Modeling 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 local effects of urban heat islands and provides ecosystem services such as energy savings through direct and indirect shading, pollution removal, storm runoff control, and carbon sequestration. This study addresses the gap in research regarding the value of energy savings provided by juvenile trees, how that value changes considering predicted tree growth and mortality by 2050, as well as the spatial distribution of ecosystem services. 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 from 2014 through 2015 by the Greening the Gateway Cities Program (GGCP) in Chicopee and Fall River, MA. Juvenile trees planted by the DCR provided $775 and $1,512 (2018) in annual ecosystem service savings in Chicopee and Fall River while GGCP Trees modeled to mature conditions show exponentially increased total annual savings of $2,294 and $4,401 in Chicopee and Fall River (2050). A minimum of two to three trees per acre are required to reach maturity in ecosystem provisioning. Results of this study reinforce the importance of tree survivorship on sustaining the urban tree canopy to provide ecosystem services.

Keywords: Greening the Gateway Cities Program, Urban Heat Island, i-Tree Eco, urban forests, ecosystem services

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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 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). From this perspective, urban forests provide more value to a city in services than in raw material (Lazaros *et al*., 2010). While previous research has been conducted to estimate the generalized and holistic value of urban forest benefits (Martin *et al.* 2011, Endreny *et al.* 2017), this study explores the spatial distribution of specific ecosystem services from service providing units.

Within a sustainable urban environment, trees are one of the most important components to the wellbeing of both human residents and natural systems (Nowak *et al*., 2001; Meineke *et al.,* 2016). The benefits provided by urban forests are dominantly seen in energy savings through canopy shading and temperature control via evapotranspiration (Lee *et al.,* 2018), but also 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, 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).

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 such as population density, imperviousness, and building intensity also greatly increasing (Nowak and Walton, 2005; Gao and O-Neill, 2020). The land use change associated with developed urban land is predominately converting forested land to impervious surfaces (roadways, sidewalks, rooftops) that negatively impact the natural landscape through modifications to surface reflectance, evapotranspiration, increased surface temperature levels, as well as increasing urban air pollution and the impacts of stormwater runoff (Tu *et al.,* 2007; Seto *et al.,* 2011; Nowak and Greenfield, 2018). Research by Nowak and Greenfield (2018) found significant declines in tree cover in urban areas across the US, an approximately 1% decrease from 2009 to 2014, and a decrease of 1.3% in Massachusetts over the same time frame.

Urban air temperatures in the USA were found to be to 9-15 degrees Fahrenheit higher than surrounding rural areas, as urban infrastructure absorbs heat and creates an urban heat island (UHI) (Hardin and Jensen, 2007). As a result, affected urban residents can be found to experience higher electricity usage of an approximate 2% per degree Fahrenheit temperature increase (McPherson et al., 1995). For context, 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). Increased activity in energy consumption levels, with higher levels of energy usage and heat emissions driving higher urban particulate and carbon dioxide pollution levels, feed a positive feedback loop into the warming effect of the UHI (Kikegawa *et al.,* 2006).

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 (About the Gateway Cities n.d.). 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's average (Commonwealth of Massachusetts, 2016). The Greening the Gateway Cities Program (GGCP) is managed by the Department of Conservation and Recreation (DCR), with funding provided from the Department of Energy Resources (DOER) and has a partnership with the 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 achieve the GGCP goals of increased canopy coverage and utility savings, 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. To date, little research has been conducted regarding the different value of urban forests between juvenile and predicted mature urban forest conditions (considering growth and mortality) and the spatial distribution of ecosystem services provided (Andersson et al., 2015), creating doubt of the effectiveness of juvenile trees to provide significant benefits to residents. Additionally, the GGCP has no information regarding the impacts of juvenile urban trees on energy usage and utility costs. By modeling the current and future ecosystem services provided by GGCP trees and how ecosystem services are distributed using the case sites of Chicopee and Fall River, this study investigates the impact of the GGCP through the energy savings and other ecological savings provided by urban trees to urban residents and cities. The research questions addressed in this study are:

1. What is the value provided through juvenile tree ecosystem services and what are the forecast ecosystem services provided in the year 2050?
2. How does this value change from 2018, considering predicted tree cohort mortality (68%) by the year of 2050?
    a. The year 2050 was chosen for future condition modeling to allow for tree growth and maturity across the juvenile GGCP trees.
    b. The predicted tree mortality by i-Tree Eco for Chicopee and Fall River in 2050 is approximately 68%.
3. How are the services distributed within GGCP planting zones in Chicopee and Fall River, MA?

1.1 Economic Valuation

This study uses i-Tree Eco software to model the current (2018) and future (2050) magnitude and extent of these ecosystem services provided by juvenile trees planted by the Greening the Gateway City Program within the Massachusetts cities of Chicopee and Fall River. 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 (i-Tree Eco n.d.).

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 (I-Tree Eco, n.d.).

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, modeling the ecosystem services of campus trees for pollution removal, carbon storage, and carbon sequestration, 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).

Study Area

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 mainly encompass environmental justice neighborhoods, which are defined in Massachusetts as a block group with an annual median household income 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). The planting zones were chosen because they are predominately high in renter population and low in existing urban tree canopy.

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 the western half of 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 planting zone (3.44 km^2) created by the GGCP is located along the western region of the city (See Figure 1) alongside the Connecticut River. This planting zone area is currently 20.6% canopy cover, which is lower than the city-wide percentage of 34.8%. In terms of impervious cover (roadways, parking lots, sidewalks, and other asphalt surfaces) the Chicopee planting zone is 47% impervious cover, compared to the city-wide percentage of 29.9%.

The city of 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 (See Figure 1), split into two areas to the east and west of Cook Pond. This planting zone area is currently 23.8% canopy cover, compared to the city-wide percentage of 55.9%. This large difference in percentage tree canopy is due to the difference between 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 in Fall River is 44.7% impervious cover, while the city-wide percentage is 18.5%.

The GGCP prioritizes private resident requests for juvenile trees, as well as conducting street and public tree plantings. The DCR conducts tree planting in spring and fall, engaging local community members in planting efforts, employing a crew of laborers and forestry assistants under the directive of the DCR (Berger et al., 2019). The tree plantings are conducted in coordination with city and community organizations, involving groups such as the Valley Opportunity Council in Chicopee and the Fall River Street Tree Planting Program in Fall River to spread information regarding the GGCP and in coordinating juvenile tree management efforts.

Data Description and Methods

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 surveyed GGCP trees in Chicopee and Fall River, MA. Clark	2018
Building Structures (2-D)	2-dimensional roof outlines for all buildings larger than 150 sq. ft. Mass.gov	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. New Bedford-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. Mass.gov	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. Mass.gov	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 block groups within Chicopee and Fall River, MA.	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, 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 undergraduates who were trained by the first author. These surveys were not inclusive of the entire population of DCR 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 percentage 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 random selection of surviving trees based on default mortality estimates projected by the i-Tree Eco Forecast module for 2050 (261 trees in Chicopee and 385 trees in Fall River, 68.3% and 68.5% mortality respectively).

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.

Tree-Building Interactions

To estimate energy savings from building heating and 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.

Environmental and Socioeconomic Factors

The canopy cover and impervious surface cover data from MassGIS (1993) 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 (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 Census data was percent of the population that is nonwhite and renter population because these criteria were used by the GGCP to create tree planting zones in environmental justice neighborhoods and 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, canopy condition, and native status, providing 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 to rates (i-Tree Eco n.d.). Using this module, estimates of annual average DBH growth and total mortality rates were produced from the 2018 i-Tree Eco projects for Chicopee and Fall River for projected tree conditions in the year 2050. Given the thirty-two-year time span between 2018 and 2050, considerable tree growth and value differences in ecosystem services can be modeled. The defined annual mortality rate for the Forecast module was set to the default mortality rates in i-Tree Eco based on the percent dieback of tree condition (0-49% dieback: 3.0% annual mortality, sick trees with 50-74% dieback: 13.1% annual mortality, and dying trees with 75-99% dieback: 50.0% annual mortality). The predicted tree cohort mortality for 2050 in Chicopee and Fall River was modeled by i-Tree Eco at 68.3% and 68.5%, respectively. The Forecast module allows for the inclusion of new tree plantings, which was not included for modeling in this study. The projected DBH growth (5.16 inches in Chicopee, 6.99 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. The process for modeling the projected ecosystem services in 2050 was identical to that of juvenile tree ecosystem services. Following the completion of the i-Tree Eco analysis, 2050 savings were limited to those provided by surviving trees based on tree mortality predictions.

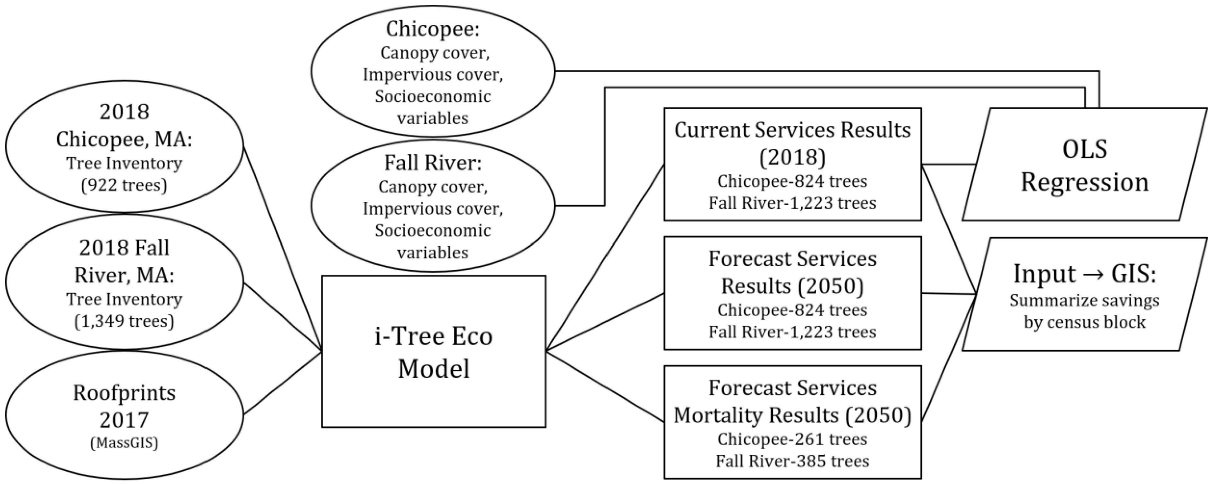

Figure 2: Flowchart highlighting main data inputs and steps of analysis.

i-Tree Eco Spatial Analysis

The i-Tree Eco results for 2018 and 2050 ecosystem services explicitly outline the savings corresponding to the ecosystem services provided. Each result of ecosystem service savings (energy savings, pollution removal, avoided runoff, gross carbon sequestration) for both current and future condition models was joined by tree ID to the DCR tree locations within a GIS. The ecosystem service savings were aggregated by census blocks to gauge the spatial distribution of services provided by spatially joining the 2018 and 2050 savings to blocks within the DCR tree planting zones. To gauge the number of trees necessary to the most amount of energy savings, the average number of trees within the five census blocks receiving the highest amounts of energy savings was calculated.

An Ordinary Least Squares (OLS) regression tested the dependence of census block group energy, pollution, avoided runoff and carbon sequestration services 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. Each regression included the 31 census block groups combined from Chicopee and Fall River. This was necessary as the planting zones each only had 15 census block groups which limited the amount of statistical analysis. While different cities, Chicopee and Fall River are both defined as Gateway Cities by the commonwealth of Massachusetts and their planting zones were chosen based on the lack of tree canopy cover and high renter populations making 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 $1,519 (296%) in Chicopee and $2,889 (291%) in Fall River. To gauge the average conditions within census blocks with the highest energy savings in both cities, the average number trees of planted and energy savings accrued under current and future conditions was explored. In Chicopee, the five census blocks providing the highest energy savings in 2018 contained an average of 23 trees each collectively producing $27 in annual energy savings per census block. Considering tree mortality, these numbers decrease to an average of 15 trees producing $126 (467% increase) in annual energy savings per census block in 2050. In Fall River, the five census blocks providing the highest energy savings in 2018 contained an average of 71 trees each collectively producing $51 in annual energy savings per block. Considering tree mortality, these numbers decrease to an average of 22 trees producing $203 (369% increase) in annual energy savings per block in 2050.

City	Year (# trees)	Energy via cooling (Kwh/yr | $/year)		Pollution (oz/year | $/year)		Avoided runoff (ft^3/yr | $/year)		Gross Carbon Sequestration (lb/yr | $/year)		Total $/year
Chicopee	2018 (824)	3,638	544	505.1	61.74	1,578.9	105.54	745	64	775
	2050 (824)	40,342	6,030	2594.9	335.12	8,189.7	547.47	6,131.1	523.01	7,436
	2050 (261)	12,310	1,840	894.3	115.22	2,534.2	169.44	1,974.5	168.33	2,294
Fall River	2018 (1,223)	6,987	1,044	1,087.1	215.5	2,060.7	137.75	1,344	115	1,512
	2050 (1,223)	71,335	10,663	7,371.8	1,634.74	15,237.5	1,018.42	13,021	1,111	14,427
	2050 (385)	21,477	3,210	4,839.1	323.45	2,343.1	519.17	4,081	348	4,401

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, 2050 with mortality).

The models of current ecosystem services show the 824 trees in Chicopee and 1,223 trees in Fall River provide $775 and $1,512 respectively in total annual savings by juvenile GGCP trees. 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 current savings. The aggregation of savings within census blocks show the blocks containing the most planted trees by the DCR receive highest value in energy savings and other ecosystem services. Visual spatial analysis in both cities show these blocks to primarily contain residential areas or housing authority complexes (see Figures 3 and 4). The Sunset Hill housing authority in Fall River (see Figure 5), which overlaps five census blocks containing ninety-one juvenile GGCP trees planted around the housing authority which cumulatively provide $120 in annual energy savings in 2018.

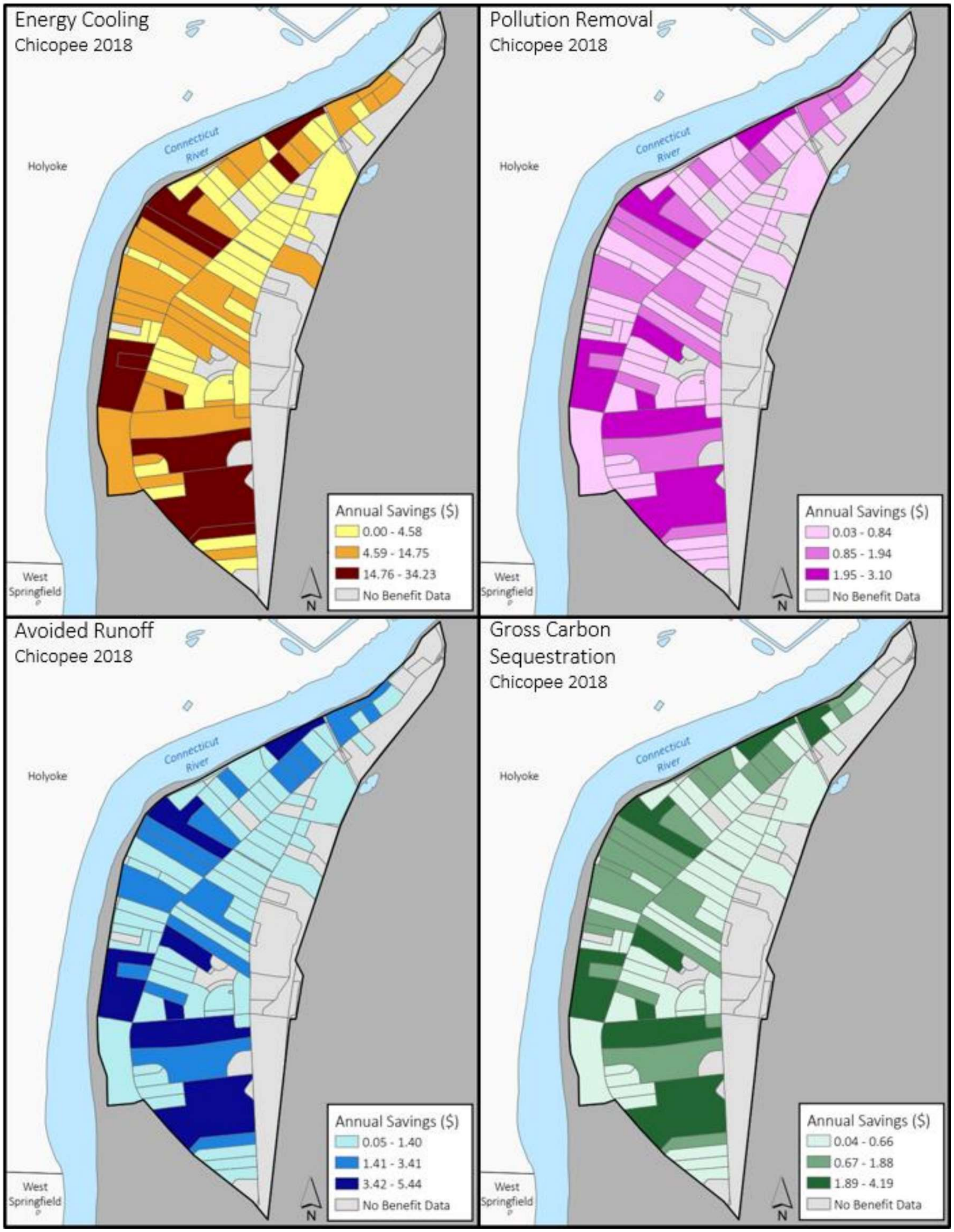

Figure 3: Distribution of ecosystem services (energy savings, pollution removal, avoided storm runoff, gross carbon sequestration) provided by the measured GGCP trees summarized

by census block within the DCR Chicopee planting zone in the year of 2018. The sum value of all monetary savings is $775 annually.

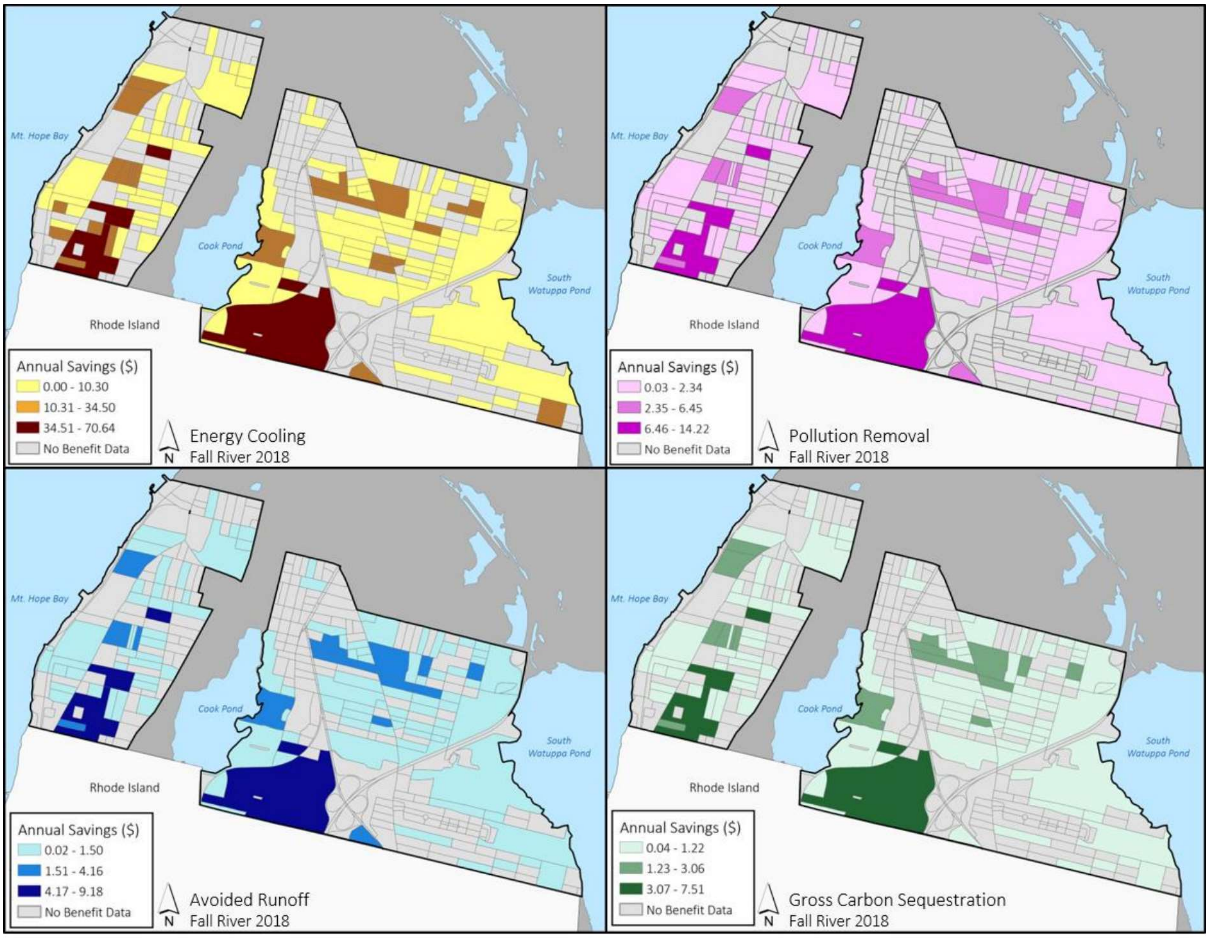

Figure 4: Distribution of a suite of ecosystem services (energy savings, pollution removal, avoided storm runoff, gross carbon sequestration) provided by the measured GGCP trees summarized by census block within the DCR Fall River planting zones in the year of 2018. The sum of all monetary savings is $1,512 annually. The pinned location in the energy cooling map designates the location of the Sunset Hill housing authority examined in this study.

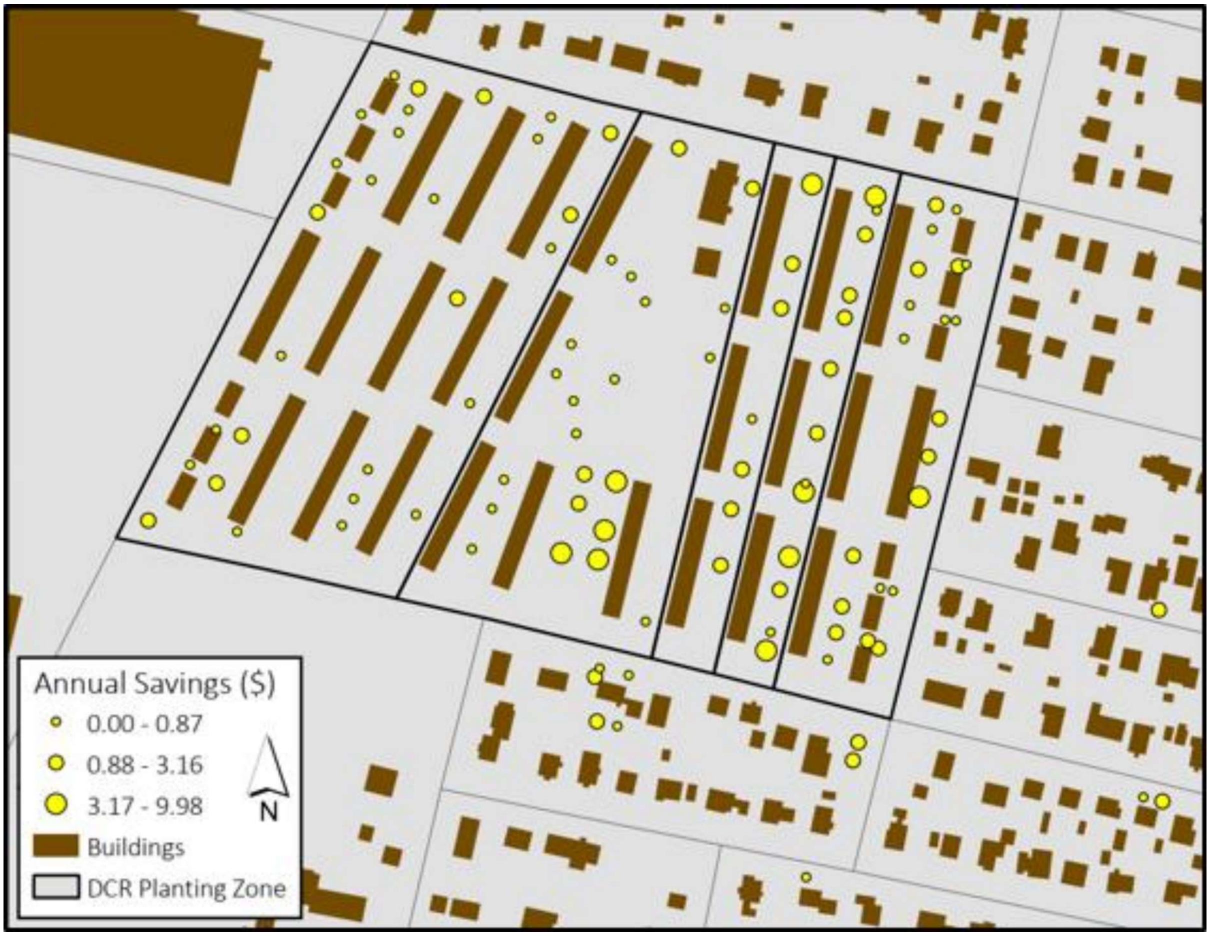

Figure 5: Sunset Hill housing authority located in the western planting zone within Fall River. This housing authority is made up of five census blocks (black outlines) and contains ninety-one GGCP trees that were assessed to be currently providing $120 collectively in annual energy savings

The projected models of future ecosystem services show the randomly selected surviving 261 Chicopee and 385 Fall River GGCP trees to provide annual savings of $2,294 and $4,401 respectively in combined services. Of all the ecosystem services modeled in the study, energy savings show the greatest growth in value between 2018 and 2050 from $544 to $1840 (an increase of 338% to 80% of total savings) in Chicopee and $1,044 to $3,210 (an increase of 307% to 72% of total savings) in Fall River. Considering the loss of approximately 68% of initial trees due to modeled random mortality in both cities, 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 6 and 7). The Sunset Hill housing authority highlighted in figure 5 shows a 66% decrease in GGCP tree numbers from ninety-one to thirty-one between 2018 and 2050 and shows an increase in the combined annual energy savings from $120 to $316 (263%) (see Figure 8).

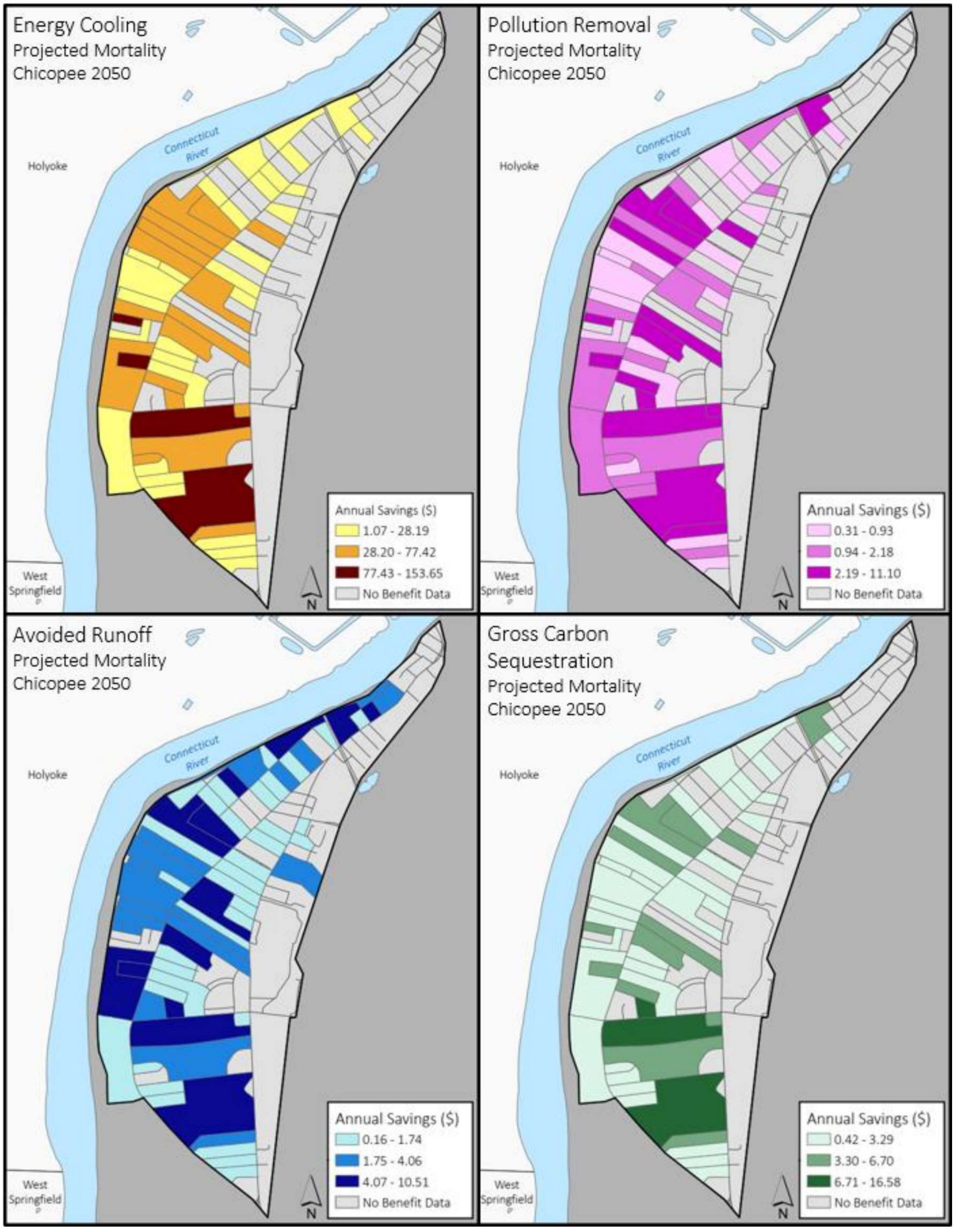

Figure 6: Distribution of a suite of ecosystem services (energy savings, pollution removal, avoided storm runoff, gross carbon sequestration) provided by the measured GGCP trees summarized by census block within the DCR Fall River planting zones in the year of 2050. The sum value of all monetary savings is $2,294 annually.

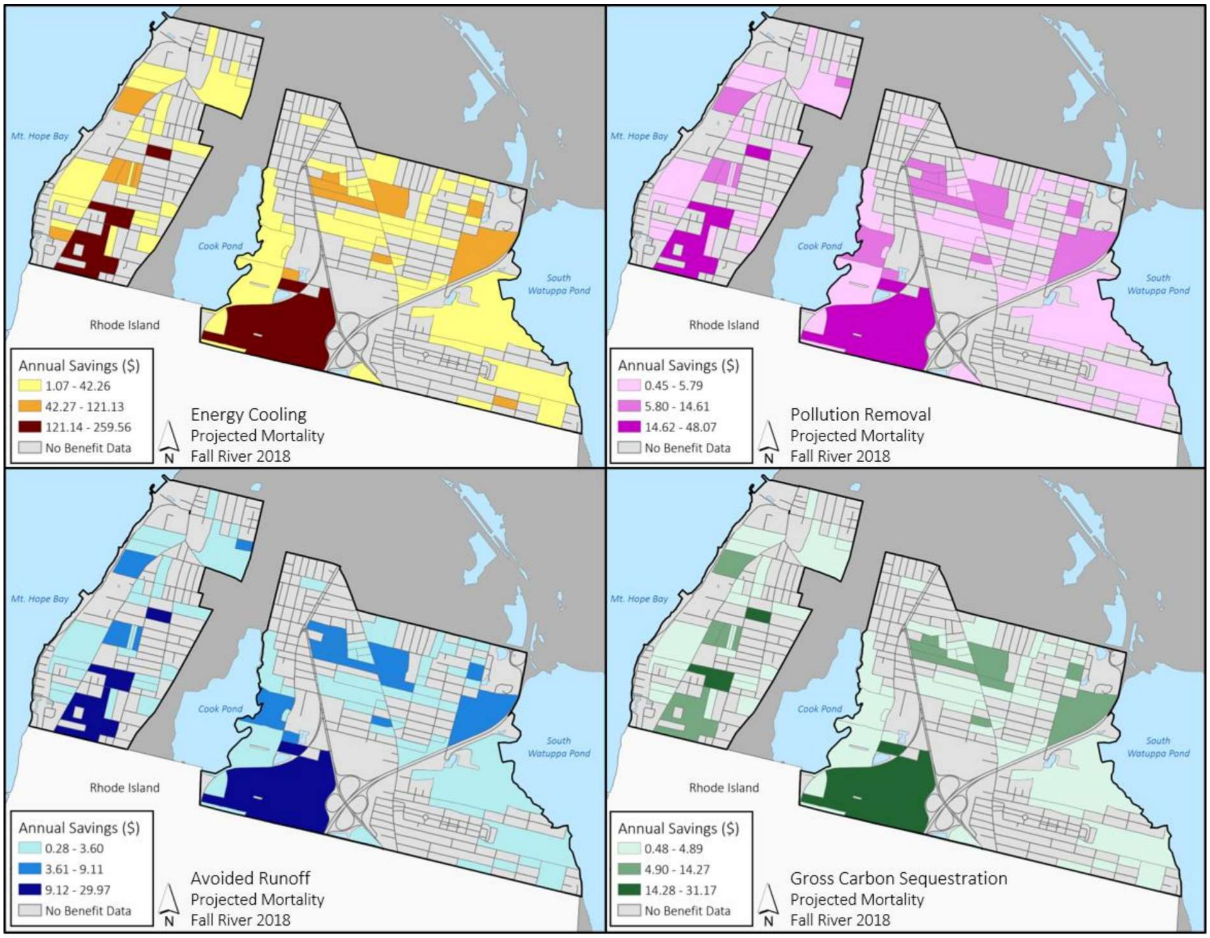

Figure 7: Distribution of a suite of ecosystem services (energy savings, pollution removal, avoided storm runoff, gross carbon sequestration) provided by the measured GGCP trees summarized by census block within the DCR Fall River planting zones in the year of 2050. The sum value of all monetary savings is $4,401 annually.

Figure 8: 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-one GGCP trees that were assessed to be currently providing $316 collectively in annual energy savings.

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 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 DCR. 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.

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 DCR in Chicopee and Fall River using i-Tree Eco. Ecosystem services were analyzed for current (2018) and future (2050) conditions, showing which services provide the highest annual savings provided and how those savings are distributed within the study areas. Results show juvenile trees planted by the DCR currently providing economic benefits of $775 and $1,512 per year in Chicopee and Fall River (2018). Trees modeled to mature conditions considering predicted mortality rates show exponentially increased savings of $2,294 (296%) and $4,401 (291%) in Chicopee and Fall River (2050). The most cost-effective ecosystem service is energy savings, providing 70% to 80% of total annual savings provided by GGCP trees in each city and year of analysis. Additionally, energy savings experienced the greatest value growth over the thirty-two year period of analysis, equaling increases of 338% and 307% in Chicopee and Fall River, respectively.

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). Based on these results, at least two to three mature trees per acre were necessary to observe the highest values of energy savings. This research, based on default i-Tree Eco mortality rates, recommends that approximately three to ten trees be initially planted per acre to achieve a robust mature cohort. 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 DCR, information flow between residents and organizations, or ease of planting permissions granted.

Based on the spatial analysis of services, the DCR is 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, these are also communities with higher existing tree canopy and higher educational attainment which indicates that it is difficult to find available planting in communities with very low existing tree canopy cover. These trends hold across all the models for other ecosystem services such as energy savings, carbon sequestration and pollution reduction but these models have less explanatory power (Table 5).

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 5: 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.

For the energy model, the low R-squared is probably because the level of energy savings provided by urban tree 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). 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). Tree location relative to the urban environment can be influential on the value of ecosystem services provided by trees. Nowak and Dwyer (2007) found the combined services of shade and wind reduction by trees oriented properly around a house to reduce energy costs by 20%-25% compared to the same house without nearby trees. These findings suggest that careful planning of planting locations is critical for energy savings and could be space for tree planting programs to offer expertise.

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).

The tree surveys in Chicopee and Fall River identified higher percent juvenile survivorship, 91.7%, than the model in i-Tree Eco, 68% (Table 3). Due to the limited time frame of these findings, the default mortality rates within the Forecast module of i-Tree Eco was relied on throughout this analysis. Considering the conservative prediction of tree mortality rates by i-Tree Eco compared to survivorship measured in the tree survey of Chicopee and Fall River, the estimated value of ecosystem services show in this research should be considered as approximate underestimates of the potential value of GGCP trees. 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 higher survivorship over time (Table 3). The predicted estimates of future tree mortality do not take tree stewardship and the expected lower mortality rate into account (Roman *et al.* 2015), which has implications for calculating benefits from tree planting programs that stress stewardship and care.

Additionally, as this research does not include the possibility of the DCR planting additional trees in 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).

Conclusion

The juvenile tree cohorts planted by the DCR for 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. The largest single ecosystem service provided is energy savings which were seen in both contemporary juvenile trees and projected savings in 2050. The spatial analysis shows that it is possible to plant high densities of trees, two to three trees per acre) in planting zones chosen for their high renter populations and high percentage of impervious surface and that the most benefits occur in census block groups with higher existing tree canopy. The projections are influenced by factors that are difficult to track and model (planting expertise, stewardship, etc.) but have a high impact on survivorship, and in this case, lead to conservative estimations. This study reinforces past ecosystem services research while highlighting how values change when considering predicted tree growth and mortality across time, as well as the spatial distribution of ecological savings.

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.

Future research conducted in the investigation of ecosystem service value and distribution provided by GGCP trees could include closer examination into the influence tree mortality. 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.

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