The International Undergraduate Journal For Service-Learning, Leadership, and Social Change

Volume 10 | Issue 1 Article 4

November 2020

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Ralph Moran
University of the District of Columbia

Turner Allison
University of the District of Columbia

Brandi Bell
University of the District of Columbia

Eric Brown
University of the District of Columbia

Monet Dews
University of the District of Columbia

See next page for additional authors

Recommended Citation

Moran, Ralph; Allison, Turner; Bell, Brandi; Brown, Eric; Dews, Monet; Foster, Sheena; Kidane, Lydia; Olukani, Zachary; Phillips, Tivon; Reyes-Mendez, Llaquelin; Roy, Natasha; Schottner, Lilla; Stancell, Kenneth; Watson, Jaheen; and Wright, Tiesha (2020) "Urban Forest and the Tree Canopy: A Pathway to Climate Resilience," *The International Undergraduate Journal For Service-Learning, Leadership, and Social Change*: Vol. 10: Iss. 1, p. 10-25.
Available at: https://opus.govst.edu/iujsl/vol10/iss1/4

Urban Forest and the Tree Canopy: A Pathway to Climate Resilience

Authors

Ralph Moran, Turner Allison, Brandi Bell, Eric Brown, Monet Dews, Sheena Foster, Lydia Kidane, Zachary Olukani, Tivon Phillips, Llaquelin Reyes-Mendez, Natasha Roy, Lilla Schottner, Kenneth Stancell, Jaheen Watson, and Tiesha Wright

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Abstract

Background: Urban ecosystems face many environmental, infrastructure, and social systems challenges. Urban forest plays an important role in urban ecology but continue to face many direct and indirect threats. Research indicates that climate change, insects, disease, and urbanization are the major causes of urban forest decline. Tree canopies play a major role in ecosystem services, providing the advantages of a natural, cost-effective system of green infrastructure, removal of air and water pollutants, modulation of energy use, and improvement

Ralph Moran is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Turner Allison is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Brandi Bell is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Eric Brown is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Monet Dews is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Sheena Foster is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Lydia Kidane is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Zachary Olukanni is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Tivon Phillips is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Llaquelin Reyes-Mendez is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Natasha Roy is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Lilla Schottner is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Kenneth Stancell is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Jahneen Watson is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.
Tieshia Wright is a graduating senior in Urban Sustainability in the College of Agriculture Urban Sustainability and Environmental Sciences at the University of the District of Columbia.

in water quality. These services increase climate resilience. *Purpose:* The purpose of this service-learning project was to gain a better understanding of ecosystem service benefits from trees in Washington, DC and whether these benefits facilitated Washington, DC being more climate resilient. Our aim was two-folds, to describe the monetary value of carbon sequestration from trees in DC, and to assist in identifying tree species in local neighborhoods. *Methods:* We collected tree canopy data using the i-Tree tool designed to provide an estimate of ecosystem service benefits and the TreeSnap tool designed to allow citizen scientists to make observations of trees in local communities and provide pictorial documents to scientists who catalog tree species. *Results:* Our results showed on average carbon sequestered by trees valued at $10,196,999 million dollars and carbon stored in trees was valued at $256,084,907 million dollars. Our other results showed the variety of tree species such as the Japanese Cherry Tree, have large bases, are plentiful throughout Washington, DC, and capable of storing large amounts of carbon. *Conclusion:* Washington, DC has increased the number of trees planted annually, which we believe creates a pathway to a climate-resilient city. As urban sustainability majors, this project enlightened our understanding of urban sustainability and climate resilience.

Introduction

Recently, the Environmental Science Senior Project class participated in the development of an urban forest tree canopy workshop held in Washington, DC on March 10, 2020. While the conference in and of itself was interesting, we learned much about how urban forest and ecosystem services are closely linked, which surprised us. Our class, consisted of 15 students, decided to investigate the concepts of urban forest and tree canopies to determine how this could be a pathway to climate resilience. Our meaning of climate resilience is the ability of our city to bounce back. Most of the students in this course are residents of the Washington, DC metropolitan area where trees are plentiful in number and variety.

At the outset of our semester, we learned that our service-learning involved working with university partner, Casey Trees, as citizen scientists to conduct evaluations and measurements of trees in local neighborhoods. Our opportunity to engage in this project was cut short following a "stay at home" order from Washington, DC's mayor as a safety measure in response to the COVID-19 pandemic. As students we had to comply; nevertheless, our professor found an innovative way for us to continue our service-learning project of tree canopy observations by using two internet-based tools: i-Tree (2006) and TreeSnap (2020). These tools allowed us to collect data from the trees in our neighborhoods, upload our observations to the tools' websites, and use the information in our final research paper to demonstrate the value of trees and the variety of tree species that provide ecosystem services to our local community.

With approval from our instructor and an innovative way to collect data, our class made this study the service-learning component of our senior class project. The purpose of our service-learning project was to gain a better understanding of the ecosystem service benefits from trees in Washington, DC and whether these benefits facilitated our city being more climate resilient. Our aim was two-folds, to determine the monetary value of carbon sequestration in DC, and to assist in identifying tree species in our local neighborhoods. This paper will evaluate urban forest and the tree canopies through the lens of ecosystem services, human health, mitigation strategies that reduces the heat island effect, threats to urban forests, and policies related to urban forests. We begin our discussion by defining urban forest and the role of tree canopies.

Background

There is lack of clarity on the definition of urban forest; however, we will rely on Lin et al.'s definition, which states that an "urban forest contains, trees, shrubs, lawns and pervious soil in urban areas" (2019, p. 2). These authors further noted that a better understanding is to see urban forest as two distinct terms: "urban" and "forest." This suggests that urban systems are multifactorial in that they include environmental functionality, social equity, and economic viability (Lin et al., 2019).

Tree canopies play a major role in urban forest and ecosystem services providing the advantage of a natural, cost-effective system of green infrastructure. Trees capture air and water pollutants as they provide shade, habitat, and inviting places for social gatherings. These qualities have significant value and have been quantified to capture that value (Turner-Skoff & Cavender, 2019). From an ecosystem services perspective, urban forests reveal that the very existence of the character within and near urban areas provide physical, mental, health benefits of residents (Watkins & Gerrish, 2018).

Ecosystem Services

Ecosystem services, as proposed by Boyd and Banzhaf (2007), are duties, organizations, processes, or functions that benefit humans, either directly or indirectly. Ecosystem services are characterized as public-private goods that are openly accessible and that directly impact the health and well-being of local citizens in communities. The role of tree canopies in ecosystem services contribute significantly to air purification and soil remediation. Ecosystem services play an essential role in urban forest by alleviating local challenges in a city environment. In Washington, DC, for example, the increase in tree canopies has improved stormwater control and has also mitigated flooding in many parts of the city. On the other hand, improper maintenance of urban tree canopies can be costly to a city's budget.

Municipalities play a substantial role in urban ecosystem services. Cities that embrace green initiatives as their main strategy for improving urban sustainability typically mitigate the environmental impacts of rapid urbanization (Smith et al., 2019). The ecosystem services of forest apply to the urban environment, otherwise we would have no oxygen, rain clouds, food, paper, etc. A forest does not have to be in the city to provide for it. To clarify, our use of the terms urban forest or forest is used interchangeably with the term urban tree canopy. Washington, DC realizes significant benefits from a health tree canopy.

Ecosystem benefits of an urban forest or urban tree canopy includes improving air quality by reducing air pollution related health expenditures (DC Urban Tree Canopy Plan, 2013), improves water quality, by slowing the stormwater, trees trap soil in around their roots preventing pollution from our waterways, and reduces our energy use by lowering air temperature (DC Urban Tree Canopy Plan, 2013). While DC has invested in planting new trees annually some researchers believe there are other strategies that can be employed to improve the health and well-being of our urban tree canopy.

Decreasing mortality rates of mature trees is an effective strategy compared to planting more trees to improve a carbon balance in the urban tree canopy (Smith et al., 2019). Greening strategies are becoming more common, for example cities are adding greenspaces and increasing more urban street trees to combat negative impacts the urban heat island (UHI) effect, decrease air pollution, and soil erosion (Jike et al., 2020). Further, cities have added greenspaces, additional trees, and maintaining existing trees as strategies to improve the health and well-being of its citizens.

Human Health

Exposure to extensive city trees has been found to improve human health and certain cognitive functions (Karjalainen et al., 2010). The benefits of city trees to humans include (1) improvement of academic performance, (2) social cohesion, (3) cognitive health, and (4) reduced air pollution (Karjalainen et al., 2010). Salmond et al. (2016) noted that beneficial ecosystem services from urban forest exist in four categories: (1) the provisioning of services (e.g., food and water supplies); (2) the regulating of services and related health benefits (e.g., temperature regulation, noise reduction, air quality improvement, moderate climate extremes, mitigate stormwater runoff, waste treatment, pollination, pest regulation, seed dispersal, and global climate regulation); (3) supporting services (or habitat biodiversity), and (4) cultural services (e.g., recreation, aesthetic benefits, cognitive development, place values, and social cohesion) (p. 97).

Health impacts are typically caused by factors, such as air pollution, which can have a negative effect on human life. It has been well established that climate change is linked to human activities and urban environments tend to be hotter than rural areas—an occurrence known as the UHI effect. Cao et al. (2016) provided evidence that aerosol or haze pollution contributes to heat island creation in urban areas (p. 1). Barron et al. (2019) noted that urban tree canopies are important factors for increasing resilience among area residents because tree canopies improve air quality. Trees also improve water quality, slow the flow of stormwater, absorb water, and increase groundwater recharge. These authors further noted that particulate matter that is not alleviated can contribute to an increase in lung and heart disease, decreased lung function, and heart attacks. Health benefits and positive emotional response to tree canopies have been connected to urban forest (Ebi et al., 2018). As more people move to urban environments, the benefits of urban forest can support mitigation efforts to decrease the effects of climate change as well as improve the health and well-beings of humans.

Mitigation Strategies for Climate Change

The concerns of climate change have increased the need to develop mitigation strategies in an effort to lower temperatures within cities. Urbanization, deforestation, and the use of fossil fuels has been shown to increase temperatures all over the globe by releasing excess carbon dioxide into the atmosphere. Research shows that planting trees and other plants in urban environments increases biodiversity, reduces the UHI effect, and mitigates the effects of climate change (Salmond et al., 2016).

Chuang et al. (2017) noted that carbon sequestration, heat-stress mitigation, noise reduction, and air and water quality have all been shown to improve human health and well-being in local communities (p. 363). These researchers compared the tree canopies of Washington, DC and Baltimore and found that tree planting alone does not constitute an effective urban tree canopy plan (Chuang et al., 2017, p. 363). Collazo-Ortega, et al. (2017) noted, “Vegetation plays a crucial role in urban ecosystems, by sequestering carbon excess, storing carbon as biomass, and releasing oxygen and water vapor through evapotranspiration. Climate change and UHI can adversely affect the population’s health. These factors also affect how well a mature tree can perform its ecosystem service of carbon sequestration.” According to Meineke et al. (2016), an urban heat island can reduce carbon sequestration by 12% due to the direct effects of warming on trees. Mitigating the effects of UHIs would benefit city dwellers, as well as the trees and vegetation for carbon sequestration.

Threats

Urban forest ecosystems have special characteristics that distinguish them from other forest types. Urban forests that are near large or dense human populations have a high diversity of species, as well as multiple public and private stakeholders. Because 80% of the U.S. population lives in urban areas, urban forests have a huge influence on the day-to-day lives of most Americans (United Nation, 2018). Many do not think about the health of the trees around them until it is too late. Often, trees—including the ones in our backyards—get sick, are attacked by pests, and are damaged due to infrastructure expansion. The future survival of our urban forest is constantly at risk (Veach et al., 2017). Sustaining our forests requires us to analyze the threats trees face while trying to provide resolutions to limit those threats.

Pest Infestation. Stress caused by urban warming and drought has been directly linked to diseases and insect infestations in urban forests. An example of this is Melanaspis tenebricosa , also known as gloomy scale. This insect lives and feeds on the trunk and branches of certain trees. When M. tenebricosa heavily infects a tree, it causes the tree to die. Increased temperature exacerbates the reproductive rate so much that M. tenebricosa can typically produce 65% more embryos on the warmest un-watered trees than on the coolest watered trees in Raleigh, NC (Dale & Frank, 2017).

Deer Damage. Increased deer populations in North America decrease the diversity and productivity of forests as well as facilitate local plant extinctions. Lack of hunting and predators make human communities prone to an increase in deer. Through selective grazing, deer affect the number of plant species in an area, impair the growth of new trees, and alter the overall structure of forests (Dobson & Blossey, 2015). Deer prefer to eat certain plant species and this action reduces the native biodiversity of a forest. When the species of a specific forest change, the way the forests ecosystem functions changes as well (Dobson & Blossey 2015).

Developers and Homeowners. The transition from rural to urban has been ongoing with many individuals around the globe moving to city centers (United Nations, 2018). Washington, DC is a good example of this trend and, in response, several developments have been erected across the city for new residents. Increasing the number of residents has a multiplier effect where cities can increase the tax base that supports additional city services. However, there is a fine balance between development and the green and blue space necessary for the overall wellbeing of citizens. Population growth leads to a cycle of consumption that directly leads to increased extinction rates, which undoubtedly places undue pressure on ecosystem services.

Urban Forest Policies

Managing urban forest is an important issue. Communities can regulate urban forests through a variety of legislation. Tree ordinances are laws that should mirror the values of a community and the worth of a community's trees or urban forest. Tree ordinances can be implemented to encourage tree planting and tree maintenance to ensure the wellbeing and public health benefits that trees provide. However, despite some examples of coordination of research and policymaking, current practices are still insufficient in decreasing negative impacts on urban forests.

Methods

The purpose of this service-learning project was to gain a better understanding of ecosystem service benefits from trees in Washington, DC and whether these benefits facilitated our city being more climate resilient. Our aim was two-folds, to determine the monetary value of carbon sequestration in DC, and to assist in identifying tree species in our local neighborhoods. To pursue this aim we needed to collect tree canopy data. Eight of us used the i-Tree tool, while seven of us used the TreeSnap tool. The data we captured was the following:

1. Tree benefit estimates of carbon
    a. Annual sequestration of carbon in trees
    b. Amount of carbon stored in trees (not an annual rate)
2. Tree benefit estimates of air pollution
    a. Annual amount of carbon removal and the estimated value of removal
    b. Annual amount of nitrogen dioxide removal and estimated value of removal
    c. Annual amount of ozone removal
    d. Annual removal of particulate matter greater than 2.5 microns
    e. Annual removal of particulate matter less than 2.5 microns
    f. Annual removal of sulfur dioxide removal
3. Tree benefit estimates of hydrological
    a. Avoid water runoff

. 4. Tree species found in our local neighborhoods

How We Collected the Data

The i-Tree tool is a free, scientific tool designed to quantify the benefits and values of trees around the world. It aids in tree and forest management and advocacy. It shows the potential risk to trees and forest health and uses data from peer-reviewed research. This software tool was developed by the U.S. Department of Agriculture Forest Service (https://www.itreetools.org/).

TreeSnap was developed through a collaboration of scientists at the University of Kentucky and the University of Tennessee to help U.S. trees. Invasive diseases and pests threaten the health of America's forests and scientists are working to understand what allows individual trees to survive. To accomplish this, they need to find healthy, resilient trees in the forest to study. By using this tool, individual citizens can locate trees in their communities and collect data for direct submission to the TreeSnap website. Scientists use the data collected to locate trees for researchprojects, like studying genetic diversity of tree species and building better tree breeding programs.

Why We Collected this Data

The group using the i-Tree tool captured data on the removal of harmful pollutants and the monetary benefits that trees provide to ecosystem services in Washington, DC. The group using TreeSnap took pictures of various species of trees in their respective Washington, DC neighborhoods and uploaded this data to the TreeSnap web portal.

Results

The i-Tree tool captured the following information for Washington DC land covers, such as trees and shrubs (see Appendix 1 for a sample of the i-Tree tool report). A sample of one report provided the following:

Tree Canopy Coverage: was 13 points for a 100% coverage over 68.44 square miles. Tree Benefit Estimates of Carbon sequestered annually in trees 59.79 kiloton valued at $10,196,999 US dollars and storage capacity of trees 1,501.52 kiloton valued at $256,084,907.

Tree Benefit Estimates for Air Pollution removal: 1) Carbon Monoxide 24.74 tons, valued at $32,993, 2) Nitrogen Dioxide 136.68 tons valued at $59,722, Ozone 1055.83 tons, and valued at $2,742,892 (see appendix 1 for full report). Tree Benefit Estimates Hydrological avoided runoff 362.81 Kgal valued at $3,242 (see appendix 1 for full report)

The group that used the TreeSnap tool captured a variety of tree species common to many areas within the neighborhoods of Washington, DC (see Appendix 2 for a sample of the TreeSnap report). Observations of tree species provided a holistic view of the urban tree canopy in our local neighborhoods.

Discussion

As students of urban sustainability issues, understanding urban forest and the benefits of trees intrigued us. It appears that none of us had given serious consideration to the trees in our neighborhood nor did we understand the benefits of a healthy tree canopy. Collecting both sets of data provided a new appreciation for the benefits that trees provide to a community.

We really saw first-hand the usefulness and benefits of using the iTree tool in each of our neighborhoods. Each of our reports generated data that estimated the benefit of the tree canopy to be quite significant, for example one report showed the benefits of removing 24.74 tons of carbon monoxide, 136 tons of nitrogen dioxide, 1,055 tons of ozone, more than 300 tons of particulate matter, and 67 tons of sulfur dioxide annually. Each report estimated that the tree canopy provided hydrological benefits, reducing stormwater run-off by 362 kilogallons, evaporation by 8,147 kilogallons, interception 8,200 kilogallons, transpiration 7,714 kilogallons, potential evaporation by 52,397 kilogallons, and potential evapotranspiration by 43,214 kilogallons per year. Overall, the report showed that the quality of human life on Earth would not be the same without trees. Trees are essential for maintaining decent air quality and play a major role in the circulation and distribution of water on Earth and its atmosphere

Our group using the TreeSnap tool was able to observe the different species of trees and observe the circumference of the base of the trees where storage of carbon takes place. There were many varieties of trees in Washington, DC, among these are the Royal Japanese Cherry Tree which at the time of the observation was in full blossom and beautiful to observe. Other prominent tree species included the purple leaf sand cherry tree, white oak, bur oak, maple oak, and chestnut oak, all fully mature, large tree bases, and well maintained. We recognized that biodiversity, planting native plants, and adoptive plants are important tools to building resilience.

Collecting tree data was a useful activity for our environmental senior project and it brought the reality of urban forest and tree canopy to life. While many of us will graduate this spring, even during coronavirus pandemic, understanding and using these tools to evaluate other neighborhoods supports our preparation as informed citizens. We are better prepared to assess the value of a community considering the ecosystem services as a primary decision factor in determining whether this would be a great neighborhood to reside in.

Conclusion

Tree canopies play a major role in urban forest and ecosystem services, providing the advantage of a natural, cost-effective system of green infrastructure. Trees capture air and water pollutants as they provide shade, habitat, and even social organization. In this paper, we discussed how tree canopies play an important role in mitigating stormwater runoff and soil amendment (Berland, et al., 2017). Our research project examined urban forest from the lens of ecosystem services, human health, mitigation strategies to climate change, threats to urban forest, and urban forest policies. Our findings from both the i-Tree and the TreeSnap tools confirmed that urban forest and tree canopies are worthy investments from city governments as trees provide significant benefits to the health and wellbeing of citizens. Washington, DC has increased its effort to become a climate-resilient city, particularly as it strives to attain its place as one of the most sustainable cities in the United States. As urban sustainability majors, this project has enlightened our understanding of urban sustainability and a climate-resilient city.

Acknowledgments

The authors wish to express their appreciation to Dr. Elgloria Harrison, Associate Dean of Academic Programs in the College of Agriculture Urban Sustainability and Environmental and instructor of ENSC 488 Environmental Field Problems for her guidance on this project.

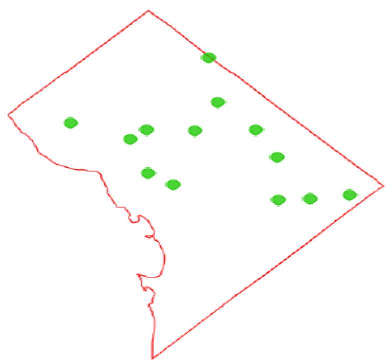
Appendix 1 i-Tree Canopy Tree Benefit Report

4/19/2020 i-Tree Canopy

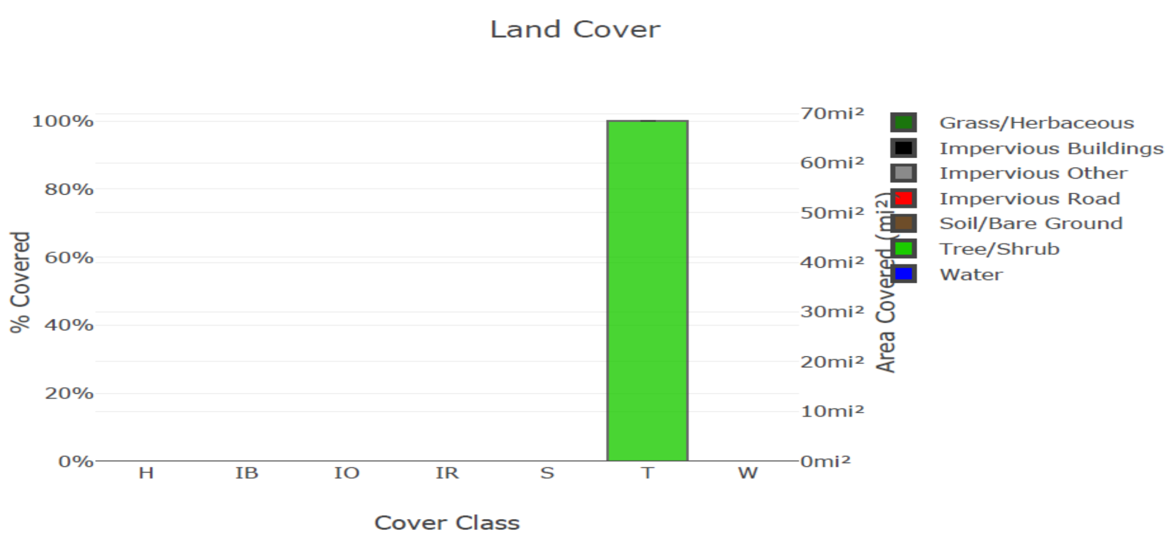
i-Tree Canopy v7.0

Cover Assessment and Tree Benefits Report

Estimated using random sampling statistics on 4/19/2020



Google



https://canopy.itreetools.org/report 1/2

4/19/2020 i-Tree Canopy

Abbr.	Cover Class	Description	Points	% Cover ± SE	Area (mi²) ± SE
H	Grass/Herbaceous		0	0.00 ± 0.00	0.00 ± 0.00
IB	Impervious Buildings		0	0.00 ± 0.00	0.00 ± 0.00
IO	Impervious Other		0	0.00 ± 0.00	0.00 ± 0.00
IR	Impervious Road		0	0.00 ± 0.00	0.00 ± 0.00
S	Soil/Bare Ground		0	0.00 ± 0.00	0.00 ± 0.00
T	Tree/Shrub		13	100.00 ± 0.00	68.44 ± 0.00
W	Water		0	0.00 ± 0.00	0.00 ± 0.00
Total			**13**	**100.00 ± 0.00**	**68.44 ± 0.00**

Tree Benefit Estimates: Carbon (English units)

Description	Carbon (kT)	±SE	CO_2 Equiv. (kT)	±SE	Value (USD)	±SE
Sequestered annually in trees	59.79	±0.00	219.23	±0.00	$10,196,999	±0
Stored in trees (Note: this benefit is not an annual rate)	1,501.52	±0.00	5,505.56	±0.00	$256,084,907	±0

Currency is in USD. Standard errors of removal and benefit amounts are based on standard errors of sampled and classified points. Carbon sequestered is based on 0.874 kT/mi²/yr. Carbon stored is based on 21.940 kT/mi². Carbon is valued at $46,513.84/kT. (English units: kT = kilotons (1,000 tons), mi² = square miles)

Tree Benefit Estimates: Air Pollution (English units)

Abbr.	Description	Amount (T)	±SE	Value (USD)	±SE
CO	Carbon Monoxide removed annually	24.74	±0.00	$32,993	±0
NO2	Nitrogen Dioxide removed annually	136.68	±0.00	$59,722	±0
O3	Ozone removed annually	1,055.83	±0.00	$2,742,892	±0
PM10*	Particulate Matter greater than 2.5 microns and less than 10 microns removed annually	299.67	±0.00	$1,878,449	±0
PM2.5	Particulate Matter less than 2.5 microns removed annually	53.94	±0.00	$5,742,267	±0
SO2	Sulfur Dioxide removed annually	67.19	±0.00	$8,993	±0
Total		**1,638.06**	**±0.00**	**$10,465,317**	**±0**

Currency is in USD. Standard errors of removal and benefit amounts are based on standard errors of sampled and classified points. Air Pollution Estimates are based on these values in T/mi²/yr @ $/T/yr:
CO 0.362 @ $1,333.50 | NO2 1.997 @ $436.94 | O3 15.428 @ $2,597.84 | PM10* 4.379 @ $6,268.44 | PM2.5 0.788 @ $106,459.48 | SO2 0.982 @ $133.85 (English units: T = tons (2,000 pounds), mi² = square miles)

Tree Benefit Estimates: Hydrological (English units)

Abbr.	Benefit	Amount (Kgal)	±SE	Value (USD)	±SE
AVRO	Avoided Runoff	362.81	±0.00	$3,242	±0
E	Evaporation	8,147.41	±0.00	N/A	N/A
I	Interception	8,200.43	±0.00	N/A	N/A
T	Transpiration	7,714.91	±0.00	N/A	N/A
PE	Potential Evaporation	52,397.54	±0.00	N/A	N/A
PET	Potential Evapotranspiration	43,214.41	±0.00	N/A	N/A

Currency is in USD. Standard errors of removal and benefit amounts are based on standard errors of sampled and classified points. Hydrological Estimates are based on these values in Kgal/mi²/yr @ $/Kgal/yr:
AVRO 5.301 @ $8.94 | E 119.049 @ N/A | I 119.823 @ N/A | T 112.729 @ N/A | PE 765.624 @ N/A | PET 631.442 @ N/A (English units: Kgal = thousands of gallons, mi² = square miles)

About i-Tree Canopy

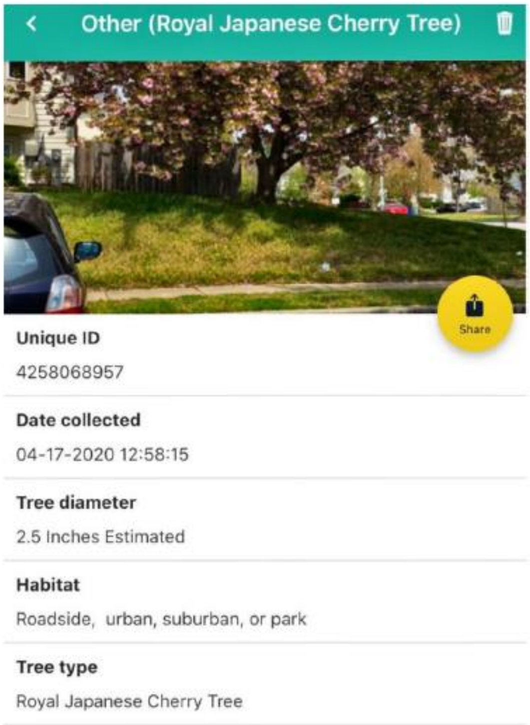
The concept and prototype of this program were developed by David J. Nowak, Jeffery T. Walton, and Eric J. Greenfield (USDA Forest Service). The current version of this program was developed and adapted to i-Tree by David Ellingsworth, Mike Binkley, and Scott Maco (The Davey Tree Expert Company)

Limitations of i-Tree Canopy

The accuracy of the analysis depends upon the ability of the user to correctly classify each point into its correct class. As the number of points increase, the precision of the estimate will increase as the standard error of the estimate will decrease. If too few points are classified, the standard error will be too high to have any real certainty of the estimate.

Use of this tool indicates acceptance of the EULA.

Appendix 2 Tree Variety in Washington, DC



Royal Japanese Cherry Tree

These trees are all over the DMV, SC is known for its Cherry Trees. The prettiest tree in my neighborhood by far

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