Modeling the Spatial Distribution of the Current and Future Ecosystem Services of Urban Tree Planting in Chicopee and Fall River, Massachusetts

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Mature urban tree canopy cover disrupts the local effects of urban heat islands and provides important ecosystem services such as energy savings through evaporation and shading, pollution removal, storm runoff control, and carbon sequestration. Sustainable urban tree canopy relies on the planting of juvenile trees. Typically, tree planting programs are only evaluated by the number of trees planted and there is a lack of analysis of juvenile trees post-planting. This study examines the value and distribution of energy savings provided by juvenile trees and how that value changes considering predicted tree growth and mortality by 2050. Using i-Tree Eco software, this study models the current and future ecosystem services provided to residents based on a juvenile tree inventory of 2,271 street and residential trees planted in Massachusetts (USA) from 2014-2015 by the Greening the Gateway Cities Program (GGCP) in Chicopee and Fall River, MA. Juvenile trees planted by the GGCP provided $776 and $1,520 (2018) in annual ecosystem service savings in Chicopee and Fall River while services modeled to mature tree 2050 conditions show exponentially increased total annual savings of $2,911 and $5,840 in Chicopee and Fall River (2050). Services were maximized in neighborhoods where large numbers of trees were planted or when right tree right place planting practices were followed. Analysis of the distribution of benefits reveals different planting strategies in Chicopee and Fall River. Ecosystem services from juvenile trees are concentrated in census block groups with more pre-existing tree canopy cover and lower median income. A tree planting density of two to three trees per acre was able to achieve the largest energy savings. Results of this study reinforce the importance of tree survivorship on sustaining the urban tree canopy to provide ecosystem services.

Keywords: Energy savings, i-Tree Eco, urban forests, ecosystem services

Introduction

Ecosystem services, defined as "...the benefits that humans derive from nature" are a major incentive for the establishment and continuation of tree planting programs as they increase the general quality of life within cities (Berghöfer *et al*., 2011 p. 1). To quantify the ecosystem services provided by trees in an urban environment, it is crucial to understand the intrinsic value of each service provided, how it relates separate trees into a functional ecosystem, and the impact that service has upon human health and society (Berghöfer *et al.*, 2011; Nowak, 2018). Previous research has estimated the generalized and holistic value of urban forest ecosystem services as a way to show cost/benefits to society, to further conservation policy and to inform tree canopy cover goals (Dwyer et al., 1992; Martin *et al.*, 2011, Endreny *et al,*. 2017).

Within the urban environment, trees are one of the most important components of the wellbeing of residents and natural systems (Nowak *et al*., 2001; Meineke *et al.,* 2016). The benefits provided by urban forests are predominantly witnessed in energy savings through canopy shading of impervious surfaces and temperature regulation via evapotranspiration (Lee *et al.*, 2018). However, other benefits include aesthetic appeal, increased property values (McPherson *et al*., 2007), windbreaks and noise reduction, (Chen and Jim, 2008), storm water interception (Berland and Hopton, 2014), carbon sequestration (Raciti et al., 2014), and pollution mitigation (Scholz *et al.,* 2018). Continued study of the social and environmental impact of urban forests validates the importance of both urban trees and the organizations that plant and maintain them (Breger *et al*., 2019; Nowak and Dwyer, 2007). As these benefits are not evenly distributed throughout a given study area, more research is needed to understand which communities are benefiting most from tree planting and how the benefits of trees are accrued over time to as they mature.

Despite the documented benefits provided by urban tree canopy cover, land in the US is predicted to continue rapidly urbanizing, increasing to approximately 392,400 km^2 by 2050—an area greater than the state of Montana—with associated environmental stressors greatly increasing such as population density, imperviousness, and building intensity (Nowak and Greenfield, 2018b; Gao and O-Neill, 2020). Research by Nowak and Greenfield (2018a) found significant declines in tree canopy cover in urban areas across the US with an approximately 1% decrease from 2009 to 2014, and a decrease of 1.3% in Massachusetts over the same time frame. Approximately 40% of the land-use change associated with developed urban land is from converting forested land to impervious cover (i.e., roadways, sidewalks, rooftops) which negatively impacts the natural landscape through modifications to surface reflectance, evapotranspiration, increased surface temperature levels, as well as increasing urban air pollution and stormwater runoff (Tu *et al.,* 2007; Seto *et al.,* 201l; Nowak and Greenfield, 2018a).

Urban air temperatures in the U.S. were found to be to 9-15 °F (5-8 °C) higher than surrounding rural areas, as urban infrastructure absorbs heat and creates the urban heat island (UHI) effect (Hardin and Jensen, 2007). A review of fifteen studies showed that for each 1.8°F (1 °C) increase in ambient temperature, the electricity demand would rise from 0.5 - 8.5% (Santamouris et al., 2015). Increased energy consumption amplifies heat emissions which drive urban particulate and carbon dioxide pollution levels higher, creating a positive feedback loop that strengthens the UHI effect (Kikegawa *et al.,* 2006).

However, trees are being planted by governments and other organizations in urban areas to increase the ecosystem services in their cities, reduce the UHI effect, and to address issues of inequity and sustainability (Pincetl et al., 2013). Massive tree planting goals have become popular in tree planting programs such as the Million Tree Initiative happening in several cities across the globe (Los Angeles, New York City, Shanghai, London, etc.), or the most recent One Trillion Tree initiative introduced at the 2020 Economic Forum which also includes national landscape restoration, not just urban areas. For these programs to be successful the trees planted must reach maturity in order to produce their promised benefits and services (Roman et al., 2015). Despite planting programs stated goals to increases ecosystem services to address social inequities, recent studies have shown that tree-planting programs can increase social inequity due to procedural injustices (Lin and Wang, 2021). More research is needed to understand the fine scale geography of tree planting to understand how ecosystem services are distributed and to whom.

The goal of this study is to examine how the ecosystem services from a Massachusetts tree planting program are spatially distributed and to model these services over time. Little research has addressed the comparative value of the juvenile and mature urban forest (considering growth and mortality) and the spatial distribution of ecosystem services provided. The paucity of research creates uncertainty about the effectiveness of juvenile trees to provide significant benefits to residents in the near-term and long-term.

To address this goal, the paper asks the following questions:

1. What are the ecosystem services provided by juvenile trees and what are the forecast ecosystem services provided in 32 years?

2. How does annual mortality impact the change in value and distribution of ecosystem services?
3. What biophysical and socioeconomic factors predict how ecosystem services distributed in a tree planting program?

Study Area

In 2014, the state of Massachusetts initiated an urban tree planting program which focuses on twenty-six municipalities identified as "Gateway Cities", a term that describes struggling post-industrial cities that serve as gateways to the regional economy (MassINC, 2015). Gateway Cities are designated as having a population between 35,000 and 250,000, with an average household income and a bachelor's degree attainment rate both below the state average (Commonwealth of Massachusetts, 2016). The tree planting initiative Greening the Gateway Cities Program (GGCP) is managed by the Massachusetts Department of Conservation and Recreation (DCR), with funding provided from the Massachusetts Department of Energy Resources (DOER) and has a partnership with the Massachusetts Department of Housing and Community Development (DHCD). The GGCP stands apart from most other planting programs, as it is both funded and managed through state government agencies acting at the municipal level (Breger *et al.*, 2019). The GGCP frames trees as green infrastructure (DCR, 2017) and has a goal of increasing canopy cover by 5%–10% within select neighborhoods in order to reduce heating and cooling costs for residents (Commonwealth of Massachusetts, 2017). To increase canopy cover, the GGCP proposes planting an average of five trees per acre so that as the trees mature (~30 years) their canopy goals will be met (Cahill, 2018). To achieve the GGCP goals of increased canopy coverage and utility savings, the DCR must judge the effectiveness of the GGCP in providing ecological benefits to urban residents and understand the relationship between the provisioning of ecosystem services and juvenile tree survivorship.

The extent of the study was confined to the GGCP planting zones established by the DCR within the cities of Chicopee and Fall River, Massachusetts (see Figure 1). These planting zones were chosen to encompass environmental justice population neighborhoods, which are defined in Massachusetts as a block group with an annual median household income that is equal to or less than 65 percent of the statewide median ($62,072 in 2010); or 25% or more of the residents identify as a race other than white; or 25% or more of households have no one over the age of 14 who speaks English only or very well (Commonwealth of Massachusetts, 2018). Additionally, the planting zones were chosen because they are predominately high in renter population and have low tree canopy cover.

Figure 1: Study area maps of the Greening the Gateway City Program planting zones created by the Department of Conservation and Recreation within the cities of Chicopee (left) and Fall River (right).

The city of Chicopee is located within Hampden County, in the Pioneer Valley region of western Massachusetts. Chicopee has a population of 55,515 (U.S Census Bureau, 2017) with a median household income of $47,182 (Mosakowski Institute, 2016) and an area of approximately 61.9 km^2. The GGCP planting zone (3.44 km^2) is located along the western region of Chicopee (See Figure 1) alongside the Connecticut River. This tree planting zone currently has 20.6% canopy cover, which is lower than the city-wide percentage of 34.8%. The tree planting zone also has 47% impervious cover, compared to the city-wide percentage of 29.9%.

Fall River is located within Bristol County, in the southeast region of Massachusetts. Fall River has a population of 89,420 (U.S Census Bureau, 2017) with a median household income of $33,416 (Mosakowski Institute, 2016) and an area of approximately 104.4 km^2. The GGCP planting zone (9.15 km^2) is located in the southern region of the city along the Rhode Island border, split into two areas to the east and west of Cook Pond (See Figure 1). This tree planting zone currently has 23.8% canopy cover, compared to the city-wide percentage of 55.9%. This large difference in tree canopy cover is due to the urban setting of the planting zone and the Freetown-Fall River State Forest that occupies a large area in the northern region of the city. The planting zone has 44.7% impervious cover, while the city-wide percentage is 18.5%.

Data & Methods

This study uses i-Tree Eco software to model the current (2018) and future (2050) magnitude and extent of the ecosystem services provided by juvenile trees planted in the study areas (See Figure 2). Adapted from the Urban Forest Effects (UFORE) model developed by the U.S. Forest Service (Nowak and Crane 2000), the i-Tree Eco software allows users to evaluate urban forest structure and the value of monetary savings provided to communities in the form of ecosystem services.

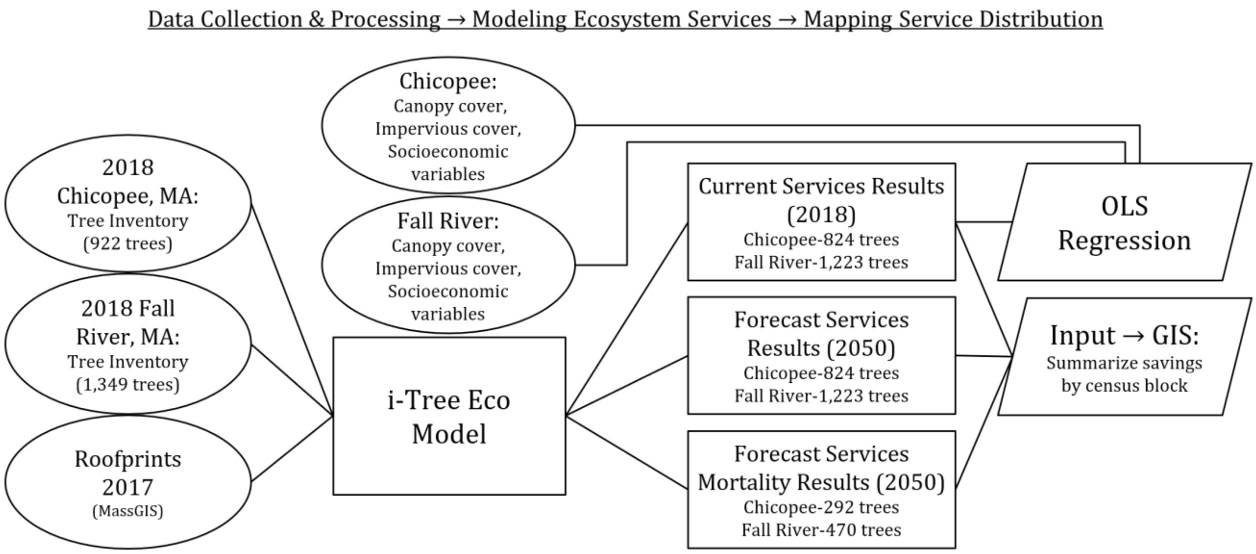

Figure 2: Flowchart highlighting main data inputs and steps of analysis.

The four ecosystem services examined in this study include energy savings, pollution removal, avoided runoff, and gross carbon sequestration. The i-Tree Eco definitions for each of these services are shown in Table 1.

Ecosystem Service	**i-Tree Eco Definition**	**i-Tree Eco Value**
Energy Use	Energy use is the monetary value of increased or decreased energy costs as a result of a tree's cooling effect on residential building energy use.	This value is estimated based on the dollar value per MBTU or MWH.
Pollution Removal	Pollution removal is the monetary value associated with tree effects on atmospheric pollution.	This value is estimated based on the economic damages associated with increases in pollution emissions and/or the impact of air pollution on human health.
Avoided Runoff	Avoided runoff is the monetary value avoided because of rainfall interception by trees.	This value is estimated based on the economic damages associated with runoff and costs of stormwater control.
Gross Carbon Sequestration	Gross carbon sequestration is the monetary value associated with tree effects on atmospheric carbon.	This value is estimated based on the economic damages associated with increases in carbon or carbon dioxide emissions.

Table 1: This table describes each ecosystem service included in this study as defined and valued by i-Tree Eco.

Previous studies have examined the utility of i-Tree Eco to model and analyze the distribution of ecosystem services. One study conducted at Auburn University in Alabama modeled the ecosystem services of campus trees for pollution removal, carbon storage, and carbon sequestration, and concluded that i-Tree Eco was effective as an industry standard for urban forest evaluation (Martin *et al.*, 2011). Endreny *et al*. (2017) recently used i-Tree Eco to estimate the ecosystem services provided across London, UK, and other global megacities, concluding that an estimated median value of $505 million was being provided annually in tree-based ecosystem services. Although these studies provide insight into the generalized value of urban forests, they lack the visualization of the spatial distribution of ecosystem services. Mapping the economic value of ecosystem services is fraught as the spatial scale must match the service providing unit (Nahuelhual et al., 2015). However, for sustainable resource management and planning, it is necessary to spatially analyze the modeled value of ecosystem services to gauge the spatial relationship between economic value and the tree locations in relation to urban variables (Campbell et al., 2020). Recent analysis of ecosystem services at the census block level shows the need to develop clear frameworks for spatially displaying and projecting ecosystem services modeled using I-Tree Eco (Nyelele et al., 2019).

The data used in this study was acquired from multiple sources in a variety of formats (see Table 2). The primary data used throughout the i-Tree Eco modeling and analysis were the DCR tree inventories, building outlines, and 2010 census block polygons.

Data Name	Description	Year
Department of Conservation and Recreation Tree Inventory	Health and locational metrics of 922 and 1,349 GGCP trees in Chicopee and Fall River, MA. *Clark University*	2018
Building Structures (2-D)	2-dimensional roof outlines for all buildings larger than 150 sq. ft. *MassGIS*	2017
Chicopee Weather and Pollution	Weather data from the Westover Metropolitan Airport. Chosen for proximity to Chicopee, MA. *Westoverairport.com*	2015
Fall River Weather and Pollution	Weather data from the New Bedford Regional Airport. Chosen for proximity to Fall River, MA. *NewBedford-ma.gov/airport/*	2015
2010 Census Block	Clusters of blocks within the same census tract that have the same first digit of their 4-digit census block number. *MassGIS*	2017
Planting Zone Canopy Cover	Canopy cover within the DCR planting zones of Chicopee and Fall River, MA. *Department of Conservation and Recreation*	2014
Impervious Surface Cover	Statewide impervious surface cover clipped within the DCR planting zones of Chicopee and Fall River, MA. *MassGIS*	2005
Socioeconomic Variables	Describes percent renter population, percent of population with a bachelor's degree, percent nonwhite, and median household income at the spatial scale of census blocks within Chicopee and Fall River, MA. *US Census Bureau*	2015-2018

Table 2: Descriptions and sources of all data used throughout research and analysis.

DCR Tree Inventory:

The input variables for the i-Tree Eco model were informational metrics such as tree ID, species, DBH, land use of planting site, location coordinates, tree native status, and a measure of tree vigor on a 1-5 point scale. This vigor scale is based on the protocol described by Roman *et al*. (2017), describing the quality of a tree canopy in relation to the percentage of dieback present. These surveys were conducted via in-person measurements in the summer of 2018 by the first, second, and third authors with the help of a group of undergraduate students who were trained by the first author. These surveys were not inclusive of the entire population of GGCP planted trees in either city, as researchers had to request access to measure trees on private property. Overall, 922 out of 951 trees in Chicopee and 1,349 out of 1,988 trees in Fall River were surveyed. Table 3 shows mean vigor scores, DBH values, and the percent distribution of tree vigor across both city's tree populations. Tree inventory survey data based on dead or removed trees were not included in the i-Tree analysis conducted in this study, resulting in smaller input tree cohort populations in each city (Chicopee: 824, Fall River: 1,233). Model tree inventories representative of future conditions were created by stratified random sampling of 2018 trees based on an annual mortality of 3.3% which is the median post-establishment annual morality rate in survivorship studies of planting cohorts (Hilbert et al., 2019). The 3.3% annual morality rate over 32 years resulted in 292 surviving trees in Chicopee and 470 surviving trees in Fall River in 2050.

City	Inventory Sample Size	Mean Vigor	Mean DBH	Juvenile Tree Survivorship	Healthy (Vigor 1)	Slightly Unhealthy (Vigor 2)	Moderately Unhealthy (Vigor 3)	Severely Unhealthy (Vigor 4)	Dead (Vigor 5)	Unknown
Chicopee	922	1.21	1.22	846 (91.7%)	765 (83.0%)	58 (6.3%)	20 (2.2%)	3 (0.3%)	54 (5.9%)	22 (2.4%)
Fall River	1,349	1.24	1.48	1238 (91.7%)	1060 (78.6%)	123 (9.1%)	42 (3.1%)	13 (1.0%)	91 (6.7%)	20 (1.5%)

Table 3: Tree inventory sample size, mean vigor scores, DBH values, survivorship, and the percentage distribution of tree vigor across Chicopee and Fall River. A vigor score of 1 is full tree canopy while 5 is standing dead.

Tree-Building Interactions

To estimate energy savings from building cooling, i-Tree Eco requires tree-building interaction data in the form of the distance and direction from each tree to the nearest buildings. The i-Tree Eco threshold for tree distance from buildings to provide energy savings is 60 feet. Building footprint data were used as an approximation of building location to calculate the distance and direction from each tree point to the nearest building. The distances to additional buildings from each tree were not calculated nor included in the i-Tree Eco model, which presents modeled results conservatively, as trees can offer benefits to more than one building.

Environmental and Socioeconomic Factors

The tree canopy cover and impervious surface cover data from MassGIS (Table 2) were converted to polygon layers. Following this, the percentage of canopy and impervious surface cover was calculated within each census block by dividing the area of canopy cover and impervious surface for each census block group and dividing by the total area. Socioeconomic data from the 5-year American Community Survey (ACS) (U.S. Census Bureau, 2019) was used as defining factors for a Massachusetts gateway city: population, median household income and educational attainment rates of a bachelor's degree. Other factors included from the ACS was percent nonwhite population and renter population because these criteria were used by the GGCP to create tree planting zones in environmental justice neighborhoods that would benefit the most from decreased energy bills.

Modeling Current and Future Ecosystem Services:

Current services (2018)

The tree inventory files for Chicopee and Fall River were input as separate projects into i-Tree Eco as complete, un-stratified inventories including: species, DBH, land use, tree-building interactions, and canopy condition. These provide the main foundation for i-Tree Eco analysis following the protocol described by Singh (2017).

Projected services (2050)

The i-Tree Eco Forecast module takes the structural estimates such as number of trees and species composition produced by running the i-Tree Eco model and estimating the future conditions of the tree inventory based on anticipated growth and mortality. Using this module, estimates of annual average DBH growth and total annual mortality rates were produced from the 2018 i-Tree Eco projects for Chicopee and Fall River for the projected tree conditions in the year 2050. The defined annual mortality rate for the Forecast module was set to 3.3%, as stated previously. The predicted tree cohort mortality for 2050 in Chicopee and Fall River was modeled by i-Tree Eco at 64.6% and 61.6%, respectively.

Mortality was simulated using stratified random sampling. It was assumed that healthier trees in 2018 were more likely to survive longer. Additionally, land use has been shown to be a factor in tree survivorship as different land uses have a wide variety of stewardship regimes (Lu et al., 2010). Individual weights were created for each city which incorporated the survivorship of the particular land use as well as the individual tree health.

$$Weight\ (i) = \frac{Tree\ Health\ (i)}{1 + LU\ Mortality}$$

Figure 3: The equation was used to create weights for each individual tree *(i)*. The tree health was divided by the land use survivorship in 2018. By adding 1 to the Land Use (LU) average mortality for the city, trees that are planted on LU with higher mortality will have a lower weight. A lower weight means there is less chance a tree would be included in the final sample.

The stratified sample was taken using the ‘sample_n’ function from the R package ‘dplyr’ which allows for the inclusion of individual weights (0-1) with lower numbers being less likely to be included in the final sample.

The projected DBH growth between 2018 and 2050 (4.29 inches in Chicopee, 5.65 inches in Fall River) was then added to the original tree size metrics within both tree inventories uniformly, creating new tree inventories approximating tree size metrics in 2050. At this point the process for modeling the projected 2050 ecosystem services was identical to that of the 2018 ecosystem services. Modeled 2050 ecosystem services were limited to the trees based on the tree mortality predictions.

i-Tree Eco Spatial Analysis

The i-Tree Eco results for 2018 and 2050 ecosystem services explicitly outline their savings. Each result of ecosystem service savings (energy savings, pollution removal, avoided runoff, gross carbon sequestration) for both 2018 and 2050 was joined by tree ID to the GGCP tree locations within a GIS. The ecosystem service savings were aggregated by census blocks by spatially joining the 2018 and 2050 savings to census blocks within the DCR tree planting zones to gauge the spatial distribution of services provided.

An Ordinary Least Squares (OLS) regression tested the dependence of the ecosystem services of energy, pollution, avoided runoff and carbon sequestration in 2018 against independent variables of percent canopy cover, impervious surface, percent renter, percent of population with a bachelor's degree, percent nonwhite, and median household income at the census block group level. Each regression included the 31 census block groups combined from Chicopee and Fall River. It was necessary to combine the cities for regression analysis as the Chicopee planting zone had only 9 census block groups. While contextually different cities, Chicopee and Fall River are both defined as Gateway Cities and their planting zones were chosen based on the same metrics of low tree canopy cover and high renter populations which for this study makes them comparable.

Results

Current (2018) and projected (2050) services

The value of annual ecosystem service savings provided by the GGCP trees in Chicopee and Fall River are distributed between energy savings, pollution removal, runoff control, and gross carbon sequestration (Table 4). Considering projected tree growth and predicted tree mortality between 2018 and 2050, the total annual savings provided by GGCP trees will have increased by $2,134 (375%) in Chicopee and by $4,320 (384%) in Fall River.

Of all the ecosystem services modeled in the study, energy savings show the greatest growth in value between 2018 and 2050, accounting for 85% of total services in dollars in Chicopee and 80% in Fall River. In Chicopee, the loss of trees caused a reduction of $5,179 (64%) in ecosystem services while in Fall River, the difference was $9,628.68 (62%).

City	Year (# trees)	Energy via cooling (Kwh/yr | $/year)		Pollution (oz/year | $/year)		Avoided runoff (ft³/yr | $/year)		Gross Carbon Sequestration (lb/yr | $/year)		Total $/year
Chicopee	2018 (824)	3,638	544	510.1	61.55	1,593.1	106.49	745	64	776.04
	2050 (824)	33,203	7,009	2,010.8	259.78	6,344.8	424.12	4,652	397	8,089.90
	2050 (292)	11,840	2,499	771.0	97.05	2,400.5	160.46	1,809	154	2,910.51
Fall River	2018 (1,223)	6,987	1,044	1,113.6	220.45	2,107.6	140.89	1,344	115	1,520.34
	2050 (1,223)	59,066	12,469	5,998.6	1,300.37	12,166.2	813.26	10,388	886	15,468.63
	2050 (470)	22,172	4,680	2,343.0	501.69	4,701.8	314.29	4,037	344	5,839.95

Table 4: Annual monetary values of ecosystem services provided within Chicopee and Fall River as modeled by i-Tree Eco across current (2018), and projected conditions (2050 with mortality and with no mortality).

The model of 2018 ecosystem services show the 824 trees in Chicopee and 1,223 trees in Fall River provide $776 and $1,520 respectively in total annual savings. The value of annual energy savings provided by GGCP trees show the greatest increase across all ecosystem services modeled in each city, providing 70% ($544) and 69% ($1,044) of 2018 values. The aggregation of savings within census blocks shows which blocks contain the most planted trees by the GGCP receive highest value in energy savings and other ecosystem services (see Figures 4 and 5). Census blocks were plotted with a box and whisker plot to identify which blocks were outliers and therefore the blocks with the highest energy savings across both cities, (Figure 6). Visual spatial analysis showed that many of the outliers in 2018 Fall River were in new housing developments, housing authorities and parks. The Sunset Hill housing authority (see Figure 7) overlaps five census blocks containing ninety-one juvenile GGCP trees which cumulatively provide $120 in annual energy savings. As multiple census blocks were outliers within the Sunset Hill housing authority, it will be used as a proxy for the high concentrations of energy savings in Fall River.

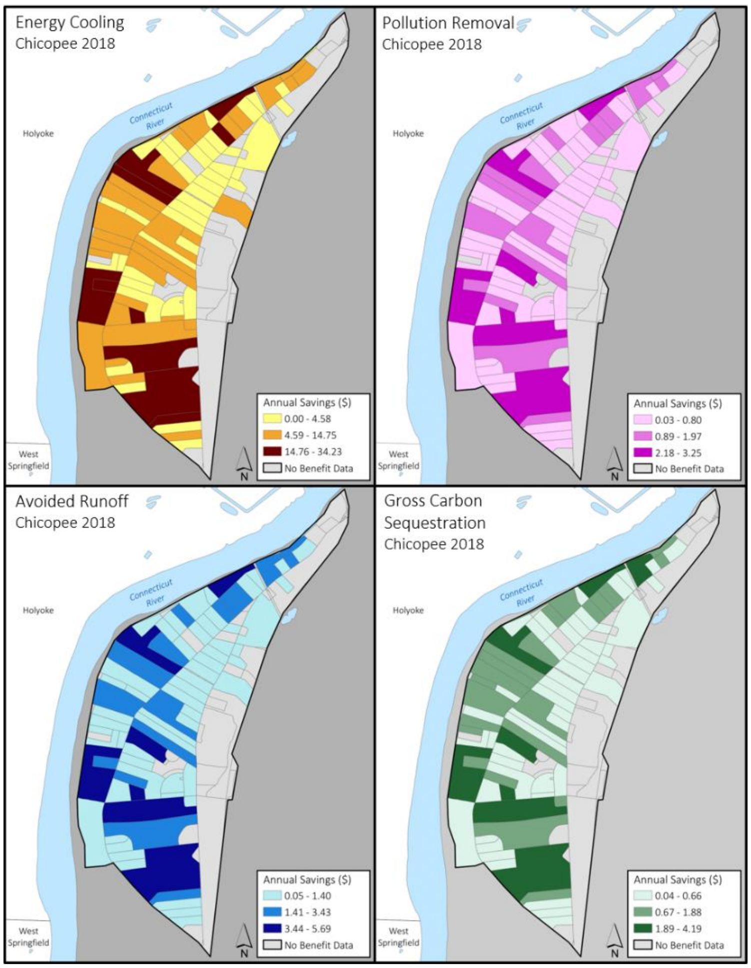

Figure 4: Distribution of ecosystem services (energy savings, pollution removal, avoided storm runoff, gross carbon sequestration) provided by the measured GGCP trees summarized by census block within the DCR Chicopee planting zone in the year of 2018. The sum value of all monetary savings is $776 annually in 2018.

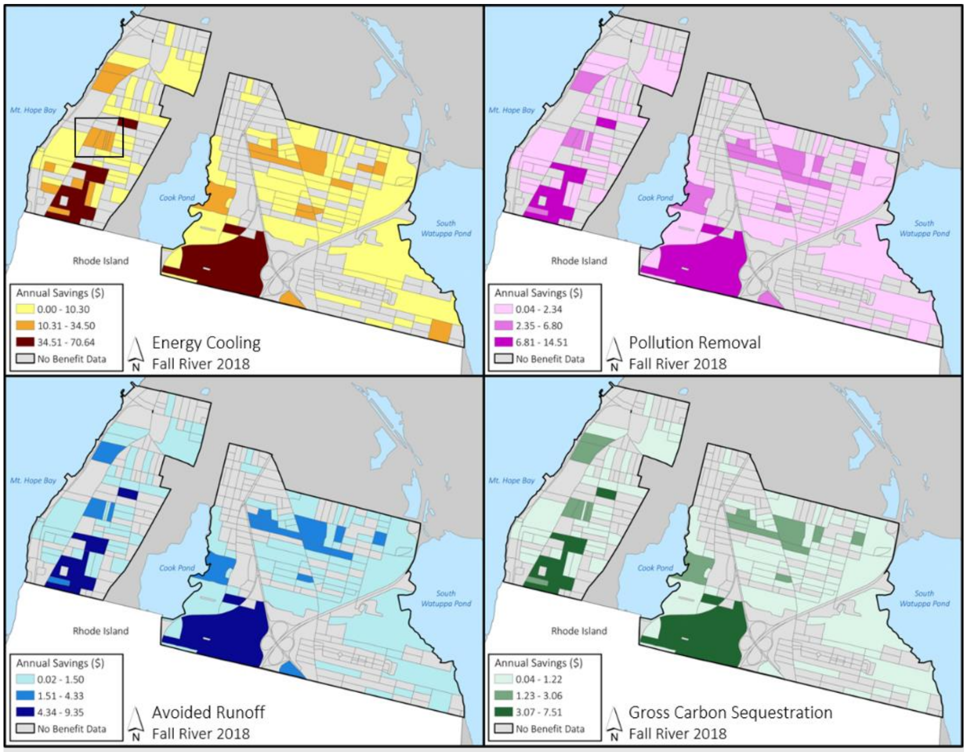

Figure 5: Distribution of a suite of ecosystem services (energy savings, pollution removal, avoided storm runoff, gross carbon sequestration) provided by the measured GGCP trees summarized by census block within the DCR Fall River planting zones in the year of 2018. The sum of all monetary savings is $1,520 annually in 2018. The box in the energy cooling map designates the location of the Sunset Hill housing authority examined in this study.

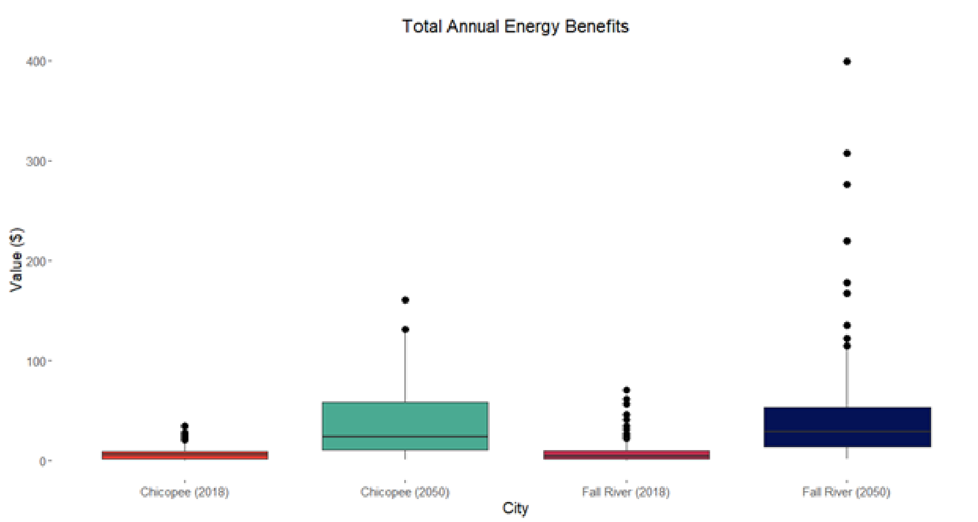

Figure 6: This box and whisker plot of energy benefits from census blocks shows the distribution of energy benefits in Chicopee and Fall River. While each city had small energy savings in 2018 right after

the trees were planted, by 2050 the median had increased from $4.98 to $23.50 (471%) in Chicopee and from $3.72 to $28.25 (759%) in Fall River.

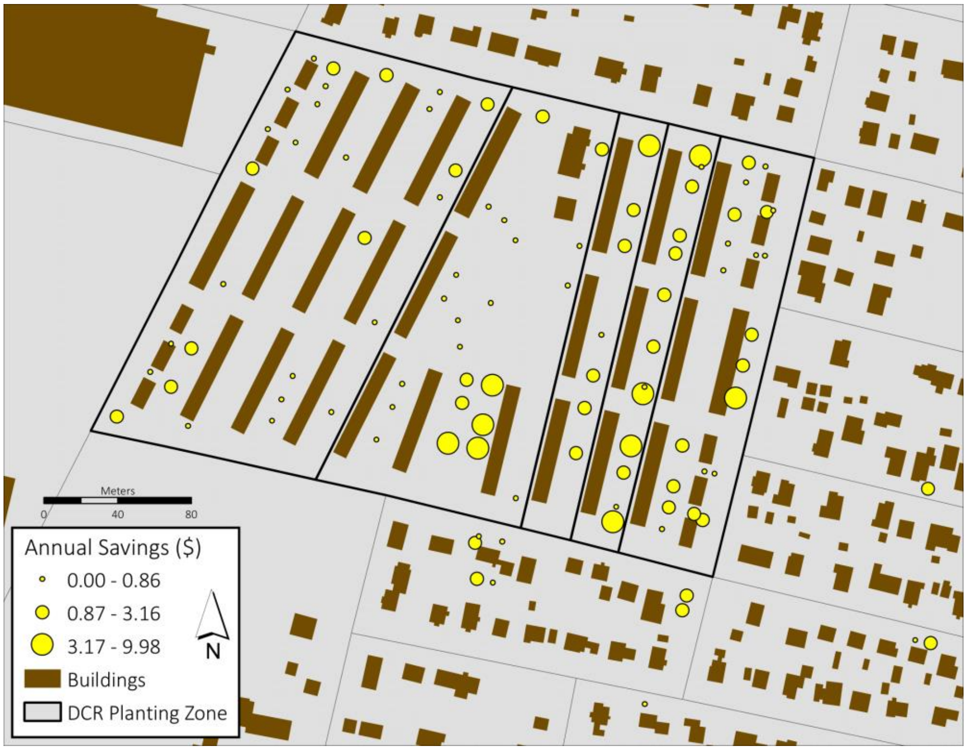

Figure 7: Sunset Hill housing authority located in the western planting zone within Fall River. This housing authority is made up of five census blocks (black outlines) and contains ninety-one GGCP trees that were assessed to be collectively providing $120 in annual energy savings in 2018.

The projected models of future ecosystem services show the randomly selected surviving 292 Chicopee trees and 470 Fall River GGCP trees to provide annual savings of $2,910 and $5,840 respectively in combined services. Considering the respective loss of approximately 64.6% and 61.6% of initial trees due to weighted mortality in Chicopee and Fall River, the range in value distribution of projected savings among census blocks is much wider in 2050 than in 2018, with higher census block savings correlated with higher surviving tree numbers (see Figures 8 and 9). In Chicopee, there were two census blocks that were outliers in energy savings while in Fall River there were nine (Figure 6). For this analysis, the outliers in 2050 were of particular interest as these census blocks with extremely high energy savings could inform best tree planting practices. While ecosystem services were evenly distributed in Chicopee, they were concentrated in nine census blocks in Fall River. Each of the outliers in 2050 was investigated to see if there were patterns in who the tree recipients were in areas where the ecosystem services were higher. In Chicopee, there were only two outliers, and the tree recipients were a community organization along with nearby concentrated street trees and a collection of private residences (Table 5). In Fall River, the census blocks that were outliers were new housing developments, housing authorities or public parks. Specifically, two census blocks in the Sunset Hill housing authority in Fall River were notable. The Sunset Hill housing authority highlighted in figure 5 shows a 58% decrease in GGCP tree numbers from ninety-one to thirty-eight between 2018 and 2050 and shows an increase in the combined annual energy savings from $120 to $451 (a 376% increase) (see Figure 10).

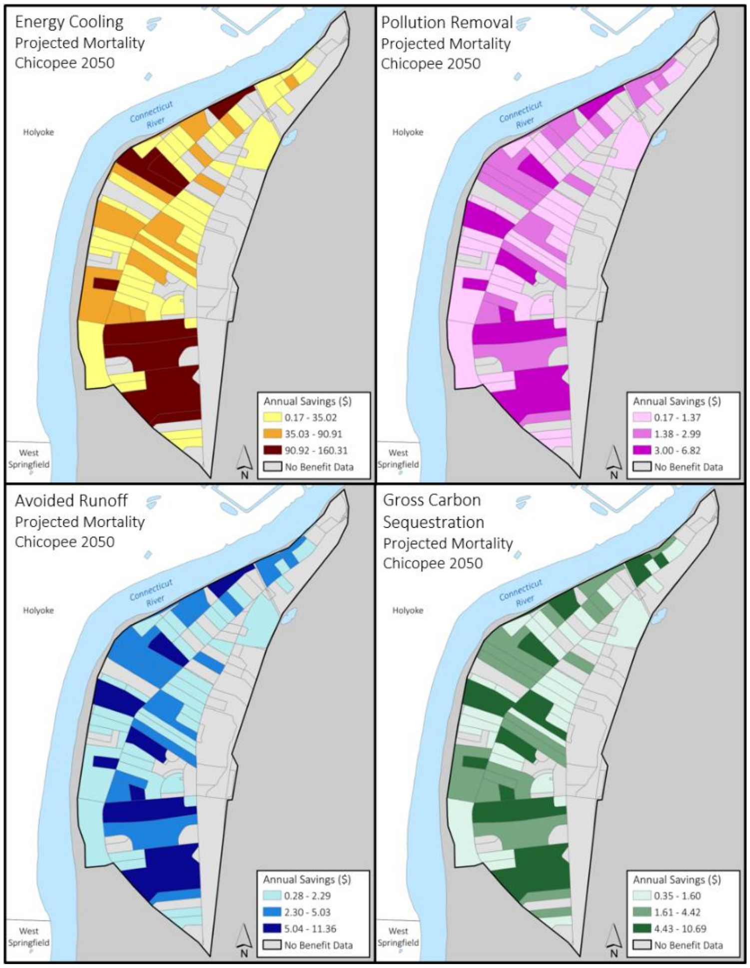

Figure 8: Distribution of a suite of ecosystem services (energy savings, pollution removal, avoided storm runoff, gross carbon sequestration) provided by the measured GGCP trees summarized by census block within the DCR Fall River planting zones in the year of 2050. The sum value of all monetary savings is $2,911 annually in 2050.

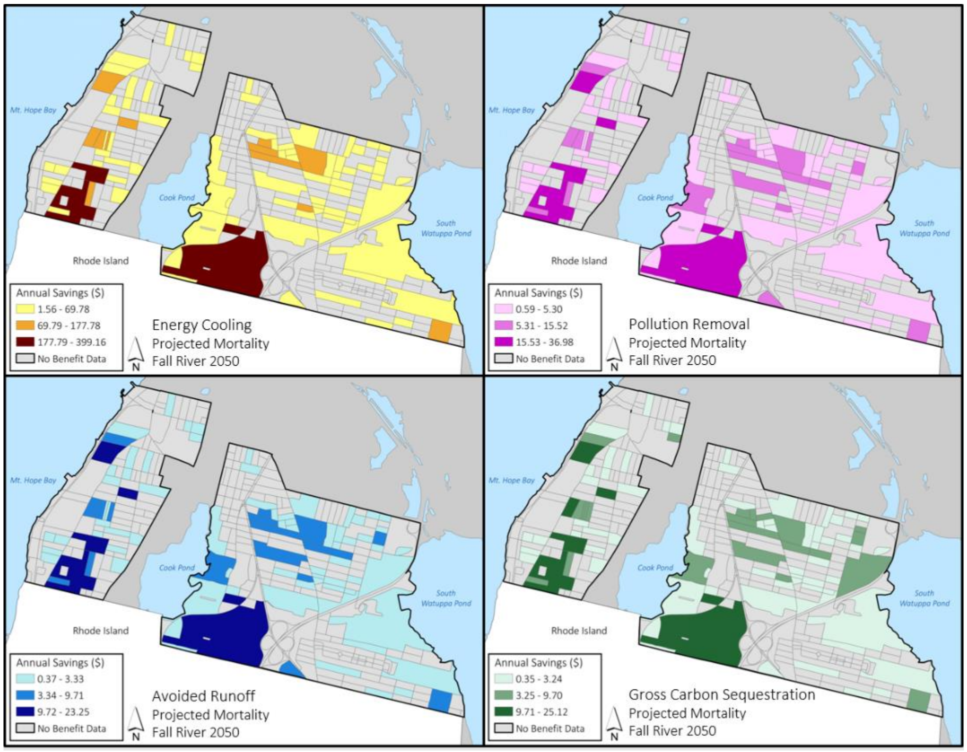

Figure 9: Distribution of a suite of ecosystem services (energy savings, pollution removal, avoided storm runoff, gross carbon sequestration) provided by the measured GGCP trees summarized by census block within the DCR Fall River planting zones in the year of 2050. The sum value of all monetary savings is $5,840 annually in 2050.

Tree Recipients	**# of Trees**	**Total Energy Benefits ($)**	**$ Per Tree Per Building**
Chicopee			
Individual Residents	11	160	14.55
Community Partner – Public Trees	8	131	16.38
Fall River			
New housing Development	31	399	12.87
Housing Authority	24	307	12.79
New housing Development	41	276	6.73
Housing Authority	18	220	12.22
New housing Development	21	177	8.43
Public Park	13	166	12.77
Housing Authority (Sunset Hill)	15	135	9.00
Public Park	17	122	7.18
Housing Authority (Sunset Hill)	9	114	12.67

Table 5: This table breaks down the census blocks that were outliers in energy benefits in 2050. The median benefits from cooling in Chicopee were 23 dollars while in Fall River, the median was 28. The number of trees generally corresponds to higher energy benefits although it is noticeable that some $ per tree per building are higher than others. Higher values correspond to trees that were planted in the right place; near buildings and along the east-west axis; as well as the size of the tree at planting.

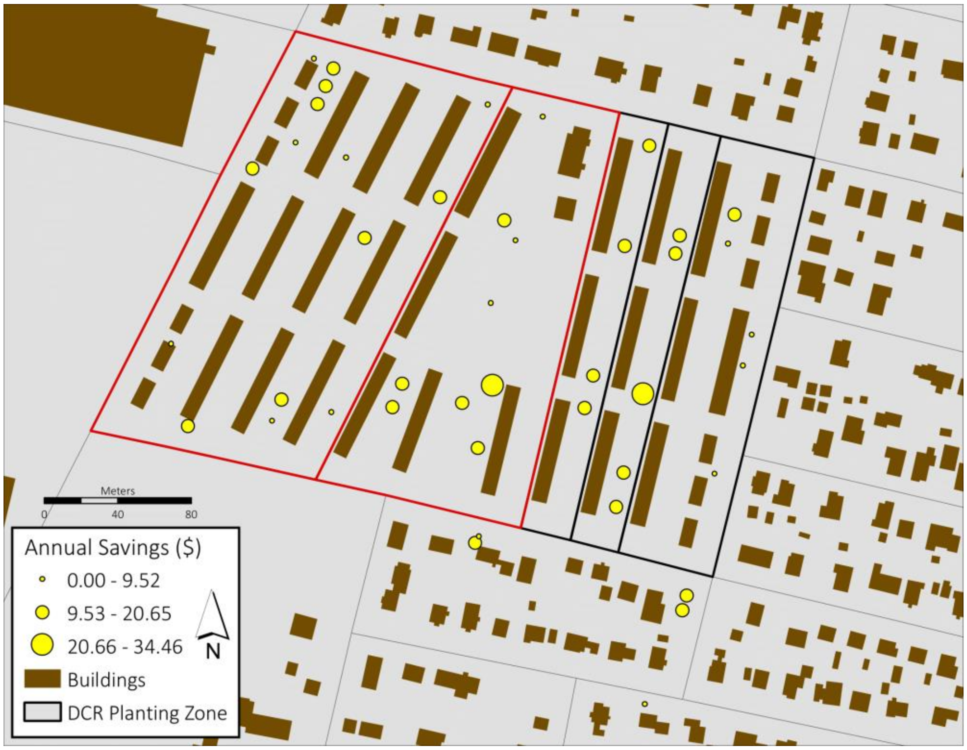

Figure 10: Sunset Hill housing authority in Fall River, reflecting the effects of tree mortality projected in the year 2050. This housing authority, made up of five census blocks, contains the surviving thirty-eight GGCP trees that were assessed to be collectively providing $451 in annual energy savings in 2050. Census blocks highlighted in red represent significant outliers in the distribution of ecosystem services.

i-Tree Eco Spatial Analysis

The coefficients for each model are displayed in Table 6 to understand how the independent variables impacted ecosystem services. In the model for Avoided Runoff, the variable Percent Canopy (PC) was significant with a confidence above 99% in predicting where Avoided Runoff benefits would occur. PC was also significant to varying degrees in each of the other models as well, highlighting its importance. The positive coefficient shows that high Avoided Runoff benefits from tree planting are occurring in census block groups with high existing tree canopy cover. The other significant variable at 99% confidence was Fall River. The negative coefficient indicates that census blocks in Fall River were less likely to see avoided stormwater benefits. This decrease in Fall River was also visible in the Carbon

Sequestration and Energy models but not in the Pollution model. On average between all models, $123 dollars of ecosystem services were added for each additional percentage of tree canopy cover. Median Household Income was also significant at 95% confidence in each model. While the unstandardized coefficient is very low, the standardized coefficient reveals that Median Household Income has a strong negative relationship with the ecosystem services in each model. This shows that census blocks with lower income have significantly higher ecosystem services than census blocks with higher income from the trees planted by the GGCP. The other socioeconomic variables such as Education (percent of population with a bachelor's degree) and Percent Nonwhite are both significant at 90% confidence for the model of Avoided Runoff. The coefficients indicate that ecosystem services from the newly planted trees are significantly higher in census block groups with higher nonwhite populations and higher educational attainment. Interestingly, there was no significant difference in Percent Renter or Percent Impervious Surface in any of the models. This might be because the planting zones are chosen based on their high renter populations and lack of tree canopy cover.

	Avoided Runoff						Pollution					
	B (unstandardized)	Std. Error	Beta (standardized)	t-statistic	p-value		B (unstandardized)	Std. Error	Beta (standardized)	t-statistic	p-value	
Education	0.371	0.207	0.429	1.792	0.086	*	0.486	0.278	0.495	1.749	0.094	*
Percent Nonwhite	0.280	0.146	0.459	1.916	0.068	*	0.417	0.196	0.602	2.124	0.045	**
Percent Renter	-0.079	0.088	-0.205	-0.904	0.376		-0.149	0.118	-0.341	-1.268	0.218	
Median Household Income	0.000	0.000	-0.505	-2.375	0.026	**	0.000	0.000	-0.614	-2.441	0.023	**
Percent Canopy	60.167	13.738	0.703	4.380	0.000	***	47.244	18.435	0.486	2.563	0.017	**
Percent Impervious	3.855	8.633	0.100	0.447	0.659		-15.575	11.585	-0.357	-1.344	0.192	
Fall River	-20.425	5.509	-1.303	-3.707	0.001	***	-9.853	7.393	-0.554	-1.333	0.196	
	Carbon Sequestration						**Energy**					
	B (unstandardized)	Std. Error	Beta (standardized)	t-statistic	p-value		B (unstandardized)	Std. Error	Beta (standardized)	t-statistic	p-value	
Education	0.284	0.159	0.472	1.791	0.086	*	2.234	1.737	0.369	1.286	0.211	
Percent Nonwhite	0.239	0.112	0.563	2.135	0.044	**	2.334	1.227	0.546	1.902	0.070	*
Percent Renter	-0.083	0.067	-0.309	-1.234	0.230		-0.531	0.734	-0.197	-0.724	0.477	
Median Household Income	0.000	0.000	-0.635	-2.714	0.012	**	-0.002	0.001	-0.564	-2.213	0.037	**
Percent Canopy	37.958	10.513	0.637	3.611	0.001	***	348.198	115.162	0.581	3.024	0.006	***
Percent Impervious	-2.529	6.606	-0.094	-0.383	0.705		-48.325	72.372	-0.179	-0.668	0.511	
Fall River	-11.753	4.216	-1.078	-2.788	0.010	**	-91.978	46.186	-0.839	-1.991	0.058	*

Table 6: OLS regression results for each model of ecosystem services. The coefficients, standard errors, standardized coefficients, t-statistics and p-values are included. Each model found ecosystem services ($) to be significantly higher in census block groups with higher tree canopy cover while none of the models indicated significant differences for percent renter population or percent impervious surface.

The trends of increased ecosystem services hold across other models such as energy savings, carbon sequestration and pollution reduction, but these models have less explanatory power (Table 7). For the energy model, the low R-squared is probably because the level of energy savings provided by urban tree canopy cover can vary based on multiple factors not included in this study, such as tree species, age, general health, size, tree orientation, and proximity to buildings (Nowak and Dwyer 2007, Hauer et al. 2015). The energy savings provided by tree shade are not linear with distance, as trees within a maximum distance provide more direct building shade (Simpson 2002).

Model	Adjusted R^2	p-value
Carbon Sequestration	0.350	0.014
Avoided Runoff	0.463	0.002
Pollution	0.249	0.052
Energy	0.229	0.065

Table 7: OLS regression results for each ecosystem service modeled in i-Tree Eco. Ecosystem services were aggregated to the block group level where they were compared to the same independent socioeconomic variables of education (percent of population with a Bachelor's degree), percent nonwhite, percent renter, and median household income as well as the biophysical variables percent canopy cover and percent impervious surface. The variable Fall River was included to determine if there was a difference between Fall River and Chicopee.

Discussion

The goal of this research was to investigate the value and distribution of ecosystem services provided by the 824 and 1,223 trees planted by the GGCP in Chicopee and Fall River using i-Tree Eco. Results show these juvenile trees currently providing economic benefits of $775 and $1,520 per year in Chicopee and Fall River (2018). Trees modeled to mature conditions considering predicted mortality rates, show increased savings of $2,911 (375%) and $5,840 (384%) in Chicopee and Fall River (2050). The most cost-effective ecosystem service is energy savings, providing 70% to 85% of total annual savings provided by GGCP trees in each city and year of analysis. The current and projected monetary savings will be especially important to the residents of the environmental justice neighborhoods where the tree planting took place and is the main purpose of the GGCP. In Massachusetts, residents pay a state average energy bill of approximately $94 per month, and $1,128 annually, ranking the state below the national average energy bill of $107 per month (Electricity Local, 2019).

Areas with higher numbers of planted trees in 2018 benefit from higher savings and services provided in 2050. This may be due to the ability of a large initial tree population to resist the negative impact of a high tree mortality (Roman, 2014). However, in census blocks with high energy benefits there was a wide disparity of dollars per tree per building. When the right tree species (large shade trees) are planted in the right place (distance and orientation to a building), they can double the amount of energy benefits (Table 5). The amount of energy benefits per tree drops in new developments where small evergreen trees are planted along the borders of yards. While this is beneficial in the summer, recent research by Erker and Townsend (2019) has shown energy saving benefit expectations may not be appropriate in cold weather cities due to direct building shade by trees during the winter. The orientation of trees to buildings can also affect the services provided, as trees planted to the east and west provide higher energy savings due to higher exposure to sunlight, while trees planted to the south can block winter sunlight and decrease energy savings (Hwang *et al.* 2015).

Based on these results, at least two to three mature shade trees planted in the right place per acre were necessary to observe the highest values of energy savings. This research recommends that approximately three to ten trees be initially planted per acre to achieve a robust, mature cohort. The GGCP planting goal falls within this range (5 trees/acre) and is above the lowest necessary number of trees for observable change although in practice the planting is varied due to site circumstances (i.e., resident perceptions, resident desire, available planting area). The range in the number of recommended trees planted by i-Tree Eco is due to the importance of tree health in determining the rate of mortality. Increased stewardship would decrease the need to plant as many as ten trees per acre. Regarding the spatial autocorrelation of ecosystem services within the DCR planting zones, residential areas and housing authority complexes containing high numbers of GGCP trees showed the highest value of savings. The concentration of trees in certain census block groups may be due to differences in planting presence by the GGCP, information flow between residents and organizations, or ease of planting permissions granted.

Based on the spatial analysis of services, the GGCP is succeeding at providing significantly (99% confidence) more ecosystem services such as avoided runoff to census block groups with lower income and larger nonwhite populations (Table 6). However, there was a significant relationship between existing tree canopy cover and ecosystem services provided, indicating that communities with high tree canopy cover may have more plantable space than communities with low existing tree canopy cover. This may be due to building density or the level of impervious surface. For example, impervious surface in a sidewalk strip needs to be broken up so that trees may be planted there but GGCP foresters do not have the necessary equipment to do this. In this situation they depend on the municipality for help, which may be unwilling or unable to provide. Therefore, more trees are planted in areas where the 'work' is easier (Locke and Grove, 2016).

The percentage of impervious surface was not a significant factor in any of the models, likely due to the high percentages of impervious surface throughout the planting zones. Increases in urban temperature are strongly linked to the buildup of impervious surfaces, while the temperature and energy benefits provided by increased tree cover and shading are especially important to disruption of UHI effects (Middle *et al.* 2015, Bodnaruk *et al.* 2017).

There are a number of reasons to believe that the modeled ecosystem services in 2050 are an extremely conservative estimation of the total value urban trees provide. First, the ecosystem services were calculated in relation to the nearest building within 60 feet. The

GGCP trees were located in high density residential neighborhoods so it is reasonable to assume each tree provides services to multiple buildings and these savings were not modeled in this study. Second, ecosystem services are only a fraction of the total benefits provided by trees. Previous research shows that a Red Maple planted on the west side of a building would provide $97.15 total benefits of which $16.99 (17%) are energy savings (McPherson et al., 2006). Finally, as over 80% of juvenile trees surveyed were deemed to be very healthy after two to three years (vigor 1 and 2), it is not unreasonable to expect lower mortality after the establishment phase (Hilbert et al., 2019). The modeled estimates of future tree mortality do not consider tree stewardship and its associated lower mortality rate (Roman *et al.*, 2015), which has implications for calculating benefits from tree planting programs that stress tree stewardship and care.

Additionally, this research does not include the possibility of the GGCP planting additional trees as part of the model available within i-Tree Eco. The impact of tree mortality significantly underestimates the potential services provided from a manually sustained tree population. When mortality is not considered, the projected savings increase by three times the value, generating thousands of dollars more savings in ecosystem services as modeled in 2050 (Table 4). This difference shows the importance of maintaining active tree planting and tree care over time, as it ensures increasing levels of services provided in perpetuity by alleviating the impact of high urban tree mortality (Roman, 2014). Monitoring and maintaining healthy and functional urban tree cover and green spaces are priorities for urban planners and governing organizations to effectively model ecosystem services (Roman, 2014; Lee *et al.*, 2015).

<u>Conclusion</u>

The juvenile tree cohorts planted by the GGCP are providing important ecosystem services within their respective planting zones and are projected to increase savings provided to residents and cities as the trees mature. Energy savings provided the largest amount of ecosystem services in both contemporary juvenile trees and projected savings in 2050. Ecosystem benefits were clustered in Fall River due to the reliance on relationships with the city parks, new housing developments, and housing authorities. However, in Chicopee ecosystem benefits were dispersed throughout the planting area on residential property. Tree planting can achieve larger ecosystem services by planting in the right places and through stewardship of juvenile trees to reduce tree morality. Despite this variability, it is recommended that tree planting programs aim to plant three to ten trees per acre to achieve sustainable ecosystem benefits. Stewardship can reduce tree mortality which decreases the number of trees need to plant per acre. The spatial analysis shows that ecosystem benefits are being provided to historically marginalized and low-income communities.

This research exemplifies the effectiveness of cross-platform integration between ecosystem service modeling in i-Tree Eco with the spatial analysis in GIS. This methodology of spatial modeling of ecosystem services encourages the future use of i-Tree Eco analysis by the DCR, GGCP, and other tree planting programs to monitor and manage the benefits provided by urban forests at different spatial scales.

Future research conducted in the investigation of ecosystem service value and distribution provided by GGCP trees could include closer examination of local tree mortality rates. More accurate predictions of mortality rate estimates could be calculated based on known survivorship rates by conducting repeated tree surveys on GGCP trees. Additionally, repeated health surveys within DCR planting zones would allow for the exploration of any spatial or temporal patterns in the survivorship and vigor of planted trees. Finally, more research is needed to understand the relationships and processes that allow the tree planting program to succeed at increasing ecosystem services in potential environmental justice communities.

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