influence the future composition and distribution of the urban forest—and thus, the future allocation of benefits—is through tree planting programs. Tree planting is an essential aspect of urban forest management; most municipal and nonprofit urban forestry organizations administer some sort of coordinated planting program. Although they share the goal of planting trees, programs are constructed in widely varying arrangements and for many different purposes—e.g. street tree stocking, environmental services, community building. Each organization also operates within a locality which has its own unique cultural, environmental, and regulatory pressures influencing program construction. Working within their local context, urban foresters generally design their programs in order to achieve their desired outcome. However, although it has serious implications for urban foresters' ability to efficiently effect changes in urban forest structure and function, the question of how planting program design affects the distribution of tree plantings has not been rigorously analyzed.

Planting program administrators have an interest in knowing how program design and operational characteristics influence the ultimate outcome of their programs. Understanding these connections would allow administrators to analyze and optimize their program in order to best achieve their specific desired outcomes. For example, if a municipality has a stormwater management goal, is it more effective to target private property owners or to focus on city-managed right of ways (ROWs)? If urban tree canopy (UTC) equity is the goal, would time be better spent developing partnerships with volunteer organizations, or reaching out directly to homeowners? Is a website good enough to recruit a sufficient number of program participants to meet an energy savings goal? Does in-person maintenance instruction lead to healthier trees than simply giving participants a pamphlet? There is little guidance in the literature as to which program characteristics are important and how they affect specific program goals. Consequently, organizations must rely solely on anecdotal evidence or prior experience in order to shape their programs.

Nevertheless, tree planting programs have discrete characteristics that can be defined and described, and these characteristics likely have an effect on the program outcomes. Despite this, there are very few studies that have connected program design characteristics to certain program outcomes. For example, a series of papers by Sommer, Learey, Summit, and Tirrell (Sommer et al., 1994a, 1994b, 1995) assessed the effect that resident participation has on satisfaction with newly planted trees, finding that residents are more pleased with the outcomes if they participate in planting a street tree than if trees are planted by others. Similarly, a 1998 study by Summit and Sommer also found that personal involvement in planting a tree and participation in planting programs in general both lead to more positive perceptions of particular trees. These studies illustrate that program design can impact the eventual outcome. However, though both studies investigated multiple programs, their focus was limited to the effectiveness of a particular design characteristic that was common to all of them, rather than examining the influence that *differences* in program characteristics had on overall outcomes.

More commonly, studies of tree planting programs are limited to case studies examining individual programs. While this approach may provide valuable information on the potential features and outcomes of planting programs, it does not allow for analysis of the interplay among program design features and their influence on program success. Studies have looked at outcomes such as tree growth and mortality (Nowak, McBride, & Beatty, 1990; Ko, Lee, McPherson, & Roman, 2015), the demographic characteristics of program participants (Greene, Millward, & Ceh, 2011; Locke & Grove, 2014), motivations for tree planting (Summit & McPherson, 1998; Donovan & Mills, 2014), and specific ecosystem service outcomes (Hildebrandt & Sarkovich, 1998). Studies on the Million Trees Los Angeles campaign provided insight on both the influences governing its implementation (Pincetl, 2010) and its eventual outcomes (McPherson, 2014), providing an interesting look at program planning and evaluation. However, it is much more common to evaluate the effect of trees in a particular location (e.g. a specific park or the total urban forest in a municipality) than trees planted as the result of an individual program (e.g. Donovan & Prestemon, 2012; Feyisa et al., 2014; Inkiläinen, McHale, Blank, James, & Nikinmaa, 2013). The ability to conduct comparative analyses to determine not only the outcomes that occurred in an individual location, but the range of outcomes that may be possible with a variety of program designs could provide valuable guidance for planting programs. However, these sorts of analyses are difficult because there is no currently recognized framework for comparative study of tree planting programs.

The wide variety of program types and design characteristics currently in use make direct comparison between programs difficult. Without a standardized way to describe programs and distinguish between the characteristics that are common among them and those that are meaningfully different, planting program analysis will produce results that are difficult to generalize. To manage these types of difficulties, a taxonomy can be a useful tool. A taxonomy is a method of grouping and classifying—commonly hierarchically, but not necessarily so—which can facilitate comparisons by reducing the array of possible characteristics into a smaller set of attributes and classes. They have been usefully applied to many fields such as education and learning (Krathwohl, 2002), psychology (Moffitt, 1993), and computer science (Mirkovic & Reiher, 2004) to simplify, analyze, classify, and compare individuals or events. In the case of planting programs, a taxonomy could be used to sort programs with similar attributes that are likely to affect outcomes.

Once described by a taxonomy, planting programs outcomes can be analyzed using commonly collected urban forest information such as planting location and tree condition, demographic data, or ecosystem service outcomes such as energy reductions or stormwater mitigation to help understand why trees end up where they do, how this impacts program outcomes, and what possibilities may exist for improvements. A good taxonomy must reflect the fact that many of desired outcomes are spatially-dependent, since many of the benefits of urban trees are spatially-dependent, that is, they accrue primarily to those in their immediate vicinity. Urban forests are highly heterogeneous, and UTC can vary based on a wide variety of factors—terrain (Heynen & Lindsey, 2003), climate (Sanders, 1984), housing density (Iverson & Cook, 2000), and each city's unique history (Berland et al., 2015), to name a few. Additionally, UTC has been shown to be correlated with income (Iverson & Cook, 2000; Pham et al., 2012; Schwarz et al., 2015) and race and ethnicity (Flocks et al., 2011; Landry & Chakraborty, 2009), with lower income areas and higher minority areas generally having less access to tree canopy. This uneven distribution of benefits has consequences for the health and well-being of citizens, the effectiveness of ecosystem service functions, and the equity of service provision. Most planting programs can be seen as attempts to modify UTC distribution towards a particular end. Therefore, the ability to capture program attributes that influence the spatial distribution of trees and their benefits in a taxonomy will allow analysis of these programs in terms of these goals.

In this paper, I develop a taxonomy through analysis of a variety of existing tree planting programs. This taxonomy is designed to capture the characteristics relevant to program outcomes in order to facilitate comparative analysis. I demonstrate its use by applying it to an example program and discuss implications for program analysis.

3.2 Methods

I gathered information about the attributes of tree planting programs through telephone interviews with planting program administrators in six U.S. cities: Austin, Texas; Charlotte, North Carolina; Denver, Colorado; Minneapolis, Minnesota; Portland, Oregon; and Sacramento, California. I selected cities with well-developed urban forestry programs and infrastructure in both the municipal and nonprofit spheres. Within these cities I gathered information on sixteen programs—seven municipal and nine nonprofit—that are illustrative examples of many common planting program types, and which had detailed data on program outcomes for future analysis.

The six cities are geographically dispersed across the U.S., and represent four different climate types. They are among the fifty most populous places in the U.S., with median household incomes (MHI) representative of the overall MHI in the U.S. ($49,445 in 2010 (DeNavas-Walt, Proctor, & Smith, 2011)), and contain a range of racial and ethnic compositions (see Table 3.1).

I interviewed thirteen planting program administrators—seven working in municipal government and six in nonprofit organizations—about the characteristics of their programs. I used primarily open-ended questions to gather information on program histories, goals, evaluation, operations, funding, technical aspects of siting, planting, and maintenance, partnerships, the local regulatory environment, recruitment and education, changes to the program over time, and any perceived barriers to program recruitment (see Appendix A on page 105). Where necessary, follow-up questions were asked in order to gather additional details.

Using the information from the interviews and the literature, I first developed the list of program attributes, selected either because they are structural components of any program (e.g. outcome goal, funding source), or because they are likely to play a role in program outcomes (e.g. outreach method). For each attribute, the individual characteristics of each program were first listed in full, and then grouped together into related classes (e.g. all ecosystem service goals were grouped) or reduced to a binary, presence/absence division. The attributes were then placed into one of four broad categories, based on their relationship to program administration, the technical aspects of planting, program recruitment and instruction, or the local policy environment.

Table 3.1: Basic demographic and physical characteristics of the cities in which the classified planting programs operate. Percent White is the percentage of non-Hispanic White residents. Population, area, and % non-Hispanic White are as reported by the 2010 U.S. Census. Median household income (MHI) is the 2009-2013 American Community Survey estimate. Climate is the Köppen climate classification (Peel, Finlayson, & McMahon, 2007).

City	Population	Area (km^2)	Climate	MHI (USD)	% White
Austin	790,390	771.56	Humid Subtropical	53,946	48.7
Charlotte	731,424	770.99	Humid Subtropical	52,375	45.1
Denver	600,158	396.27	Cold Semi-Arid	50,313	52.2
Minneapolis	382,578	139.78	Humid Continental	49,885	60.3
Portland	583,776	345.58	Mediterranean	52,657	72.2
Sacramento	466,488	253.61	Mediterranean	49,753	34.5

3.3 Results

I developed a taxonomy that captured seventeen attributes in four categories, encompassing many aspects of planting program design and execution (see Figure 3.1). The four categories are aligned with organizational themes that are addressed during the design process. *Organization* attributes are those that deal with the higher-level structure of the program, such as the funding source, outcome goals, and presence of partnerships. They define the type of program, the outcomes that constitute success, and how the program is managed. *Planting* attributes address the more technical aspects of planting. They determine how tree planting locations are decided upon at both the city and site levels, and assign responsibility for labor and maintenance. *Communication* attributes deal with program recruitment and education regarding planting and maintenance. They determine how residents find out about the program and what technical resources are presented to participants. *Policy* attributes describe the local regulatory environment, providing some context regarding the level of municipal commitment to maintaining urban tree canopy.

The program attributes under these categories are broken down into a range of classes, selected to encompass the variety of characteristics described by planting program administrators, while remaining broad enough to be useful for analysis. For example, primary outcome goals of urban heat island reduction, stormwater management, or energy savings each refer to a particular ecosystem service, and can be grouped together under the 'Ecosystem Service' class. Some attributes are classed only by their presence or absence (e.g. 'Master Tree Plan').

The presence or absence of an equity component is a special case. It was selected as an attribute since program administrators reported that this is a common objective for tree planting programs, though it is rarely the primary or funded outcome goal. Since the taxonomy requires that only the primary goal be classified, this important information would otherwise not be captured, reducing the taxonomy's usefulness when attempting to analyze programs for equity outcomes. This taxonomy could be similarly adapted to incorporate another attribute of interest that is not often the primary outcome goal. For example, if a researcher wishes to determine the program design characteristics that are associated with increased diversity in urban wildlife, they may include an attribute that captures whether suitability for habitat is a consideration of the program. In this way, the taxonomy can be extended to meet specific research needs.

To classify a program according to this taxonomy, the single best class for each attribute is selected. In Table 3.2, the Sacramento Tree Foundation's Shade Tree program is used as an example to illustrate how classes are assigned. In this case, the program's scope, goal, and operational tactics are clearly defined, making classes easily determined in the *Organization* and *Planting* categories. The "Outreach Method" attribute, however, requires a little more thought. Since, like many organizations, they use a variety of outreach tactics (bill inserts, websites, and social media), it must first be determined if these tactics all belong to the same class. If they do not, the most prominent tactic should be used to assign the class. In this case, all tactics are targeted towards a broad audience, so the "General" class is selected. Similar criteria should be applied when ambiguities are encountered with other attributes.

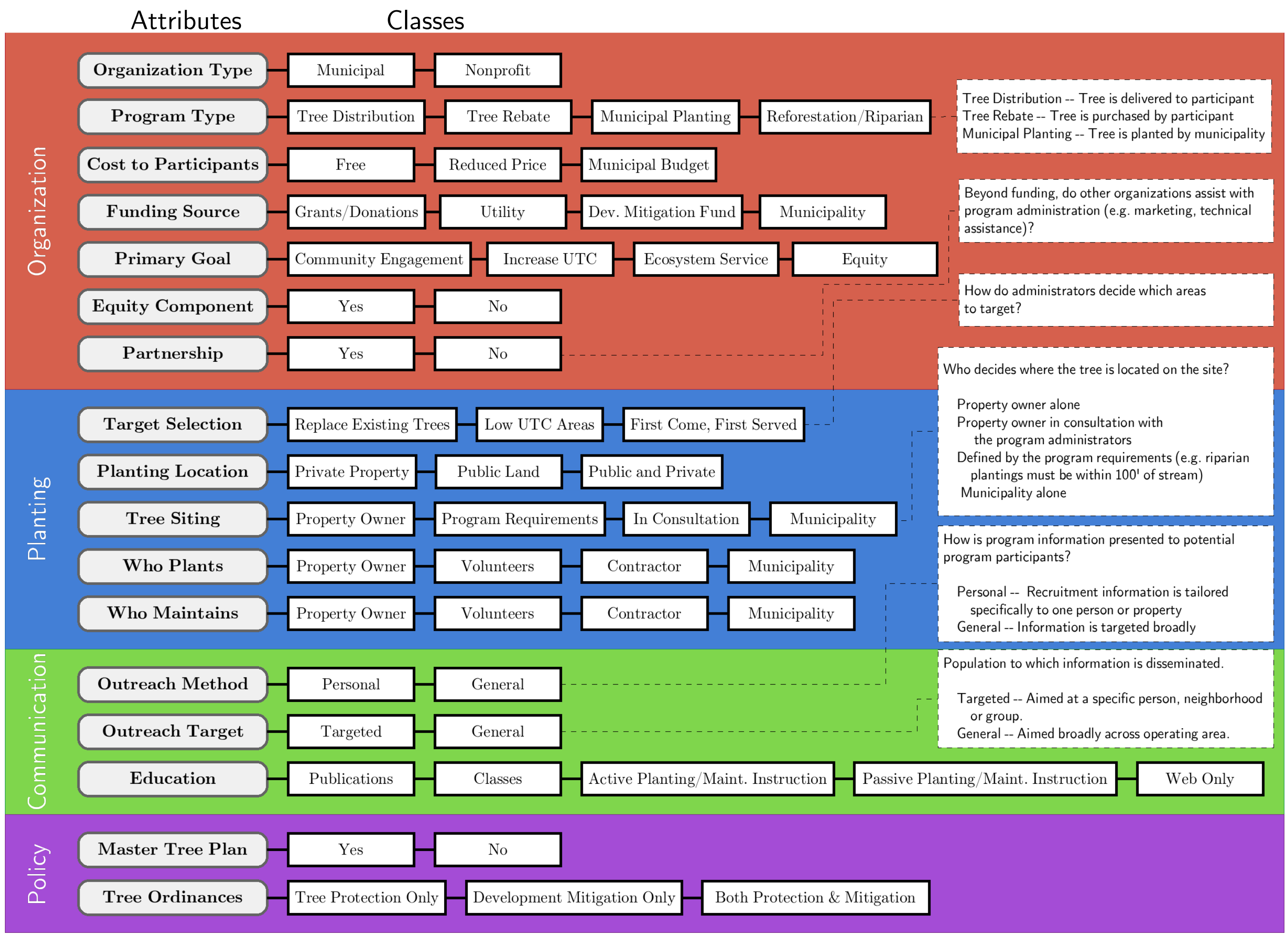

Figure 3.1: Tree planting program taxonomy, developed from a literature review and interview data gathered on sixteen planting programs in six U.S. cities. To classify a planting program, the single best class is selected for each attribute. Notes are provided in boxes on the right for clarification.

Table 3.2: Application of the tree planting program taxonomy (Figure 3.1) to the Sacramento Tree Foundation's Shade Tree program.

Classification of the Sacramento Tree Foundation's Shade Tree Program According to the Planting Program Taxonomy			
	Attribute	Class	Rationale
Organization	Organization Type	Nonprofit	Sacramento Tree Foundation (STF) is a nonprofit.
	Program Type	Tree Distribution	Trees are delivered to program participants' homes.
	Cost to Participants	Free	County residents can receive up to ten free shade trees.
	Funding Source	Utility	Sacramento Municipal Utility District (SMUD) funds the program.
	Primary Goal	Ecosystem Service	The program's goal is a particular ecosystem service: energy savings.
	Equity Component	No	Though as of July 1, 2015, state climate regulations mandate that equity must get 25% of state funds, which may change program targeting.
	Partnership	Yes	SMUD handles some marketing and recruitment.
Planting	Target Selection	First Come, First Served	Trees are provided to those who request them.
	Planting Location	Private Property	The program only targets private property.
	Tree Siting	In Consultation	Property owner consults with STF, who develops a site plan for energy savings.
	Who Plants	Property Owner	Tree and materials are delivered to homeowner.
	Who Maintains	Property Owner	Property owner is responsible for maintenance.
Communication	Outreach Method	General	Bill inserts, websites, social media.
	Outreach Target	General	Targets all SMUD customers.
	Education	Passive Planting & Maintenance	Tree care tips delivered with tree; online planting instruction video.
Policy	Master Tree Plan	Yes	Sacramento is operating under the 1994 Urban Forest Management Plan.
	Tree Ordinance	Protection	Sacramento has an ordinance protecting heritage trees.

3.4 Discussion

Tree planting programs are a fundamental urban forestry activity, and research into this area has immediate practical implications for both nonprofit and municipal organizations. Currently, tree planting program design is largely guided by anecdotal evidence or organizational experience, but there are many programs with valuable information waiting to explored, analyzed, and applied by urban forestry practitioners. The planting program taxonomy aids researchers seeking to uncover this information by simplifying and facilitating comparison and analysis.

Planting programs are not static. They adapt based on changing conditions and organizational priorities. I looked at Sacramento Tree Foundation's Shade Tree Program in Table 3.2, a venerable energy savings-focused program with more than twenty years of history. Over time, the program has been tweaked, modified, and adapted to better reach their target audience. However, a saturation point for energy-focused plantings may be nearing. How might an organization such as this restructure its program to shift focus to a previously subordinate outcome goal? What sort of program structure would be likely to succeed? How should an organization react to rapid changes in policy mandates, perhaps to meet climate change mitigation goals? At this point, there are very few answers in the literature. The presented taxonomy can be used as a tool for researchers to begin to address these questions through comparative analysis. Data relating to outcomes (e.g. locations of planted trees, amount of energy saved, temperature reduction) already exists in many locations, allowing relatively quick and easy analysis. New research on planting programs could then be applied by practitioners to extend the influence and effectiveness of their planting programs within the tight financial constraints that most organizations operate under. For example, if a researcher wanted to discern which program characteristics are most effective at planting streamside buffers, they could classify many programs with similar outcome goals according to the taxonomy, use GIS layers of urban waterways and tree plantings to find trees planted within a defined distance from streams, and analyze the outcomes (trees planted) in terms of the program characteristics.

This taxonomy can accommodate very small-scale programs such as a few plantings a year at local schools, up to large-scale municipal street tree operations; it works equally well with long-running programs and short-term programs intended only to address a specific need (e.g. replanting after a storm event). If desired for a particular analysis application, programs being compared can be made more or less homogeneous by selecting programs of a similar size, funding level, or other characteristic not captured by this taxonomy.

3.5 Conclusions

This new taxonomy is based on three principles: first, that tree planting programs have discrete attributes; second, that these attributes have an influence on program outcomes, which is supported by the limited literature (e.g. Ko et al., 2015; Sommer et al., 1994b) and by my interviews (e.g. many subjects indicated that working in partnerships extended their capabilities); and third, that these outcomes can be analyzed and compared across many programs in terms of program characteristics. The taxonomy's category groupings and range of attributes encompass the administrative, technical, and outreach activities that are key aspects of any planting program, and they provide an organized method to describe, classify, and compare programs operating in different regions and contexts. The example of STF's Shade Tree program illustrates how a program can be classified by the taxonomy, a process that can be applied to virtually any program. The use of this taxonomy in the future analysis of planting programs will provide the empirical guidance for planting program design, which is currently lacking.

While this planting program taxonomy accommodates the range of program types described to me in the interviews, it yet requires validation and refinement. Though I believe the attributes are appropriate and robust enough for analysis of a wide variety of research questions, and that the classes chosen to describe these attributes are mutually exclusive, exhaustive, and likely to be relevant to program outcomes; the development of this taxonomy was based on the limited literature available and a narrow range of interview subjects. It would be presumptuous to think that all cases have been anticipated; there may be novel methods of program design not captured or analysis questions for which the classes are too coarse or too narrow to provide a definitive answer. I expect that the use of the taxonomy by researchers will reveal opportunities for the improvement of this tool. However, in its current state, it provides an important first step toward increased understanding of planting programs, facilitating expansion of the literature regarding this crucial aspect of urban forestry.

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CHAPTER 4

Influence of Tree Planting Program Design Factors on Environmental Justice Outcomes

4.1 Introduction

Urban trees provide a host of environmental services for residents and municipalities. They improve urban environmental quality by removing pollutants from the air (Nowak et al., 2014; M. Rao et al., 2014), reducing stormwater runoff (Armson et al., 2013; B. Zhang et al., 2012), and reducing the urban heat island (UHI) effect (Hart & Sailor, 2009; Yu & Hien, 2006). They provide economic support for communities by contributing to the vitality of commercial areas (Wolf, 2003), adding value to property (Payton et al., 2008), and reducing energy consumption (Akbari et al., 2001; Donovan & Butry, 2009). Though trees and improved health outcomes have long been linked (Ulrich, 1984; Ulrich et al., 1991), research into the health effects of urban trees has recently accelerated (Beyer et al., 2014; Donovan et al., 2013; Jiang et al., 2014; Kardan et al., 2015; Nowak et al., 2014), providing additional evidence that trees have a positive effect on human physical and mental health.

While urban trees are an important resource for healthy, livable communities, urban forest distribution is heterogeneous (Nowak et al., 1996; Sanders, 1984), with many environmental services and benefits accruing primarily to those living in the immediate vicinity of trees. Though urban tree canopy distribution (UTC) can be partially explained by variations in terrain (Berland et al., 2015), land use (Jim, 1989), neighborhood age (Lowry et al., 2012), population density (Troy et al., 2007), and other human or environmental factors; there is evidence that income level is an important correlate of UTC (Iverson & Cook, 2000; Landry & Chakraborty, 2009; Pedlowski et al., 2002; Schwarz et al., 2015), with more affluent areas generally having more canopy than low-income areas. And, though the effect is not as prominent, in some cities, racial or ethnic composition is also correlated with canopy cover (Flocks et al., 2011; Heynen et al., 2006; Landry & Chakraborty, 2009; Pham et al., 2012); where minority residents are concentrated, there tends to be fewer trees. Both of these populations tend to live in more degraded environments (Grineski et al., 2007), and as a result, are more likely to be exposed to the negative impacts of urban environmental hazards such as air pollution and heat stress (Curriero et al., 2002; Grineski et al., 2007; Jesdale et al., 2013). Because canopy cover and green space are often less available in low-income and minority communities, there can be disproportionate negative impacts on health outcomes (Jennings & Gaither, 2015).

Tree planting is a fundamental urban forestry activity, and one of the primary mechanisms for modifying the future extent, structure, and distribution of the urban forest. The tendency for UTC disparities to be present in low-income or minority communities is common knowledge among urban forestry professionals, and many municipal and nonprofit organizations are interested in incorporating equity goals into their tree planting programs in order to improve this situation. Though there is evidence that even a tree planting effort that is concentrated in underserved communities may not be able achieve true UTC parity due to site constraints (e.g. greater housing density, lack of planting strips) (Danford et al., 2014), improvements in equity can be made. But how should a program be constructed in order to best achieve an equity goal? Planting program administrators have little information available to guide them, and a recent paper suggests that planting program efforts may even exacerbate inequities (Locke & Grove, 2014). Literature on tree planting programs is disappointingly slim. What does exist is generally focused on individual planting programs with little or no discussion of the role that planting program design played in generating the studied outcomes (Hildebrandt & Sarkovich, 1998; McPherson, 2014; Nowak et al., 1990). While case studies can provide useful information, they do little to illuminate the range of outcome possibilities or to examine the effect that differing program construction may have on a desired outcome (e.g. equity, an environmental service, or community engagement). As a result, planting program administrators must currently rely solely on organizational experience or anecdotal evidence if they wish to design a program to meet a particular outcome goal. To improve this situation, systematic comparative analysis of tree planting programs is needed.

Tree planting programs are constructed in a variety of ways and have many different outcome goals. In this paper, I provide comparative analysis of municipal and nonprofit tree planting programs in six cities in order to identify program strategies and techniques that are effective at placing trees in low-income and minority neighborhoods. I hypothesize that including a stated equity goal, personal and targeted outreach methods, and low-cost trees will be more effective at placing trees in low-income or minority communities.

4.2 Methods

The study area consisted of six U.S. cities—Austin, Texas; Charlotte, North Carolina; Denver, Colorado; Minneapolis, Minnesota; Portland, Oregon; and Sacramento, California. These cities were selected because they have well-established municipal and non-profit urban forestry programs, are geographically diverse, and are representative of a range of racial and ethnic compositions.

I conducted telephone interviews with thirteen planting program administrators in municipal and nonprofit urban forestry organizations in these cities, and gathered descriptive information regarding the operational characteristics of their tree planting programs. These included program history, funding sources, outcome goals, partnerships, methods for selecting planting locations, costs to participants, and responsibilities for planting and maintenance (see Appendix A on page 105). In order to be able to compare the relevant design attributes of each planting program and facilitate analysis, all programs were classified according to the planting program taxonomy described in Chapter 3 (page 53). The taxonomy requires that only the primary outcome goal be listed, however, the outcome of interest to this study was increasing UTC equity, which is rarely the primary goal of planting programs. Therefore, the classification contained an attribute that flags whether or not there is a stated equity component to the program.

Data were collected on tree planting locations for eleven tree planting programs (see Table 4.1 for program descriptions). These data were delivered in a variety of formats: lists of planting projects (e.g. names of schools, parks, or housing developments), tabular data with addresses locations, GIS shapefiles, and tree inventory data. I used all available planting data from 2005 on in order to create a dataset that was temporally close to the demographic data. The number of trees per program ranged from 1414 for Austin's City Shade to 33,953 for Sacramento's Shade Tree program, with a median of 10,640 trees. Due to the variety of data formats and wide range in data quality, data were processed to obtain comparable, spatial datasets for each city. Tabular address data were normalized using OpenRefine (2011), and addresses were geocoded to X-Y coordinates using the API provided by Data Science Toolkit (http://www.datasciencetoolkit.org). When planting data were limited to lists of projects, project boundaries were manually digitized as polygons in QGIS (2014) using maps, organizational publications, and aerial imagery for reference. For data without reliable planting dates (e.g. data derived from an inventory system), all trees over 6" DBH and all trees that are of small stature at maturity were removed from the dataset. Remaining trees were assumed to have been recently planted.

Demographic data were obtained at the block group level from the U.S. Census Bureau. The source for data on racial and ethnic composition was the 2010 decennial census, while median household income (MHI) is from the American Community Survey (ACS) 2008-2012 5-year estimates, downloaded

Table 4.1: Brief description of the municipal and nonprofit tree planting programs analyzed.

City	Organization	Program	Description
Austin	TreeFolks	City Shade	Partnership with the municipality, conducting volunteer planting events in parks and greenbelts.
Austin	TreeFolks	Neighborwoods	Partnership with the municipality, distributing street trees to property owners.
Charlotte	TreesCharlotte	Neighborwoods	Targeted tree plantings at schools and housing developments.
Charlotte	Municipal	ROW Planting	Street tree planting in the public ROW targeting low-UTC areas.
Denver	The Park People	Denver Digs Trees	Reduced cost trees for private property. Targeted neighborhoods are eligible to receive free trees.
Minneapolis	Tree Trust	Tree Distribution	Reduced cost trees for private property in Minneapolis and St. Louis Park, Minnesota.
Portland	Friends of Trees	Neighborhood Trees	Reduced cost trees planted in the public ROW in Portland and Vancouver, Washington neighborhoods.
Portland	Municipal	On-Call	On-call landscape contractors used for plantings in areas selected by the Bureau of Environmental Services (e.g.highway ROWs, industrial areas).
Portland	Municipal	Treebate	Rebate program credits residential property owners for eligible trees planted on private property, with the goal of water quality improvement.
Sacramento	Sacramento Tree Fdn.	Shade Trees	Utility funded, provides free shade trees for Sacramento Co. property owners for energy conservation.
Sacramento	Municipal	ROW Planting	Street tree planting in the public ROW. Replacement after tree removals and plantings in new locations.

through the R package acs (2014; the script used is in Appendix B on page 108). Though the margins of error in ACS small area estimates (i.e at the tract and block group levels) can be quite high (Spielman, Folch, & Nagle, 2014), it has been the sole source of nationwide income data since 2010. Higher quality local income data was not available from municipal planning departments in the six cities, as they also rely on ACS data.

Census Bureau TIGER/Line shapefiles were downloaded for block groups in the study areas, and joined to the demographic and tree planting location data in QGIS. When plantings represented by polygons crossed multiple block groups, the number of trees assigned to each block group was allotted proportionate to area. All data were exported to tabular form and consolidated, resulting in a data set listing the number of trees planted by each program in each block group.

Areas of interest (AOIs) for the study—that is, block groups with low median household income or a high proportion of racial or ethnic minorities—were then identified. AOI thresholds were scaled to the context of a local reference area: Income AOIs were defined as block groups for which the MHI did not exceed 80% of either the statewide MHI or metropolitan area MHI. This determination was based on a definition of "low-income community" defined in the internal revenue section of the United States Code (26 U.S.C. §45D (e)(1)). Block groups with a minority population—that is, residents who do not identify as non-Hispanic Whites—greater than 150% of the overall metropolitan area average were classified as minority AOIs. Similar approaches utilizing a threshold over a local baseline have been used by the Environmental Protection Agency and by localities to define communities of concern (e.g. see Region 2 Environmental Justice Work Group, 2000; Greater Hickory Metropolitan Planning Organization, 2014). Within the six cities, the number of AOI block groups of any type ranged from 213 (Portland) to 386 (Denver), and comprised from 44.5% of all block groups in the city (Portland) to 68.3% of all block groups (Sacramento).

I determined the proportions of block groups of each AOI type within the limits of each city to establish local baselines. For the purposes of evaluating Friends of Trees' Neighborhood Trees program, Vancouver, Washington was included in addition to Portland, as it is an integral part of their operating area. The operating area for each planting program was defined as all block groups that they had planted in within the city limits. As with the cities as a whole, the proportions of block groups in each AOI type was determined for each planting program's operating area.

I developed an index that indicates the relative reach of planting programs into AOI block groups in each city that uses the simple formula:

$$\left(\frac{\%AOIBlockGroups_{program}}{\%AOIBlockGroups_{city}}\right) - 1 = PIV$$

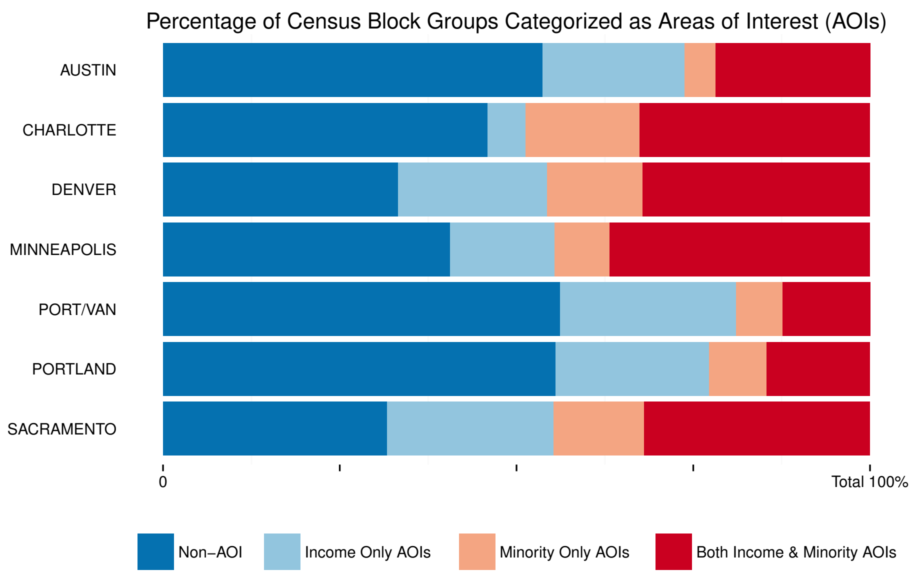
A program that plants in an AOI type at the same rate it is present the city as a whole will receive a planting index value (PIV) of 0; a higher rate will be positive, and a lower rate will be negative. Thus, a positive value indicates a program is successful at placing trees in a given AOI type. This index allows comparison between programs operating in different local contexts and between programs of different sizes and reach.

4.3 Results

The cities show a range of AOI distributions (Figure 4.1). The variation partially reflects the widely different racial and ethnic compositions among the cities. For example Portland's 2010 population was more than 72% non-Hispanic White with no single racial or ethnic group comprising even 10% of the population. Sacramento, on the other had, had only a 34.5% non-Hispanic White population and substantial proportions of Hispanic (26.9%), Asian (18.3%), and Black (14.6%) residents. The patterns for Austin and Charlotte are interesting as both have similarly large proportions of minority residents, yet Charlotte has a much higher proportion of minority AOIs. This may reflect historical patterns of segregation in Charlotte that are not as prominent in Austin. As all cities have a median household income within 10% of the U.S. MHI ($49,445), the variation in income-based AOIs may be indicative of the patterns of wealth distribution in the overall metropolitan areas.

Regardless of the individual demographic characteristics of each city, maps reveal that block groups tend to be clustered by income level and racial or ethnic composition (Figure 4.2). The proportions of AOI block groups types that each program planted in suggest that, at least in some cases, program characteristics influence AOI penetration (Figure 4.3). For example, both Charlotte right-of-way (ROW) planting and Neighborwoods programs operate in the same geographic area, but have widely differing AOI distributions. This may reflect specific program characteristics such as the ROW planting program's mandate to supply street trees throughout the city and to respond to citizen requests, while Neighborwoods is able take a more targeted approach. However it could also be an artifact of some difference

Figure 4.1: Citywide proportions of Area of Interest (AOI) block groups for the six studied cities. Portland, Oregon and Vancouver, Washington are combined as a reference for the Friends of Trees Neighborhood Trees program.



in morphology between the planting space available to the two programs; that is, there may be less room to plant in the ROW in AOI block groups compared to the space available in the schools, parks, and neighborhoods that Neighborwoods operates in.

Program PIVs allow for comparison across cities (Figure 4.4). The Sacramento programs have very similar reach; both are near the citywide AOI proportions. This is also true of the Minneapolis Tree Distribution program. Portland's Neighborhood Trees and BES On-Call programs are similar to each other, but the PIV indicates that the Treebate program has difficulty reaching low-income AOIs. TreesCharlotte's Neighborwoods program was the top performer across all AOI types in terms of environmental justice outcomes. Three programs—the municipal BES On-Call and nonprofit Neighborhood Trees programs in Portland and Austin's City Shade program—were successful at reaching minority block groups, but seemed to have less success reaching income AOI block groups.

The most successful programs in terms of penetrating AOIs that meet both minority and income thresholds were Austin's City Shade, Charlotte's Neighborwoods, and Portland's Neighborhood Trees and BES On-Call (see Table 4.2). All of these with the exception of City Shade had a stated equity component to their program. Though parks were selected for City Shade plantings based on existing UTC in the past, they have since adopted a comprehensive planting prioritization system that does include explicit environmental justice considerations. In contrast, only three of the seven programs that were less successful in terms of environmental justice outcomes had a stated equity component. This suggests that when program articulate an equity goal, they may be more likely to be successful in penetrating income and minority-based AOIs. The four more successful programs selected their

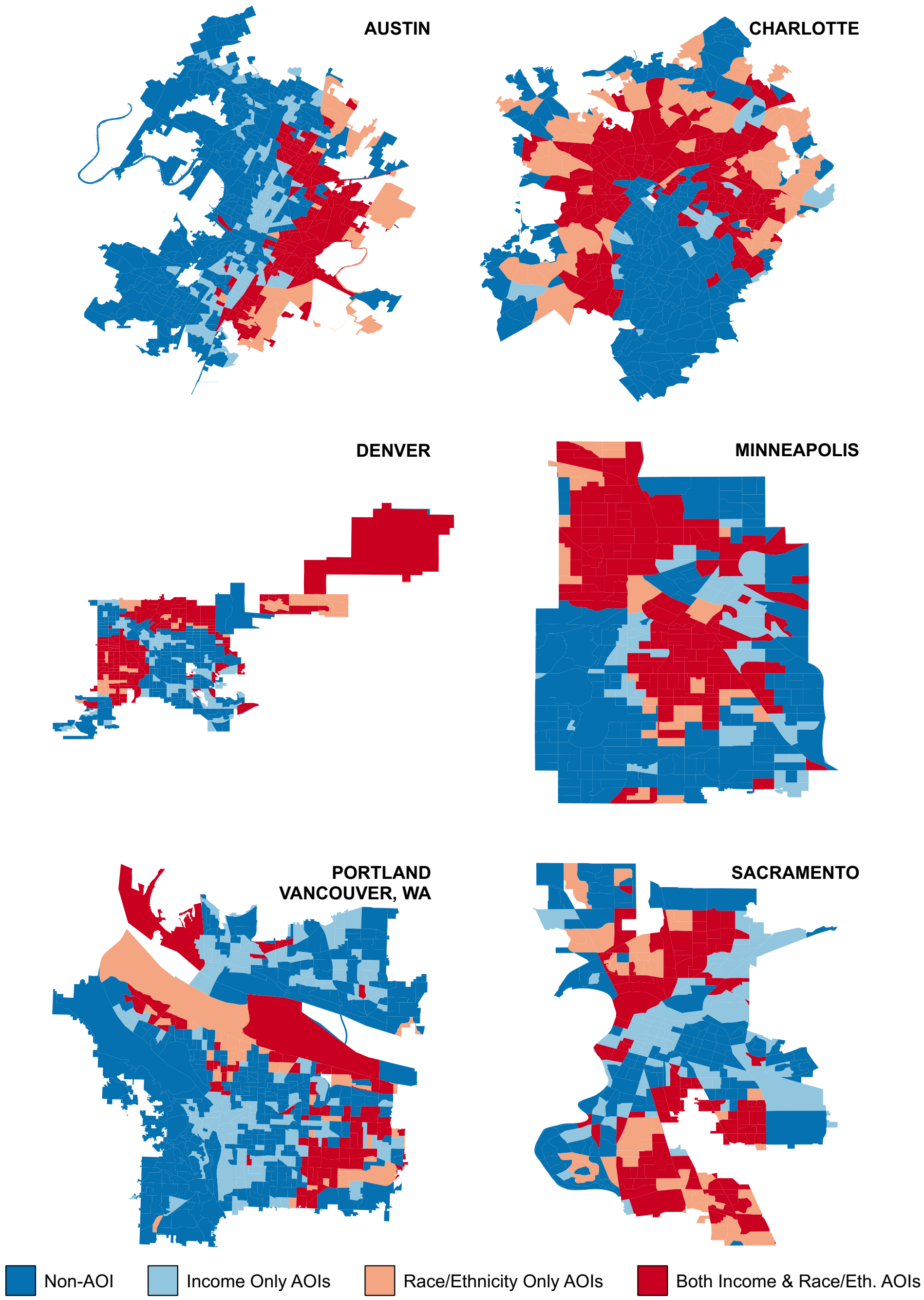


Figure 4.2: Distribution of U.S. Census block groups by Area of Interest (AOI) type within the city limits of the target cities. Map scales vary. DATA: 2010 U.S. Census and 2012 American Community Survey 5-year estimates.

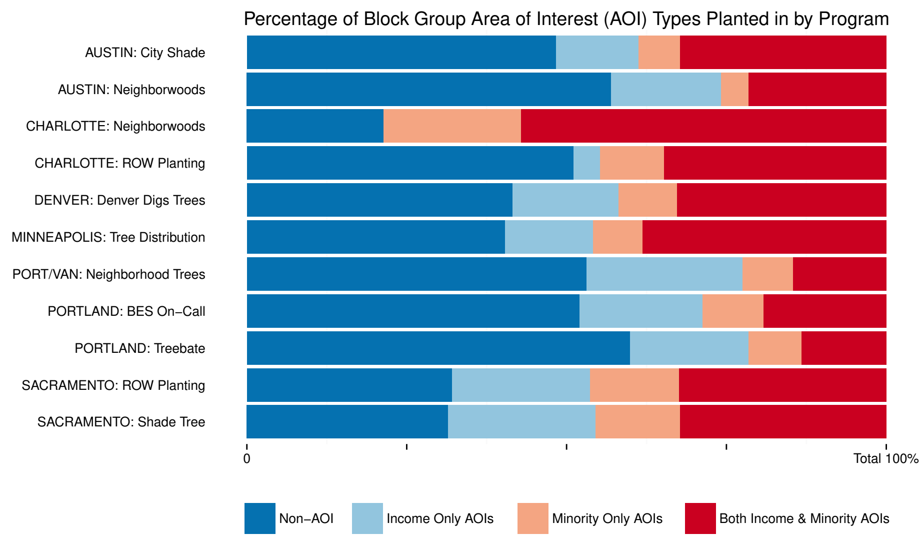


Figure 4.3: For each studied program, the proportion of AOI block groups types in their area of operation.

target areas primarily on the basis of existing UTC, suggesting that higher PIV may be at least in part a function of disproportionately low canopy cover in AOI block groups.

Programs with both personal and targeted outreach were considered to be the most active outreach. Somewhat active programs included either of these characteristics. In both cases there appears to be no clear effect on environmental justice success (Table 4.2). However, this analysis included several programs for which the recruitment of many individual property owners is not a necessity for success (e.g. by planting in parks or ROWs). When comparing programs with similar recruitment goals, outreach tactics may prove influential. More research is needed.

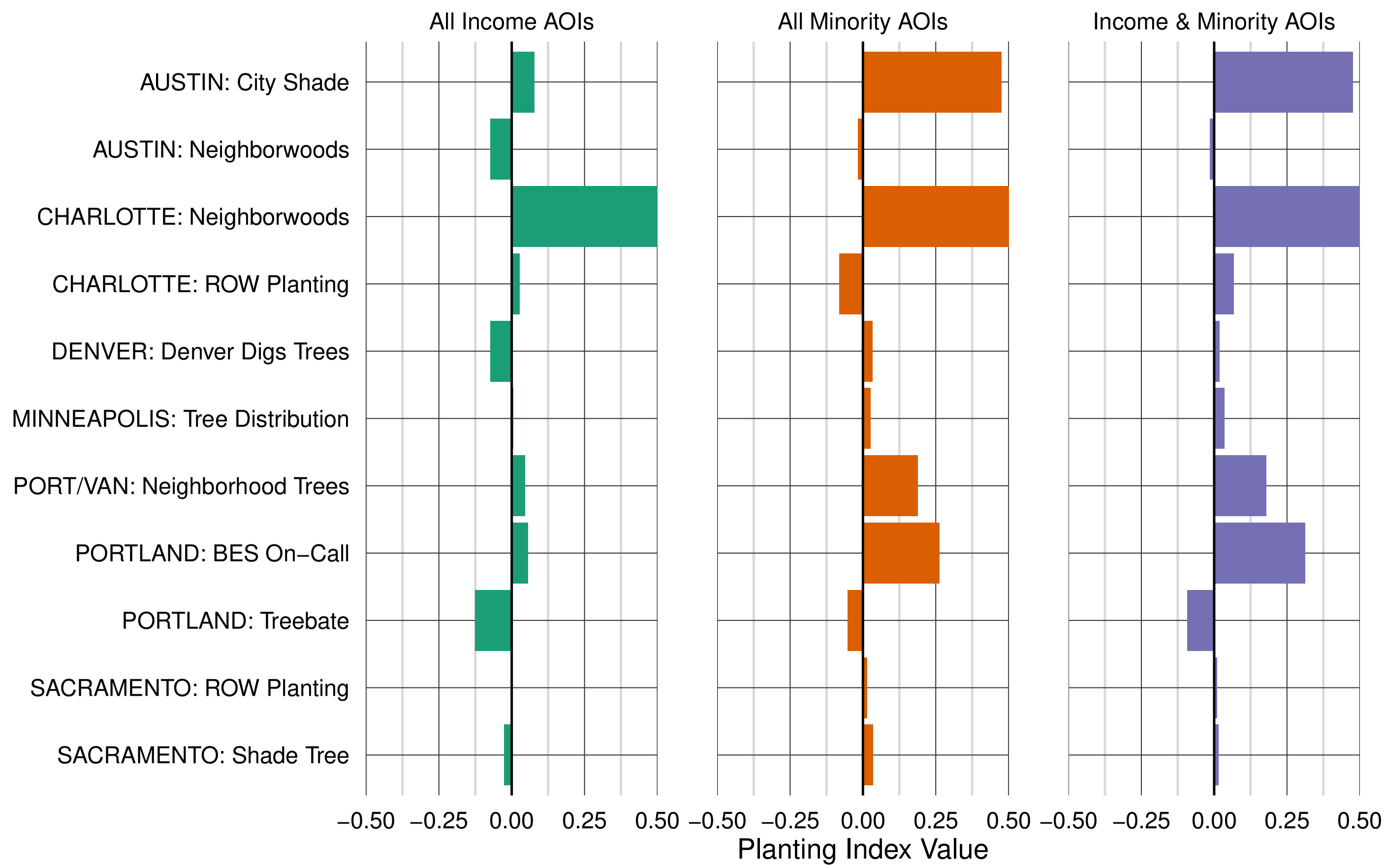


Figure 4.4: Planting index values for the eleven studied tree planting programs. A value of 0 indicates that the program planted in the same proportion of AOI block groups that are present in the city as a whole. Positive values indicate that it planted in proportionally more AOI block groups; negative values, proportionally less.

Table 4.2: Attribute classes and planting index numbers for the eleven studied programs. Attribute classes are assigned according to the planting program taxonomy in Chapter 3 (page 53). Index values represent the proportion of census block groups that each program planted in relative to the overall proportion of block groups of that area of interest (AOI) type in the reference area. Positive values indicate that it planted in proportionally more AOI block groups; negative values, proportionally less.

		AUSTIN		CHARLOTTE		DENVER	MPLS	PORTLAND			SACRAMENTO	
		City Shade	Neighborwoods	Neighborwoods	ROW Planting	Denver Digs Trees	Tree Dist.	BES On-Call	Neighborhood Trees	Tree-bate	Shade Tree	ROW Planting
	Org. Type	N	N	N	M	N	N	M	N	M	N	M
	Prog. Type	MP	TD	TD	MP	TD	TD	MP	TD	RB	TD	MP
	Cost	MUN	FR	FR	MUN	RED	RED	MUN	RED	RED	FR	MUN
	Fund Src.	GDN	UTIL	GDN	MUN	GDN	MUN	MUN	GDN	MUN	UTIL	MUN
	Goal	CE	ES	UTC	UTC	EQ	UTC	ES	CE	ES	ES	UTC
	Equity Comp.	N	N	Y	N	Y	Y	Y	Y	N	N	Y
	Partner.	Y	Y	Y	N	Y	Y	N	Y	N	Y	N
	Target Sel.	UTC	UTC	UTC	UTC	UTC	UTC	UTC	UTC	FC	FC	MUN
	Plant. Loc.	PUB	PP	PP	PUB	PP	PRIV	PUB	PUB	PRIV	PRIV	PUB
	Siting	MUN	PO	PO	MUN	PO	CON	MUN	MUN	PO	CON	MUN
	Plant. Grp.	VOL	PO	VOL	CON	PO	PO	CON	VOL	PO	PO	MUN
	Maint. Grp.	MUN	PO	PO	MUN	PO	PO	MUN	PO	PO	PO	MUN
	Outreach Sty.	GEN	GEN	GEN	GEN	PER	GEN	N/A	PER	PER	GEN	GEN
	Outreach Targ.	GEN	TAR	TAR	TAR	TAR	GEN	N/A	TAR	GEN	GEN	GEN
	Education	APM	PPM	APM	WEB	PPM	PB	PPM	APM	PB	PPM	N/A
	Tree Plan	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Regulation	PM	PM	PM	PM	PM	PRO	PM	PM	PM	PM	PM
INDEX	Inc Only	-0.656	-0.085	-0.011	-0.536	-0.157	-0.057	-0.128	-0.053	-0.181	-0.123	-0.080
	Minority Only	-0.344	0.052	0.127	-0.302	0.082	-0.009	0.192	0.255	0.054	0.055	-0.010
	Inc All	0.079	-0.074	0.505	0.026	-0.075	0.005	0.054	0.046	-0.125	-0.027	-0.002
	Minority All	0.048	-0.024	0.356	-0.117	-0.011	0.023	0.260	0.243	-0.010	0.013	0.002
	Inc & Min	0.285	-0.071	0.549	0.042	-0.044	0.033	0.301	0.236	-0.055	-0.013	0.010

Of the four most successful programs, two had tree costs paid for by the municipality, one had trees provided free, and one had reduced cost trees. Notably, in all cases where the municipality bore the cost, trees were planted in public spaces only. In contrast, the three programs that planted exclusively on private property had PIVs near zero. It appears that tree cost to citizens is not a factor in equity outcomes, however, the planting location—whether on public or private property—does seem to play a role. This may be because planting on private property sidesteps a significant barrier to planting. In the interviews, the most common barrier identified by program administrators that operate primarily on private property is citizen fear of maintenance costs and infrastructure damage, while the most common barriers identified by administrators planting largely on public property were related to lack of available planting space (e.g. poor streetscape design). Where space exists on public land, there is little to stand in the way of planting.

Unexpectedly, responsibility for planting and maintenance appears to influence environmental justice outcomes. For example, Austin's Neighborwoods and City Shade programs both targeted low-UTC areas, but Neighborwoods has much worse equity outcomes than City Shade. This may be partially due to the increased role that the property owner must take on. In four of the eleven planting programs responsibility for both planting and maintenance rests with the property owner. This includes the three programs with the lowest PIVs in AOIs that are both low-income and minority areas. Two of the top four programs had property owners responsible for tree maintenance, but none had property owners planting trees. The better performing programs focus their efforts largely in parks, greenways, and public ROWs, and utilize contract or volunteer labor to plant.

While many programs include partnerships as an operational characteristic, the degree of integration seems to play a role in equity outcomes. The most successful nonprofit programs exhibit a high degree of partnership with the municipality, relying on them for funding, technical assistance, or labor, while the nonprofit organization provides volunteers, outreach, or education. In some cases, the partnership is so deeply embedded in the program that it proved difficult to determine which organization should be credited as the operating organization. Such is the case with Austin's City Shade program; the municipality does the planning and maintenance, while TreeFolks coordinates volunteers, manages the planting, and provides educational opportunities for program participants. Successful programs were also highly targeted, placing a higher number of trees in smaller, carefully-selected areas each year.

4.4 Discussion

Though no one characteristic seems to be sufficient on its own, the results of this analysis suggest that there are discrete aspects of program design that can have a positive impact on a tree planting program's ability to penetrate low-income and minority areas. A strong partnership and cooperation allows the programs to leverage the respective strengths of municipal and nonprofit organizations; nonprofits are able to make use of a relatively large pool of money and access technical expertise, and the municipality is better able to expand its reach onto private property or to make use of volunteers. Reducing the responsibility of individual property owners for planting can help overcome reluctance to participate, and planting on public property can remove that concern altogether.

Planting in concentrated areas can be an effective way to increase canopy in select communities, though this hints at a weakness in the planting index that favors relatively small programs over large, broad-based programs such as the municipal ROW planting programs or large nonprofit programs such as Sacramento Tree Foundation's Shade Tree program and Austin's Neighborwoods program. Since block groups rather than trees are the analysis unit, a smaller program that plants in relatively few block groups is more likely to have an extreme distribution. As a program's reach increases to more and more parts of a city, the AOI distribution of block groups it operates in will increasingly come to resemble the overall city distribution, and the index will tend towards zero. Perhaps when a program reaches a threshold proportion of a city's block groups, it requires a different measure of success.

There are other ways that penetration into low-income and minority AOIs can be measured. One obvious way would be to use trees planted as the unit of analysis rather than block groups penetrated. Figure 4.5 shows the result of modifying the PIV to reflect the proportion of each program's trees that were planted in AOI block groups relative to the city's overall proportion. Note that the scale is twice as wide as the block group-based PIV. By this measure, Austin's City Shade, Charlotte's Neighborwoods, and Portland's BES On-Call programs still perform quite well, though Neighborhood Trees is no longer a top performing program. Denver Digs Trees performs much better by this measure, suggesting that they place more trees per block group in AOI areas than in non-AOI block groups. Minneapolis' Tree Distribution program and Sacramento's Shade Tree program perform worse under this measure. As both of these programs target private property owners, their relative lack of success at reaching low-income and minority AOIs may be due to the higher proportion of renters that is typical of these areas. Though I did not perform such analyses, programs could also conceivably be evaluated on the proportion of AOI block groups in a city that they were able to penetrate, the number of low-income or minority residents within a buffer distance from their tree plantings, the number of trees per capita, or some other measure as yet unknown. There may be many reasonable ways to evaluate success at achieving environmental justice outcomes. While the limited number of programs precluded rigorous statistical analysis—indeed it would be exceedingly difficult to gather program information and planting data for a sufficient sample—in this case, the PIV provided a scaled measure that could be combined with interview data to derive useful information.

A limiting factor for this study was the availability and quality of data. Though I interviewed program administrators regarding the characteristics of sixteen programs, only eleven were able to provide usable data. In some cases, municipal and nonprofit partners had overlapping and conflicting datasets representing the same program, requiring careful comparison to identify duplicate records, and in some cases data could not be verified and had to be discarded. Most datasets required considerable effort to manipulate into an format that could be analyzed. Though the necessity of gathering data on tree planting programs is well-recognized, many organizations lack the technical expertise necessary to design and maintain databases. Any information is certainly better than none, though inaccuracies and inconsistencies in the data may limit study of planting programs.

Of course, there are very real barriers to planting in low-income and minority areas. Nearly all administrators I interviewed mentioned participants' fear of the future costs of maintaining trees as a serious impediment to participation. Cultural and language barriers were also noted as a difficulty, but administrators reported improvements in program recruitment

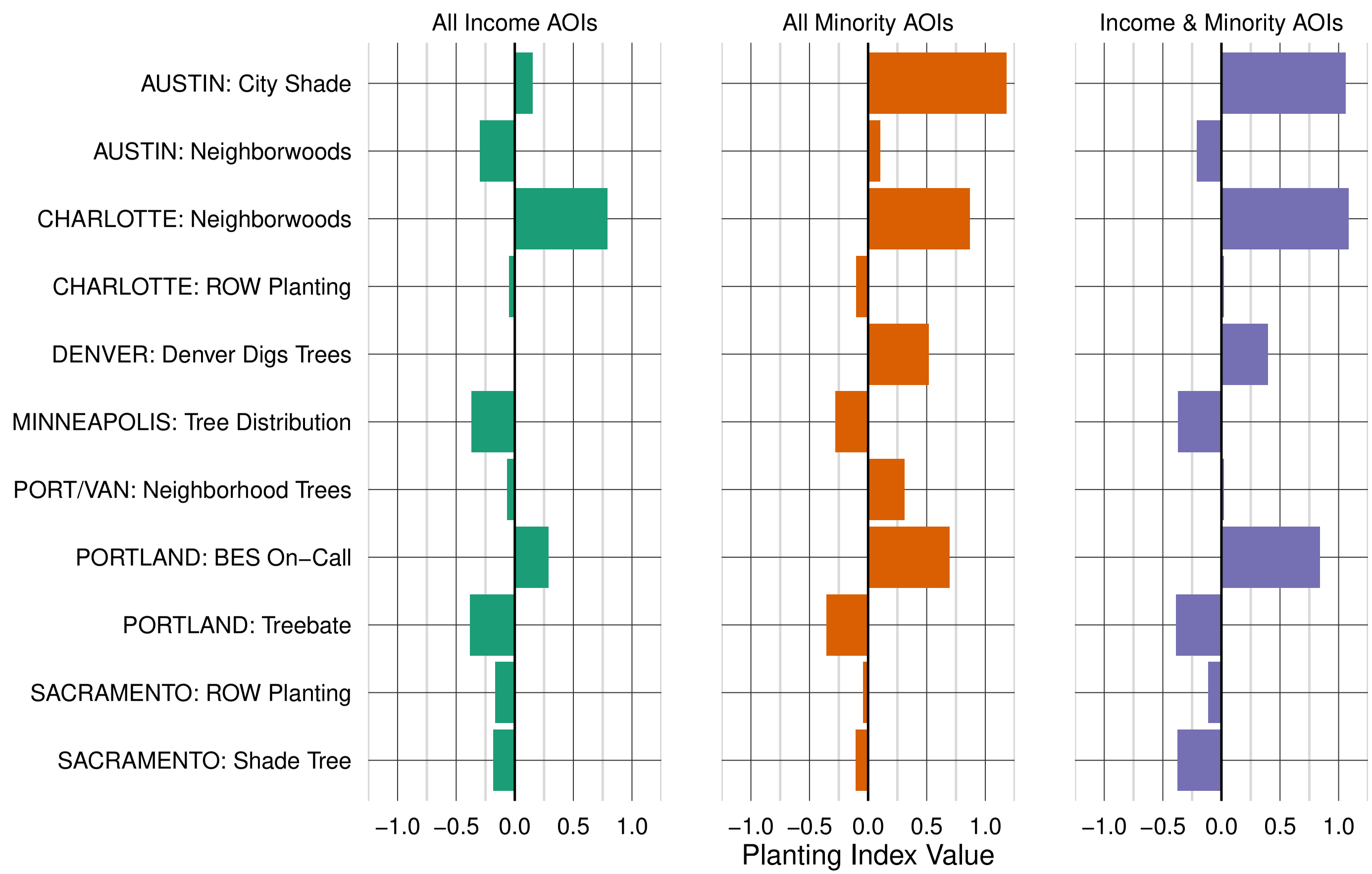


Figure 4.5: Planting index values for the eleven studied tree planting programs based on proportion of trees planted in AOIs. A value of 0 indicates that the program planted in the same proportion that AOI block groups that are present in the city as a whole. Positive values indicate that it planted proportionally more trees in AOI block groups; negative values, proportionally less.

when promotional materials were translated. These are difficult problems, but not insurmountable. Future research on effective education and outreach strategies may reduce some of these barriers.

There are also physical barriers that inhibit the effectiveness of tree planting in AOI areas. Program administrators in Denver and Sacramento mentioned streetscape designs that were incompatible with planting or that made tree survival difficult as significant barriers to planting in AOI areas. Overcoming these barriers requires the cooperation of urban planners, public works departments, and utilities. In a review of the effect of urban design on human health, Jackson (2003) emphasizes cross-discipline cooperation as a strategy to build healthier cities. In the case of environmental justice in tree planting, this cross-discipline cooperation urban foresters involvement in discussions when changes to existing streetscapes are being planned to ensure that proper spaces for trees are included.

4.5 Conclusions

In the interviews it was evident that urban forestry professionals take environmental justice concerns seriously. Half of the programs had a stated equity component affecting targeting, outreach, or cost considerations, and several that did not currently incorporate environmental justice principles in the programs mentioned that such concerns were driving imminent program changes. Programs are actively seeking ways to meet these goals, and there is great diversity in planting program tactics that are currently in use. This diversity in program styles can be a rich source of knowledge to improve tree planting program operations, increasing tree canopy in underserved areas, and improving the equity of the urban forest and the quality of life for residents.

Based on this analysis, when designing a tree planting program with environmental justice and equity in mind, the following program characteristics should be considered:

- A highly integrated partnership between the municipality and nonprofit organizations.
- Reduced responsibility for private property owners, particularly concerning planting.
- A high degree of utilization of public property locations for planting.
- Concentrated plantings in smaller geographic areas.

Planting largely on public land allows programs to avoid barriers such as citizen concerns over maintenance costs and low levels of community organization, and the large amounts of land in the public ROW, in parks, and on school grounds allows them to plant a lot of trees where it is easiest, requiring minimal levels of individual recruitment. This hints at an issue: in many cities there may be an opportunity to improve tree canopy cover in low-income and minority neighborhoods by focusing on the low-hanging fruit, concentrating effort where success is most likely; however, doing so, these areas will quickly reach a saturation point, and further gains will almost certainly require engaging individuals, community groups, and owners of rental properties, building capacity in neighborhoods. It will entail doing more work and more difficult work in order to plant fewer trees. This is the stage at which research into planting program design will become crucial in order to share knowledge, identify successful tactics, and enhance the capabilities of urban forestry organizations. As Locke and Grove (2014) illustrated in their recent paper, tactics that seem like obvious means to address disparities, such as offering reduced cost trees, may actually have the opposite effect. Strong research and clear guidance are needed in order to have confidence that tree planting efforts are having the desired impact.

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CHAPTER 5

Conclusion

Tree planting program design *does* affect program outcomes, but additional research on planting programs will allow for greater confidence that desired goals can be achieved. The conclusions that I reached regarding program design for environmental justice outcomes provides greatly needed guidance for urban foresters seeking to incorporate equity components into their programs. As rapidly emerging research fortifies the linkages between positive health outcomes and the presence of trees and greenspace, urban foresters must be able to act effectively to reach underserved areas, framing their planting programs as tools to enhance public health for vulnerable residents and to reduce income and race-based disparities in urban green infrastructure. To do this they require actionable information

Until recently, researchers have largely avoided studying planting programs, though they are an integral part of nearly every urban forestry program, and are deserving of serious inquiry. This research provides justification for action, a tool for comparative research of planting programs in the taxonomy, and research into multiple programs on an important outcome goal. Though it was sufficient for my analysis, weaknesses in the taxonomy became apparent through use. For example, while many programs include a partnership arrangement between the municipality and nonprofit, the only way to distinguish those programs in which the two were very closely integrated was though my interview notes. Additionally, there were attributes such as regulation that did not seem to be related to program outcomes, and attributes such as the presence of a tree plan for which all programs had identical values. The taxonomy could possibly be improved in the future by removing attributes which are irrelevant and increasing the granularity of those that are. By studying planting programs in the way I have here, I am aware that there are few statistical tests that could be used to evaluate the effectiveness of programs as one is unlikely to be able to gather data from enough planting programs to constitute a sufficient sample size. This is a weakness, though the PVI provides an easy-to-calculate, normalized measure for comparing planting programs that accounts for local contexts, and could be easily adapted to evaluate other outcome goals.

I strongly feel that improved data collection, storage, and maintenance would greatly enhance the ability of researchers and program administrators to evaluate, compare, and plan planting programs. Though the value of planting data was recognized by all interview subjects, some were not able to gather any data due to technical or personnel limitations, and others, though well-meaning, provided datasets of strikingly poor quality. As this sort of technical expertise is often not available within urban forestry organizations, clear, easy to follow guidelines should be developed by a commission of both researchers and professionals, and disseminated out to urban forestry organizations. A common set of standards for data collection and handling could even provide the basis for a repository of shared data, allowing simplified cross-program analysis.

The idea that urban forests and other green infrastructure initiatives can be used to meet municipal environmental and quality-of-life goals has been gaining momentum in cities. Urban forest professionals must have a greater understanding of the likely outcomes of their planting programs in order to effectively and accurately describe to local governments the services that they can provide. There is an emerging opportunity for urban foresters to raise the profile of their programs and increase the importance of urban trees in the minds of government officials and the public, but the research must be there to support their ability to achieve predictable outcomes.

APPENDIX A

Interview Questions

- Can you describe the tree planting programs that your organization administers?
- How long has this program been in operation?
- GOALS
  - What was the stated reason for creating this program? What are its goals?
  - How did you arrive at those goals?
  - How do you determine if it is meeting those goals? Is it meeting them?
  - Have the program's strategies or goals changed over time?
  - What methods do you use to track this program's efficacy?

- LOCATION
  - Is there a locational component? Do you target a particular area of the city?
  - What is your perception of why this area needs more trees?
  - How are planting locations selected?
  - Who decides where trees are planted (e.g. resident, professional)?
- LABOR
  - Who is responsible for planting the trees (digs the hole) (e.g. employees, contractors, partner organization, volunteers)?
  - What is the funding source for program activities?
- Do you engage with nonprofits/municipality or the public in any of your planting programs? If so, in what capacity?
- How do citizens become aware of this program? Can you describe your outreach strategies?
- Is there an educational component to this program? If so, describe.
- Are there other organizations in your city that are engaged in tree planting programs?
- How do you view your program's place among all tree planting programs in your city?
- What do you perceive as barriers are to tree planting? Physical? Cultural? Economic? Historical?

- Is there a tree protection or preservation ordinance in your city? If so, can you describe it?

- Do you have planting data that you would be willing to share with me? At a minimum, I'm looking for planting date and location (GPS, address, neighborhood), but any additional information you can provide would be helpful.

APPENDIX B

acs.R Census Data Download Script

NOTE: *This script downloads both income and racial and ethnic data from the 2008-2012 American Community Survey 5-year estimates. Though I ultimately ended up using data from the 2010 decennial census for racial and ethnic categories, I left information on downloading them from the ACS in this script for informational purposes.*

```
# Load acs package.
library(acs)

# Install Census API key (redacted). Requested a key from
# U.S. Census Brueau developers page.
# key = "xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx"
 api.key.install(key)

# Make GEO.SETs. The geo.make function creates specified
```

```
# geographies for use with the acs.fetch function. Creating a
# space for data from all block groups and tracts within the
# counties containing target cities.

austin <- geo.make(state = 48, county = c(453, 491, 209, 053,
    031, 055, 021), tract = "*", block.group = "*")
charlotte <- geo.make(state = 37, county = c(119, 071, 109,
    097, 025, 179, 035), tract = "*", block.group = "*") + geo.
    make(state = 45, county = c(091, 057), tract = "*", block.
    group = "*")
denver <- geo.make(state = 8, county = c(031, 005, 001, 059),
    tract = "*", block.group = "*")
minneapolis <- geo.make(state = 27, county = c(053, 123, 003,
    163, 037, 139, 019, 171, 141), tract = "*", block.group = "
    *")
portland <- geo.make(state = 41, county = c(051, 067, 005, 027,
     009), tract = "*", block.group = "*") + geo.make(state =
    53, county = c(011, 015, 059), tract = "*", block.group = "
    *")
sacramento  <- geo.make(state = 6, county = c(067, 113, 101,
    061, 017, 005, 077, 013, 095), tract = "*", block.group = "
    *")

# I want to make a geo.set here containing all my geographies.
all.geog = c(austin + charlotte + denver + minneapolis +
    portland + sacramento)

# Now I can use acs.fetch to pull down the tables I need for
# all geographies.
#
# First, "Median Household Income in the Past 12 Months"
#(weighted to last year of survey).
```

```
income <- acs.fetch(geography = all.geog, table.number = "
    B19013", col.names = "pretty", endyear = 2012)

# Let's check the column names to make sure I have the right
# table.
acs.colnames(income)

# Now I'll get tables related to population and race: "Race,"
# and "Hispanic or Latino Origin by Specific Origin."
pop.race <- acs.fetch(geography = all.geog, table.number = "
    B02001", col.names = "pretty", endyear = 2010)
pop.hisp <- acs.fetch(geography = all.geog, table.number = "
    B03003", col.names = "pretty", endyear = 2010)

acs.colnames(pop.race)
acs.colnames(pop.hisp)

# A note on acs.fetch: I can also ask for specific columns with
# the argument variable = "B05001_006" or multiple columns
# using c, variable=c("B16001_058", "B16001_059")

# More information on data structure can be found with str().
# Will show year, time frame, standard error, estimates,
# and so on.
str(pop.hisp)

# Now I want to get proportions for these tables.
pop.race.pct <- apply(pop.race[,2:10], MARGIN = 1, FUN = divide
    .acs, denominator = pop.race[,1], method = "proportion",
    verbose = "F")
# Dividing just column 3 -- "Hispanic or Latino." Column 2 --
# "Not Hispanic or Latino is irrelevant and throws an error,
# preventing the completion of this function:
```

```
# Error in if (proportion == T & all((p^2 * standard.error(den)
# ^2) > 0)) { :
# missing value where TRUE/FALSE needed
pop.hisp.pct <- apply(pop.hisp[,3], MARGIN = 1, FUN = divide.acs, denominator =
pop.hisp[,1], method = "proportion", verbose = "F")

# Exported estimate(pop.hisp[,2]) and standard.error(pop.hisp
# [,2]), but could not see any problems with the values. All
# are >= 0 with no NA values.

# Now I write the estimates and 90% MOEs to data.frames, and
# then to CSV files using write.csv().
income.df <- data.frame(estimate(income), 1.645 * standard.error(income))
race.pct.df <- data.frame(estimate(pop.race.pct), 1.645 * standard.error(pop.race.pct))
hisp.pct.df <- data.frame(estimate(pop.hisp.pct), 1.645 * standard.error(pop.hisp.pct))

# This gives me some pretty ugly column headings, so I'll
# specify ones that look nicer and that play nice with GIS.
colnames(income.df) = c("Med_HH_Income_Past_12_mos_in_2010_dollars", "Med_HH_Income_90MOE")
colnames(race.pct.df) = c("White_alone", "Black_or_African_Am_alone", "Am_Indian_and_Alaska_Native_alone", "Asian_alone", "Native_Hawaiian_and_Other_Pacific_Islander_alone", "Some_other_race_alone", "Two_or_more_races", "TwoOrMore_Two_races_incl_Some_other_race", "TwoOrMore_Two_races_excl_Some_other_race_and_three_or_more_races", "White_alone_90MOE", "Black_or_African_Am_alone_90MOE", "Am_Indian_and_Alaska_Native_alone_90MOE", "Asian_alone_90MOE", "Native_Hawaiian_and_Other_Pacific_Islander_alone_90MOE", "Some_other_race_
```

```
    alone_90MOE", "Two_or_more_races_90MOE", "TwoOrMore_Two_
    races_incl_Some_other_race_90MOE","TwoOrMore_Two_races_excl
    _Some_other_race_and_three_or_more_races_90MOE")
colnames(hisp.pct.df) = c("Hispanic_or_Latino", "Hispanic_or_
    Latino_90MOE")

# Here I need to generate GeoIDs from FIPS codes.

income.df$GEOG.NAME <- rownames(income.df) # rownames to column
    , so I can parse.

# FIPS State and County lookup table
fips.lookup <- read.csv("~/path/fips_lookup.csv")

# Split rowname column on comma so I can continue to parse.
income.geoid <- data.frame(t(sapply(income.df[,3], function(y)
    strsplit(y,split=", ")[[1]])))
income.geoid[,5] <- income.df$GEOG.NAME
colnames(income.geoid) = c("BG_FULL", "CT_FULL", "COUNTY",
    "STATE", "GEOG.NAME")
#income.geoid[,7] <- cbind(income.df[,3])
hisp.pct.df[,3] <- cbind(income.df[,3])
race.pct.df[,19] <- cbind(income.df[,3])
colnames(hisp.pct.df)[3] <- "GEOG.NAME"
colnames(race.pct.df)[19] <- "GEOG.NAME"

# Use stringr function str_sub to extract block group and
# tract numbers.
library(stringr)
income.geoid$BG_NUM <- str_sub(income.geoid$BG_FULL, start= -1)
income.geoid$CT_NUM <- str_sub(income.geoid$CT_FULL, start= 13)

# Lookup FIPS codes for state and county from table.
```

```r

geoid.merge <- merge(income.geoid, fips.lookup, by = c("STATE",
    "COUNTY"))

geoid.merge$COUNTY_FIPS <- sprintf("%03d", geoid.merge$COUNTY_
    FIPS) # Pad zeros
geoid.merge$STATE_FIPS <- sprintf("%02d", geoid.merge$STATE_
    FIPS)

# My census tract number field has leading spaces, so I define
# a function to strip them using regular expressions.
trim <- function (x) gsub("^\\s+|\\s+$", "", x)
geoid.merge$CT_NUM <- trim(geoid.merge$CT_NUM)

class(geoid.merge$CT_NUM) <- "numeric"
geoid.merge$CT_NUM <- formatC(geoid.merge$CT_NUM, digits = 2,
    width = 7, format = "f", flag = "0")
class(geoid.merge$CT_NUM) <- "character"
geoid.merge$CT_NUM <- str_replace_all(geoid.merge$CT_NUM, "[[:
    punct:]]", "")

geoid.merge$GEOID <- paste(geoid.merge$STATE_FIPS, geoid.merge$
    COUNTY_FIPS, geoid.merge$CT_NUM, geoid.merge$BG_NUM)
geoid.merge$GEOID <- gsub("\\s","", geoid.merge$GEOID) # remove
    spaces

#All columns into one table.
demographic <- merge(geoid.merge, income.df, by = "GEOG.NAME")
demographic <- merge(demographic,hisp.pct.df, by = "GEOG.NAME")
demographic <- merge(demographic,race.pct.df, by = "GEOG.NAME")

# And clean up some of these redundant columns.
demographic$GEOG.NAME <- NULL
```

```
demographic$BG_NUM <- NULL
demographic$CT_NUM <- NULL

# Need to add a single-quote to the first record in GEOID so
# GIS recognizes it as string, not double.
demographic[1,7] <- paste("\'", demographic[1,7], sep = "")

# Export final table to CSV.
write.csv(demographic, "~/path/demographic_5yr_2012.csv")
```

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