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# What Does It Take to Achieve Equitable Urban Tree Canopy Distribution? A Boston Case Study.

Rachel S. Danford
*University of Massachusetts - Amherst*, rlevine@eco.umass.edu

Chingwen Cheng
*University of Michigan*, chingwen@umich.edu

Michael W. Strohbach
*University of Massachusetts - Amherst and Thünen-Institute of Biodiversity*, michael.strohbach@ti.bund.de

Robert Ryan
*University of Massachusetts - Amherst*, rlryan@larp.umass.edu

Craig Nicolson
*University of Massachusetts - Amherst*, craign@eco.umass.edu

Paige S. Warren
*University of Massachusetts - Amherst*, pswarren@eco.umass.edu

# What Does It Take to Achieve Equitable Urban Tree Canopy Distribution? A Boston Case Study.

Considerable attention has been paid to the benefits that urban trees provide and recent research has focused on how the distribution of trees in the urban landscape is affected by socioeconomic processes like social stratification, as indicated by associations with income, race, ethnicity, and education. These studies have found marked disparity in urban canopy cover, with primarily low income and minority neighborhoods commonly being underserved. However, few studies have investigated the potential to overcome urban canopy inequities through urban planning and reforestation. This question becomes even more important as many U.S. cities pledge to increase urban canopy cover as part of larger climate change mitigation strategies. Can today's heavily developed U.S. cities use these tree planting initiatives to increase equity in urban canopy cover while still providing the infrastructure and housing necessary for expected population growth? This case study characterizes the socioeconomic drivers of the current urban canopy cover in Boston, Massachusetts, and further explores the possibility of distributing trees to increase equitable access to environmental justice and ecosystem services, while meeting housing and infrastructure needs. Results suggest that even when tree planting initiatives focus specifically on increasing canopy cover for environmental justice communities, equitable distribution of urban trees is difficult to achieve. Our findings indicate that difficulties arise not only from the expected policy and funding aspects, but also from ecological ones, including the physical availability of tree planting sites in environmental justice communities.

**Keywords**
environmental justice, urban trees, urban canopy, ecosystem services

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# 1. INTRODUCTION

## 1.1 Benefits of Urban Trees

Trees contribute to the quality of urban life in many ways, including improving air quality (Nowak 1994; Nowak et al 2006), mitigating urban climate (Souch and Souch 1993; Bolund & Hunhammar 1999; Akbari et al. 2001), contributing to energy and water conservation and carbon sequestration (McPherson 1990; Nowak 1993; Nowak and Crane 2000; Hutyra et al 2010), decreasing stormwater runoff and mitigating flooding risks (Sanders 1986; Bolund & Hunhammar 1999), helping to remediate brownfields (Westphal and Isebrands 2001), and increasing biodiversity and providing habitat for urban wildlife (Johnson 1988; Strohbach et al. 2013; Shanahan et al. (in press)). Trees also provide social and cultural benefits to urban residents, such as reduction of noise levels (Cook 1978; Bolund and Hunhammar 1999), improved urban aesthetics (Schroeder 1989), enhanced sense of community (Brunson et al. 2001), and reduction of stress (Ulrich 1984; Kaplan and Kaplan 1989; Kaplan 1993). However, there are costs associated with urban trees. Inappropriate tree selection or placement can affect water use in arid climates, and can cause human health issues associated with allergies to pollen or potential injuries due to tree failure, urban forests can support insects that are associated with infectious diseases (e.g. insect born diseases), and the monetary cost of planting a tree coupled with the cost of tree maintenance and the fossil fuels burned to power maintenance tools may outweigh the benefits of urban trees in some cases (Nowak and Dwyer 2007; Lyytimäki et al. 2008; Pataki et al. 2011). Therefore, careful tree planting and management plans are essential to achieve the maximum community benefits of trees.

## 1.2 Distribution of Urban Trees as an Environmental Justice Issue

Environmental justice research in recent decades has shifted from a focus on avoiding proximity to environmental waste and pollution to gaining access to environmental and community resources as a measure of quality of life (Witten et al. 2003). These community resources include outdoor recreation and parks (Talen 1998; Wolch et al. 2005; Tarrant and Cordell 1999), urban greenways (Lindsey et al. 2001), public playgrounds (Talen and Anselin 1998), and urban tree cover (Dwyer et al. 2000). Since urban trees provide important social and physical benefits to urban residents, inequitable access to these benefits creates an environmental justice condition (Heynen 2003; Heynen et al. 2006). This uneven distribution of urban trees is often the result of socioeconomic factors instead of ecological ones (Landry and Chakraborty 2009). It is important to note that the factors affecting distribution of urban trees are often a combination of current drivers (i.e. where new trees can be planted, funding for upkeep) and historical processes (i.e. social stratification, neighborhood succession (Warren et al. 2010)). These factors interact to create current inequity in tree canopy cover, and researchers have found that cities differ in which socioeconomic factors are associated with canopy cover (Landry and Chakraborty 2009). Canopy cover has been positively correlated with education level (Heynen and Lindsey 2003; Kendal et al. 2012), homeownership (Heynen and Lindsey 2003; Landry and Chakraborty 2009), employment (Kirkpatrick et al. 2011), housing age (Heynen and Lindsey 2003; Kendal et al. 2012), and income level (Iverson and Cook 2000; Landry and Chakraborty 2009; Pham et al. 2012). Canopy cover has been negatively correlated with rentership (Heynen and Lindsey 2003; Landry and Chakraborty 2009), household density (Iverson and Cook 2000; Kendal et al. 2012), and minority population (Heynen and Lindsey 2003).

### 1.3 U.S. City Tree Planting Initiatives

Many U.S. cities are implementing tree planting initiatives as part of larger climate change mitigation plans and in order to improve quality of life for urban residents. Notable initiatives include New York City's MillionTreesNYC (www.milliontreesnyc.org), Los Angeles' MillionTreesLA (www.milliontreesla.org), Chicago's Tree Initiative (www.chicagotrees.net/chicago-trees-initiative), and Boston's Grow Boston Greener (www.growbostongreener.org). Policy makers tout the benefits of urban canopy and the importance of increasing the urban forest and claim a focus on redressing inequity in urban canopy cover. However, the success of these programs is seldom measured and the actual potential to remedy inequities is unknown.

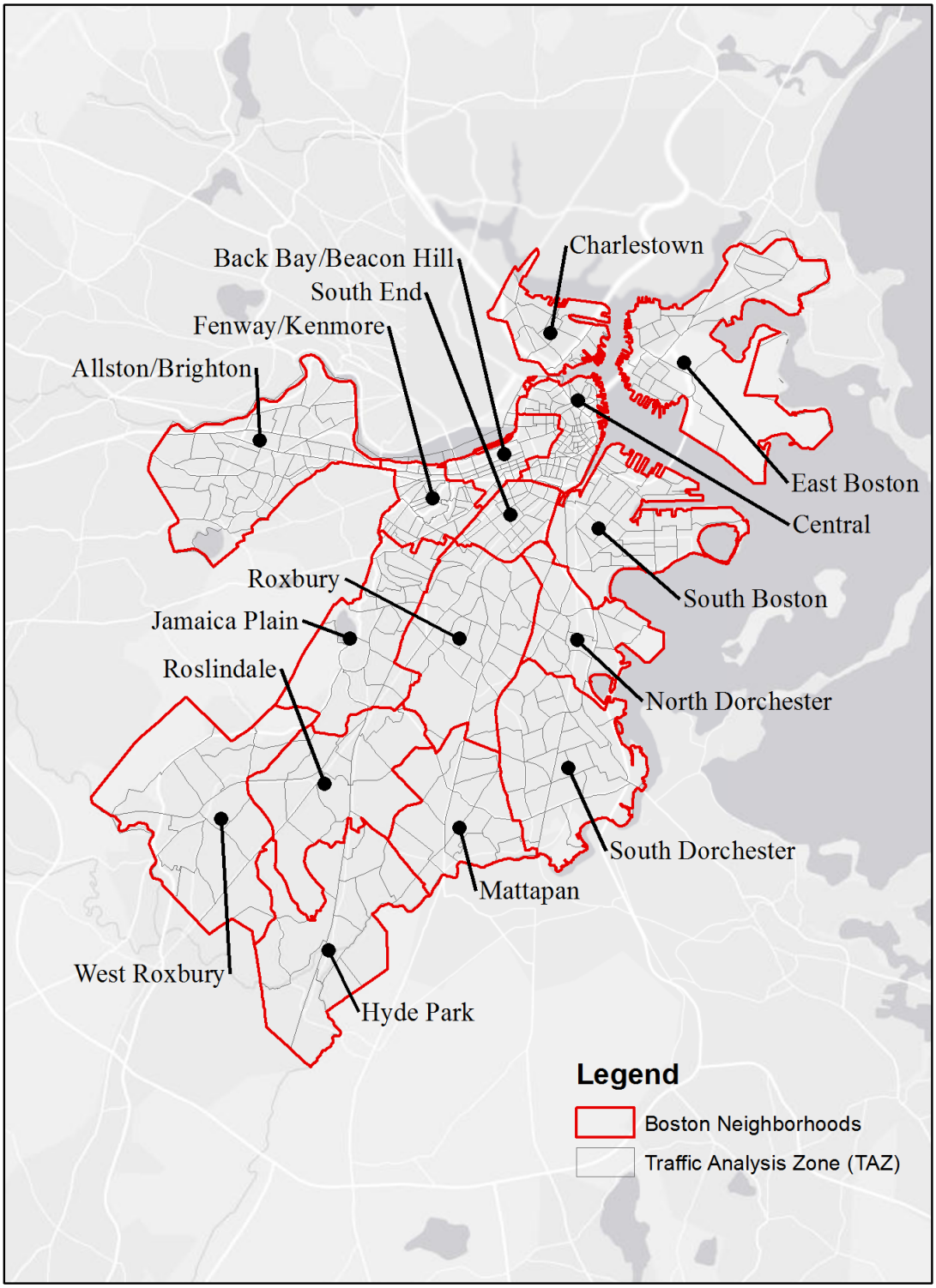
Can today's heavily developed U.S. cities use tree planting initiatives to remedy urban canopy cover inequities while still providing the infrastructure and housing necessary for expected population growth? To answer this question we explored the case study of Boston, Massachusetts, to understand the ecological and socioeconomic potential for planting trees to equalize urban canopy cover in an intensely developed city. More specifically, we investigated three questions: (1) What is the current state of urban canopy distribution in the City of Boston, and what neighborhoods are most lacking the benefits provided by urban tree cover? (2) What is the range of possible scenarios for planting trees in Boston while taking into account the real-world availability of planting sites under current land use constraints and future population growth? and (3) How much can each of these future scenarios realistically increase the equity of urban tree cover in Boston?

## 2. METHODS

### 2.1 Study Area and Data

The study area is Boston, Massachusetts, located in the Northeastern United States (Figure 1). It is home to over 625,000 people across approximately 121 $km^2$ (population density around 5000 per $km^2$) and is one of the oldest cities in the U.S. The City of Boston and the surrounding region of Greater Boston is an Urban Long-Term Research Area Exploratory (ULTRA-Ex) site, one of several such research sites across the country, funded jointly by National Science Foundation and USDA Forest Service.

Information regarding socio-economic data was obtained from the Massachusetts Metropolitan Area Planning Council (MAPC) based on 2000 U.S. Census data. As in previous research, we used tree canopy cover as an indicator of the spatial distribution of trees within Boston (Heynen et al. 2006). Tree canopy cover data was obtained from the Urban Ecology Institute's 2005 urban tree cover survey (Urban Ecology Institute 2008). Baseline data regarding projected population growth is derived from MAPC. GIS data (e.g. land use, impervious area, building footprint, roads) were obtained from the Office of Geographic Information for the Commonwealth of Massachusetts (www.mass.gov/mgis/).




**1.Figure 1.** Map of Boston, Massachusetts, with neighborhoods and traffic analysis zones outlined. (Basemap: ©2013 Esri, DeLorme, NAVTEQ).

We used the Traffic Analysis Zone (TAZ) as the unit of analysis for our scenarios. This was done to maintain compatibility with MAPC data, which uses the TAZ for all projections. A TAZ is commonly delineated by state or local transportation officials and usually consists of one or more census blocks, block groups, or census tracts. MAPC used TAZs specifically for tabulating traffic-related data, such as journey-to-work and place-of-work statistics, and as a unit for projecting population and employment growth. Although TAZs can be any size, exurban TAZs are often larger than urban TAZs, which can be as small as a city block or even a single building.

All statistical analyses were performed using the statistical package R (R Development Core Team 2012).

### 2.2 Grow Boston Greener

We used the goals of the Boston tree planting initiative, Grow Boston Greener, to inform our projections of plausible tree planting goals in the city over the next 30 years. Grow Boston Greener (GBG) is a competitive mini-grant program that provides small grants for tree plantings in Boston neighborhoods. Grants are available to non-profit organizations and their partners. The program is a joint effort between the city of Boston and Boston Natural Areas Network (BNAN) to increase and improve the urban forest of Boston (Boston Natural Areas Network 2006; Grow Boston Greener 2012). Through Grow Boston Greener, nonprofit organizations can apply for funds to plant trees in publicly accessible areas, especially those areas that are identified as underserved by tree canopy in the State of the Urban Forest report (Urban Ecology Institute 2008).

The city of Boston endeavors, through Grow Boston Greener, to increase the overall percent canopy of Boston to 35%, a 6% increase from 29% canopy cover estimates in 2005 (Urban Ecology Institute 2008). According to Grow Boston Greener, this increase will require the planting of approximately 100,000 trees by 2020, as well as the upkeep of currently planted trees through community stewardship (Grow Boston Greener 2012).

### 2.3 Scenarios

We used a scenario analysis approach to explore the range of possible arrangements for planting trees in Boston while taking into account the real-world availability of planting sites under current land use constraints. Input variables used for each scenario are explained in section 2.5.3. For this study, we developed five tree distribution scenarios using input from MAPC population projections and Grow Boston Greener targets. Two of the scenarios, *Current Trends* and *MetroFuture*, were based on 30-year population projections (2000 to 2030) provided by MAPC. The *Current Trends* scenario assumed the status quo, with no focus on tree planting or population growth in Boston proper. Population change, economic conditions, and land conversion are projected to continue along their present trajectories. The *MetroFuture* scenario is based on the strategies developed by the MAPC over the past seven years. This scenario emphasizes densification in Boston as well as an increased investment in urban greening.

The third scenario, *Green Equity*, was developed by our Boston Metro Area ULTRA-Ex team to assess the potential for achieving even greater equity in urban canopy cover. This

scenario projects a modest population increase in Boston that is greater than *Current Trends* but less than *MetroFuture*. Our greening target for the *Green Equity* scenario was an overall percent canopy cover of 40%, which has been recommended for U.S. cities where the ecological climax community has the potential to be temperate deciduous forest (Heynen and Lindsey 2003).

To assess the policy goals of the Grow Boston Greener initiative, we also calculated the overall canopy cover and equity that would result from a *Grow Boston Greener* scenario using our model and information from the Urban Ecology Institute's 2008 State of the Urban Forest Report (Urban Ecology Institute 2008). Finally, to provide an upper limit for tree distribution we looked at the equity and greening implications of planting every tree that could be potentially planted based on our calculations. In this *All Trees* scenario, we distributed trees solely on the basis of ecological availability (i.e. a tree is planted in every potential tree planting site regardless of socio-economic factors).

**2.4 Population Projections**

Population projections for the year 2030 for both *Current Trends* and *MetroFuture* were provided by MAPC. MAPC used standard methods for projecting population growth based on Massachusetts' birth and death rates, by age-sex-race cohorts for the region, and a community's overall recent growth trends. Projections were presented by MAPC for a public review period where the 101 municipalities, 6 adjoining Regional Planning Agencies (RPAs) and 2 collaborating agencies, Central Transportation Staff (CTPS) and the Executive Office of Transportation (EOT) were invited to comment (Metropolitan Area Planning Council 2006). We projected the *Green Equity* population at 72% of the *MetroFuture* population increase for each TAZ, keeping the distribution of population the same as that for the *MetroFuture* scenario. The *Green Equity* scenario plays out a plan to reduce pressure from urban infill that could interfere with greening efforts relative to that under *MetroFuture.* In contrast with *Current Trends,* however, it still commits to growth focused on the urban core of the metropolitan.

For the *Grow Boston Greener* and *All Trees* scenarios, we used *MetroFuture* population projections, since *MetroFuture* is the agreed upon plan for Boston growth and we were interested in how these two scenarios would affect equity under Boston's current plan.

To ensure the population projections were reasonable, we compared the projected populations for each scenario to the population of Boston from previous decades. Figure 2 shows that the projected populations for our scenarios do not exceed the highest historical population in Boston. This provides a real world check to ensure that our projected populations are realistically achievable for the city of Boston (US Census Bureau 2010).

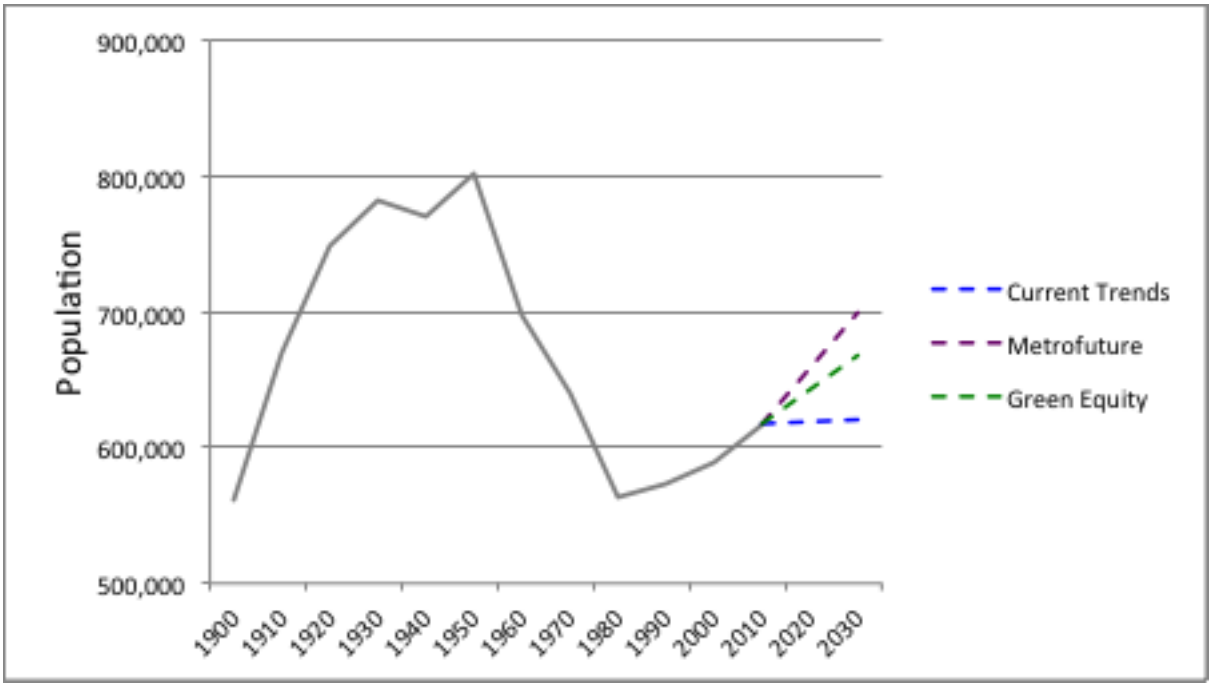



**Figure 2.** Population and Population Estimates (Boston, 1900-2010) and 2030 Scenario Population Projections (MAPC).

## 2.5 Distribution of Trees

### *2.5.1 Tree Planting Potential Analysis*

Urban tree planting can be accomplished in two ways in the already built-out Boston: retrofitting existing conditions or redeveloping the site. Each TAZ has tree planting potentials whether or not experiencing population growth. Our estimate of the number of trees that could be allocated to each TAZ in each scenario was based on three conditions: (1) tree planting on impervious areas; (2) tree planting on pervious areas; (3) street trees.

Tree planting on impervious areas excludes building footprints and roads and focuses on retrofitting or redesigning existing large impervious surfaces, such as parking lots, in commercial, industrial, and institutional land uses. In addition, current tree canopy areas overlapping with impervious areas were subtracted under the assumption that new trees will not be planted underneath existing tree canopy. Several case studies for impervious areas reduction in parking lots demonstrate an average of 19% potential through alternative parking design (Table 1). We used 20% for the tree planting potential on impervious areas for estimating reasonable number of trees.

**Table 1.** Case studies for impervious reduction in parking lots

| Case Studies | Impervious Reduction | References |
|---|---|---|
| Sacramento Home Depot Parking Lot | 18% | McPherson 2001 |
| Green Parking Lot Case Study: Heifer International Inc. | 27% | Industrial Economics, Inc. 2007 |
| Fitzgerald Marine Reserve Parking Lot | 18% | San Mateo County 2009 |
| Commercial/Industrial Template for Conservation vs. Conventional Site Planning and Stormwater Design | 14% | Conservation Design Forum, Inc. 2003 |
| **Average** | **19%** | |

For tree planting on pervious areas, we estimated the number of additional trees that could be planted on current planting beds or lawn areas in residential, commercial, industrial, and institutional lands. All current forest, wetlands, water, agriculture, recreational, utilities, and transportation lands were excluded from our calculations. In addition, current tree canopy areas overlapping with pervious area (derived from an inverse of GIS impervious area data) were also subtracted. The maximum potential for tree planting on pervious areas (tree canopy covers entire planting beds and lawn areas) would leave no open lawn areas in private yards. Considering the culture in the Northeast where direct sun is appreciated year round, we conservatively used 50% of potential pervious areas for additional tree planting estimation.

We derived the number of trees that can be planted on impervious and pervious areas with greening potential from dividing the total tree planting area by the proposed tree crown area. Based on an inventory for Boston, the average canopy of a tree in the city is 27 $m^2$ (Nowak and Crane 2002). Assuming a circular crown shape, this translates to roughly 6 m crown diameter. Therefore, we used a circular area with 6 m in diameter for estimating the number of trees.

The potential for additional street trees was estimated based on characteristics derived from the street tree inventory of Boston (Urban Ecology Institute 2008) and the Massachusetts Department of Transportation road data set (MassDOT; www.mass.gov/mgis/). First, we extracted the current number of trees per street segment and normalized it to 100 m. Then, we analyzed the existing street tree densities for each of MassDOT's road types (six classes from limited access highways to minor street or road with no street name) in order to get an estimate of the kind of densities that are realistic for Boston. We used the $95^{th}$ percentile (95% of the streets in Boston have fewer trees per 100 m) for each road, multiplied it by the respective length of the street type in each TAZ and subtracted the number of existing trees to get an estimate of the maximum potential street trees that could be allocated into each TAZ. We used a 4 m crown diameter for estimating the canopy added by street trees, because 4 m is the average crown diameter of a street tree in Boston (Urban Ecology Institute 2008).

**Table 2.** Potential greening area and number of trees for the city of Boston

| Tree Planting Potential Areas | Number of Trees | Estimated Crown Diameter |
|---|---|---|
| **Tree planting on impervious surface** | 212,967 | 6m |
| **Tree planting on pervious surface** | 207,987 | 6m |
| **Street Trees** | 123,956 | 4m |

### *2.5.2 Canopy Loss Due to Population Growth*

Population growth in Boston will likely have an impact on tree canopy, but the magnitude of this impact depends on development patterns and best management practices. To estimate loss of tree cover due to population growth, we used data from Nowak (2012). Nowak (2012) used paired aerial photographs to assess tree cover changes and population changes over time in 20 major U.S cities, including Boston. Our analysis used data from 18 of these cities. We excluded two cities, New Orleans and Detroit, because of their expected extreme tree cover losses due to hurricane Katrina and the emerald ash borer, respectively. According to Nowak (2012) data, the remaining 18 cities lost an average of 1.9 $m^2$ of tree cover per person per year. Assuming linear population growth from 2000 to 2030, we integrated this number over the change in population for each TAZ in each scenario (Table 3). We used *MetroFuture* population projections (and therefore canopy loss projections) for both our *All Trees* and *Grow Boston Greener* scenarios.

**Table 3.** Percent canopy loss at rate of 1.9 m2 per person per year for each scenario

| | Population Increase | Canopy Loss |
|---|---|---|
| *Current Trends* | 7% | -1.00% |
| *MetroFuture, All Trees, Grow Boston Greener* | 18% | -2.58% |
| *Green Equity* | 13% | -1.58% |

### *2.5.3 Scenario Inputs*

After integrating canopy loss for each scenario, we distributed canopy cover based on our tree planting potential analysis coupled with social criteria (see below) for adding new canopy in each TAZ for each scenario. In the *Current Trends* scenario, we targeted an overall canopy cover of 29% with no net change under the assumption that no new trees will be planted, there would be some canopy loss due to population growth, and existing trees that were not lost to population growth would be replaced if they died or failed.

The *MetroFuture* scenario targeted an increase in overall urban canopy cover to 35% (Grow Boston Greener 2012). Tree planting efforts are focused on compact growth areas. In our model, compact growth areas were represented by areas with high population density. As a rule, we used population density greater than 75% of existing TAZs (13,000 persons per square m) to represent high population density. For each TAZ with 'high' population density, we added the maximum potential of canopy cover. Since it would be unlikely for officials to completely ignore residents who did not fit this threshold of high population density, we distributed a fraction of potential trees in TAZs below the 75% population density threshold. These TAZs received 33% of the total potential canopy cover.

For the *Green Equity* scenario, we targeted an increase in overall urban canopy cover to 40%. Tree planting efforts would be focused on Environmental Justice areas of Boston. Environmental Justice areas are typically associated with areas of low-income or ethnic minority residents who have disproportionately low access to green space or ecosystem services (US EPA 1994). However, our analyses found that TAZs with a large minority population (defined as African American and Latino by MAPC) were not associated with low canopy cover. Increased minority population was weakly but positively correlated with increased canopy cover in Boston

(see section 3.1). For this reason, we did not include percent minority population in our model criteria. We modeled Environmental Justice areas in the *Green Equity* scenario by TAZs with a median household income less than $44,600 per year. For each TAZ that met these conditions, we added the maximum potential canopy cover. As in the *MetroFuture* scenario, we deemed it unlikely for residents above the median household income to be ignored completely by officials. Therefore, we added 33% of the potential canopy cover to those TAZs that were above the income threshold (Figure 3).

The Grow Boston Greener initiative sets a goal of increasing canopy cover by 6% in the city of Boston through the planting and maturation of 100,000 trees by 2030, with tree planting concentrated on areas identified as "underserved" by the State of the Urban Forest Report (Urban Ecology Institute 2008; Grow Boston Greener 2012). We considered Boston neighborhoods that Urban Ecology Institute identified as having overall canopy cover less than 29% (ranging from 6% to 24%) as "underserved". Based on our calculated tree planting potentials for TAZs within each of these neighborhoods, we determined that the total number of trees we could add to "underserved" neighborhoods was 268,636. However, the Grow Boston Greener initiative provides for 100,000 trees to be planted. To meet their tree planting target we planted 50% of the potential in each "underserved" neighborhood and 8% potential in neighborhoods that were not considered "underserved", for a total of 102,285 trees. *MetroFuture* scenario population and canopy loss projections were used for this scenario.

To explore a Boston in which trees are distributed purely on ecological availability and funding for tree planting is not an issue, we created an *All Trees* scenario, in which we added the entire calculated tree planting potential for each TAZ. *MetroFuture* scenario population and canopy loss projections were used for this scenario.

### *2.5.4 Scenario Outcomes*

#### *2.5.4.1 Canopy cover (greening)*

After using our scenarios to distribute potential trees, we assessed changes in overall canopy cover for each of the scenarios by converting the number of trees to percent canopy cover. We multiplied the potential number of trees by the average crown area (12.56 $m^2$ for street trees and 28.26 $m^2$ for non-street trees) to obtain the tree canopy area in $m^2$ in each TAZ. To obtain overall proportion of canopy cover for Boston for each scenario, we divided the sum of the canopy area by the sum of the land area in each TAZ.

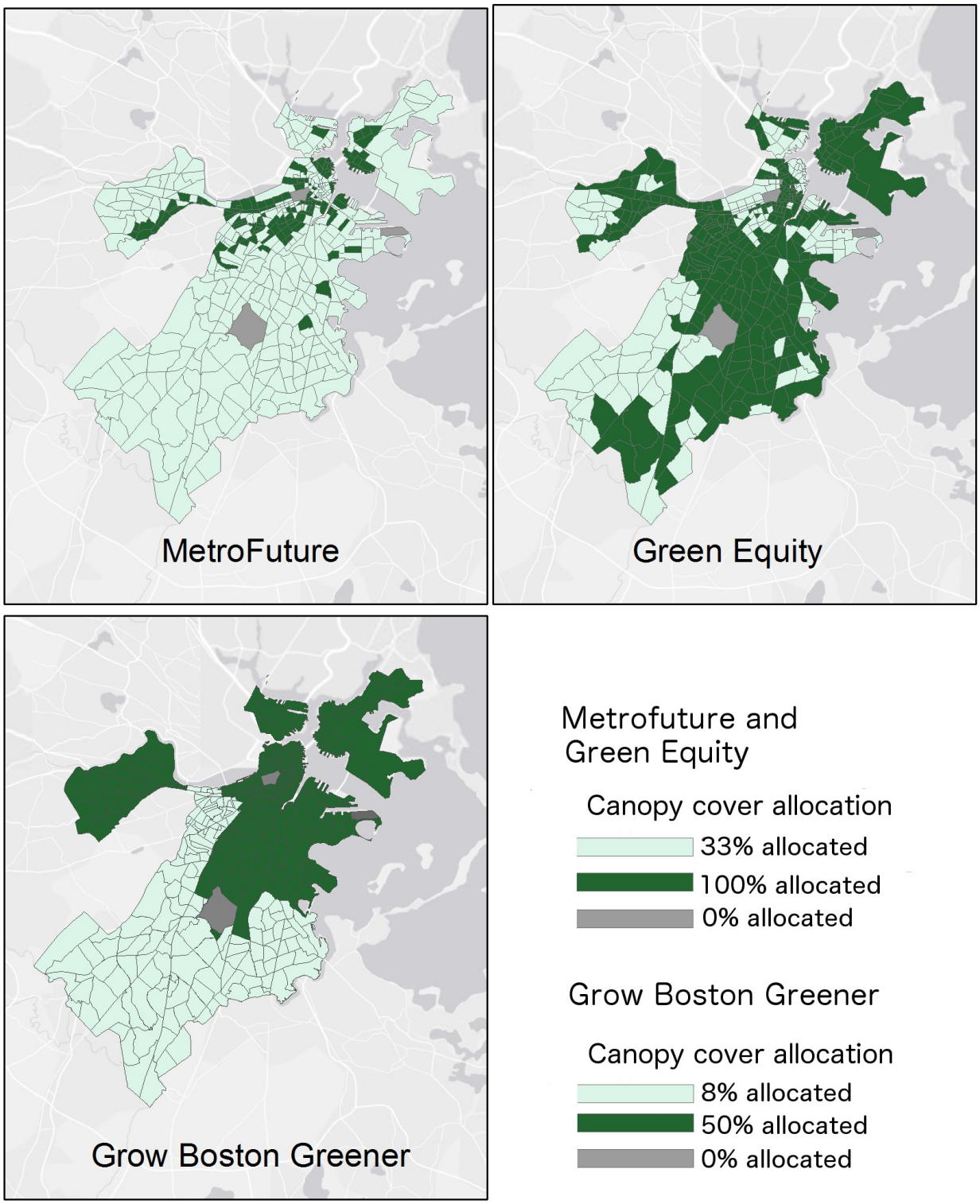



**Figure 3.** Canopy cover allocation for MetroFuture, Green Equity and Grow Boston Greener scenarios. (Basemap: ©2013 Esri, DeLorme, NAVTEQ).

*2.5.4.2 Equity measures*

We used the Gini Index as a measure of canopy cover equity. The Gini Index is commonly used in economic studies and has been successfully used in canopy cover equality studies (Jenerette et al. 2011). The index identifies the degree of inequality in the distribution of a variable, a value of 0 indicates perfect equality and a value of 1 indicates complete inequality. Gini coefficients were calculated using the statistical program R (R Development Core Team 2012), and the ineq R package (Zeileis 2012).

## 3. ANALYSES AND RESULTS

### 3.1 Current Distribution of Tree Canopy

We used socio-economic attributes—median household income, population density, and percent minority population—to explore correlation with tree canopy distribution. Pearson's correlations indicated that urban canopy cover was positively correlated with median household income ($r$ = .31) and percent minority population ($r$ =.25) (Table 4).

**Table 4.** Correlations, percent urban canopy cover and socio-economic variables for TAZs with population > 10 in 2000.

| | Median Household Income | Population Density | Minority Population (%) |
|---|---|---|---|
| Canopy Cover (%) | 0.31* | -0.04 | 0.25* |

*Indicates significance at $p$ <0.05

### 3.2 Model Results

#### *3.2.1 Canopy Cover*

The results indicate that our targets for tree canopy cover were not met in any scenario in which potential trees were added except for the *All Trees* scenario. The *MetroFuture* scenario reached 33% (target of 35%), the *Grow Boston Greener* scenario reached 32% (target of 35%) and the *Green Equity* scenario reached 39% canopy cover (target of 40%) (Figure 4).

Adding 100,000 new trees to TAZs in "underserved" neighborhoods in the *Grow Boston Greener* scenario resulted in a 3% increase in canopy to 32%, in contrast to the 6% increase to 35% aimed for in the Grow Boston Greener initiative. One major factor affecting the calculation of tree canopy is the size of tree crown diameter. In our model, in order to meet the target of 6% increase, an average tree diameter of 70 $m^2$ would be required for 100,000 trees proposed by the Grow Boston Greener initiative. In contrast, planting all available potential trees (375,930) in the *All Trees* scenario increased the overall percent canopy cover to 40%, which is above the City's target of 35% and equal to our *Green Equity* scenario target.

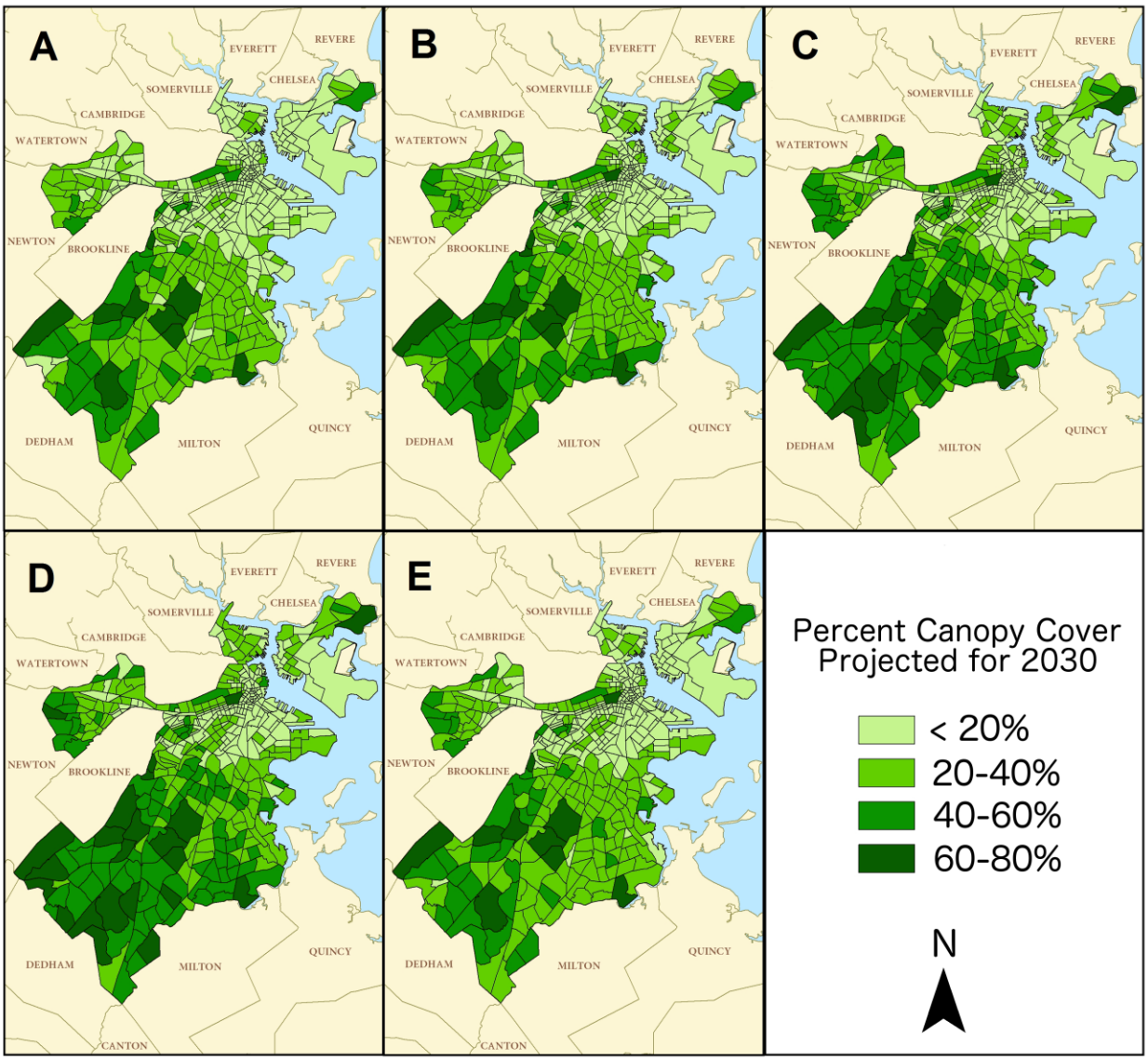



**Figure 4.** Resulting percent canopy cover by TAZ in each of the five scenarios. A) Current Trends, B) MetroFuture, C) Green Equity, D) All Trees and E) Grow Boston Greener. (Basemap: ©2013 Esri, DeLorme, NAVTEQ).

### *3.2.2 Equity*

We calculated the Gini Coefficient for current tree distribution from UEI (2005) canopy cover data and current median household income data from MAPC (Gini Coefficient = 0.201). This level appears to be similar to levels of vegetation variability for Phoenix in 2000 according to Jenerette et al. (2011). Table 5 shows the greening and equity outcomes for each of our scenarios. As expected, canopy cover distribution was least equitable (Gini coefficient closest to 1) in the *Current Trends* scenario because we did not add trees in this scenario and 20,361 trees were lost due to projected population growth (Gini Coefficient = 0.212). Canopy cover was most equitable in the *Green* Equity scenario, since our distribution was focused on addressing equity issues in this scenario (Gini Coefficient = 0.157). The *MetroFuture* scenario was more equitable than *Current Trends* and less equitable than *Green Equity* with a Gini Coefficient of 0.180. Adding all potential trees (*All Trees* scenario) resulted in a Gini coefficient more equitable than

*MetroFuture* but still less equitable than *Green Equity* (Gini coefficient = 0.162). The *Grow Boston Greener* scenario was as equitable as the *MetroFuture* scenario, but required adding about 20,000 fewer trees (Gini coefficient = 0.180). It is worth noting that, even though the *Green Equity* scenario is the "most" equitable of the scenarios we looked at, none of our scenarios approach a *truly* equitable distribution of canopy cover, i.e. a Gini coefficient of 0.

**Table 5.** Inputs and outcome of the five tree planting scenarios.

| | Current Trends | Metro-future | All Trees | Grow Boston Greener | Green Equity |
|---|---|---|---|---|---|
| ***INPUTS*** | | | | | |
| Pop. Increase (2000-2030) | 31,449 | 109,389 | 109,389 | 109,389 | 79,479 |
| Canopy loss due to pop. Increase | 7% | 18% | 18% | 18% | 13% |
| (Tree Distribution) Potential tree planting focused in: | No additional trees | High pop density TAZs | All TAZs | TAZs in neighborhoods with overall canopy cover < 29% | TAZs with low median household income |
| Overall % canopy cover | 29% | 33% | 40% | 32% | 39% |
| Trees added in scenario | None | 121,751 | 420,392 | 102,285 | 365,076 |
| ***OUTCOME*** | | | | | |
| Equity (0 = perfect equity) | 0.212 | 0.180 | 0.162 | 0.180 | 0.157 |

## 4. DISCUSSION

### 4.1 Socio-economic Factors and Canopy Distribution

Our results indicate that low income neighborhoods are associated with disproportionately low levels of urban canopy in the city of Boston. Our finding that minority neighborhoods are weakly correlated with increased canopy cover may seem surprising. However, predictors of canopy distribution vary from city to city depending on historical and cultural context. Age, geographical characteristics, and political and cultural backgrounds all affect how current socioeconomic drivers are associated with canopy cover in U.S. cities and socioeconomic drivers of canopy cover differ from city to city. Heynen and Lindsey (2003) investigated the correlation of canopy cover in urban areas in Central Indiana and found education level and housing age, but *not* population density or median household income were associated with urban canopy cover. In contrast, Iverson and Cook (2000) did find housing density and median household income to be associated with canopy cover in Chicago, Illinois. Pham et al (2012) found that both income and minority status were associated with canopy cover in Montreal, Canada, but that income was more negatively associated with vegetation than minority status was in all their models. Our

finding that higher percentages of minority residents had moderately more canopy cover may relate to the fact that in Boston some of the higher percentage minority neighborhoods are more distant from the high-density downtown which has fewer trees; and/or the resultant tree canopy could be the result of abandonment of property, which results in urban forests "regenerating" on vacant lots. As a result, in the city of Boston low income seems to be a more significant Environmental Justice indicator than minority status.

### 4.2 Tree Canopy Cover and Equity

To ensure that our study was real-world applicable and useful for policy makers we chose to constrain our scenarios by actual socioeconomic and land use variables. This led to an inability to reach our target goals for canopy cover and equity, even in the *Green Equity* scenario where we focused potential tree planting in Environmental Justice communities. Interestingly, utilizing the entire calculated potential for tree planting resulted in lower equity than using most of the calculated potential and distributing based on income (as we did in the *Green Equity* scenario). This may be due to site constraints. For instance, communities most in need of trees may not have the pervious surface necessary to plant the trees, while areas that already have high canopy cover may have more land available for more trees. Site constraints can decrease equity even more as the number of total trees planted increases without focusing on the neighborhoods that need trees most.

The Grow Boston Greener initiative's goal of a 6% increase in overall canopy cover is not met in our *Grow Boston Greener* scenario. To achieve this goal, the 100,000 trees planted by 2020 would have to reach a crown area of approximately 70 $m^2$ by 2030, which is roughly a crown diameter of 9.44 m. This is unlikely in such a short timeframe. We used a target crown size of 28.62 $m^2$, which is realistic for trees growing in densely populated urban areas, where trees may have slower growth rates and increased mortality due to urban stressors (Nowak, Kuroda, and Crane 2004). Still it is important to note that given enough time the 100,000 additional trees may reach a 6% canopy cover increase. Peper, McPherson and Mori (2001) found that most tree species would not reach a 9 m crown diameter by 15 years, but that 30 years was sufficient for several species to reach or exceed that diameter. Therefore, Grow Boston Greener's goal may be achievable by 2050 assuming a low mortality rate and funding for upkeep.

*Green Equity* was the most equitable of our scenarios, but required adding 3 times the number of trees than were added to *MetroFuture* or *Grow Boston Greener* (365,076 trees). However, our model shows that this number of trees is at least ecologically plausible, and may be necessary to approach an optimal level of canopy cover that could provide the greatest benefit for the city (Heynen and Lindsey 2003).

### 4.3 Tree Planting Implementation and Equity

Although few studies have explored whether tree planting initiatives are actually successful in equalizing urban canopy cover, several studies focused on the MillionTreesLA (MTLA) initiative in Los Angeles appear to support our findings. Researchers studying the initiative found that practical issues such as funding, stakeholder disagreement, and lack of oversight greatly affected the actual rate of tree planting in MTLA. Most notably for our study, although

one goal of MTLA was to redress the issue of poorer neighborhoods of color having fewer trees, in reality trees were "planted opportunistically where partnerships can be forged" (Pincetl et al. 2012). Furthermore, researchers found that poorer neighborhoods were underserved by the planting initiative since residents and community groups were responsible for requesting plantings and many immigrants residing in the poorer neighborhoods did not request trees because participation required a signature (Pincetl 2010). This model of tree planting is very similar to the one used in Grow Boston Greener. A recent newspaper article reported that issues of funding, maintenance, and canopy loss due to storms and disease have slowed Grow Boston Greener's progress towards its goal of 100,000 trees planted by 2020, but that the economic upturn gives policy makers hope that the initiative will pick up in future years (Abel 2012).

The MTLA studies did not specifically investigate whether the availability of tree planting sites might also affect efforts to increase tree cover in environmental justice communities. Our *Green Equity* scenario assumed a focused effort to increase tree cover in these communities and found that, even if obstacles such as funding and stakeholder disagreement can be overcome, equalizing canopy cover distribution will still be difficult in Boston's Environmental Justice communities because public tree planting sites are often not available in those communities as they are often located near areas prone to higher air and water pollutants and less open space such as intensely built-out industrial, transportation or utilities land uses.

This finding implies policy goals of increasing urban tree cover equity in Boston need to be in tandem with associated land use policies and landscape ordinances. For example, development codes can require new (re)developments to reach a certain percentage of canopy on sites as well as on the streets and provide incentives for building parking garages and shared parking spaces to free up more surface area for tree plantings. In addition, more aggressive and innovative urban planning and design strategies will be critical to allow even more trees to be planted on impervious parking surfaces and in unconventional places such as green roofs.

## 5. CONCLUSIONS

The city of Boston has embarked on an ambitious plan to create an even more "livable" city for its residents, while maintaining and enhancing infrastructure, economy and housing. There are many obstacles to this goal, not least of which we have found is the physical availability of potential planting sites for proposed increases in tree canopy cover. Taken together, our findings have important implications for policy makers, managers and community organizers. First, they illustrate the ecological problems with using tree planting initiatives to increase environmental equity in urban areas. For example, our scenarios show that even with a strong focus on planting in underserved areas, canopy cover equity in some neighborhoods will be nearly impossible to attain, due to a lack of physical space to plant trees. Second, our results reinforce findings from other studies that outline the policy and funding difficulties that tree planting initiatives face. It is important to note, however, that even very small clusters of urban trees can provide important ecosystem services for neighborhoods (Streiling and Matzarakis 2003, Strohbach et al. 2013), therefore, tree planting initiatives are still very important, even if optimal equity is never obtained.

The most important and potentially useful implication of our study is that tree planting initiatives alone cannot provide the environmental equity that is required for a more "livable"

city. We suggest that policy makers create more comprehensive "green initiatives", using the techniques from this study to take into account a neighborhood's current development and infrastructure. In neighborhoods where planting sites are available, funding could be used to plant trees, increasing both the local "urban nature" benefits to neighborhood residents as well as providing city-wide ecosystem services from overall canopy cover. In neighborhoods where planting trees is ecologically difficult – due to lack of planting sites – funds could be allocated to greening alternatives. Greening alternatives, such as green roofs or walls, rain gardens, and bioswales, are pockets of nature in the city that can have similar local social and psychological benefits as trees in neighborhoods where tree planting is impossible. By broadening tree planting initiatives to include other types of urban nature, policy makers and managers may improve their chances of creating environmental equity in densely developed cities.

## GLOSSARY

BNAN: Boston Natural Areas Network

GBG: Grow Boston Greener

MAPC: Metropolitan Area Planning Council

MassDOT: Massachusetts' Department of Transportation

MTLA: MillionTreesLA

TAZ: Traffic Analysis Zone

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