TABLE OF CONTENTS

Air Quality Health Impacts and Values by Shrubs

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

	NO2		O3		PM2.5		SO2	
	Incidence (Reduction/yr)	Value ($/yr)	Incidence (Reduction/yr)	Value ($/yr)	Incidence (Reduction/yr)	Value ($/yr)	Incidence (Reduction/yr)	Value ($/yr)
Acute Bronchitis					58.996	5,199.39		
Acute Myocardial Infarction					12.223	1,097,406.22		
Acute Respiratory Symptoms	5,656.177	178,623.50	60,209.261	5,147,182.32	24,853.882	2,436,130.39	99.095	3,129.46
Asthma Exacerbation	79,274.385	6,612,776.57			23,681.857	1,925,150.32	930.314	73,379.88
Chronic Bronchitis					19.251	5,382,893.62		
Emergency Room Visits	55.075	22,973.79	32.316	13,513.63	35.472	14,706.28	3.093	1,282.31
Hospital Admissions	134.963	4,010,823.08	92.608	2,768,884.54			3.710	112,638.19
Hospital Admissions, Cardiovascular					6.977	271,173.06		
Hospital Admissions, Respiratory					2.582	82,751.90		
Lower Respiratory Symptoms					720.174	37,392.27		
Mortality			15.832	122,880,630.47	37.232	289,465,811.97		
School Loss Days			31,661.027	3,108,802.12				
Upper Respiratory Symptoms					573.148	25,731.04		
Work Loss Days					4,310.967	873,110.70		
Total	**85,120.600**	**10,825,196.93**	**92,011.044**	**133,919,013.07**	**54,312.759**	**301,617,457.15**	**1,036.212**	**190,429.84**

EPA Environmental Benefits Mapping and Analysis Program http://www.epa.gov/airquality/benmap/index.html
Incidence: the total number of adverse health effects avoided in a year due to a change in pollution concentration
Value: the economic value that is associated with the incidence of adverse health effects

Air Quality Health Impacts and Values by Trees

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

	NO2		O3		PM2.5		SO2	
	Incidence (Reduction/yr)	Value ($/yr)	Incidence (Reduction/yr)	Value ($/yr)	Incidence (Reduction/yr)	Value ($/yr)	Incidence (Reduction/yr)	Value ($/yr)
Acute Bronchitis					288.287	25,407.24		
Acute Myocardial Infarction					59.732	5,362,960.05		
Acute Respiratory Symptoms	17,504.974	552,811.52	164,132.591	14,031,402.32	121,459.467	11,905,226.86	273.960	8,651.72
Asthma Exacerbation	244,913.719	20,428,679.45			115,731.852	9,408,097.09	2,509.777	197,769.41
Chronic Bronchitis					94.069	26,303,947.19		
Emergency Room Visits	172.999	72,163.12	87.814	36,720.86	173.351	71,868.72	8.545	3,542.77
Hospital Admissions	426.757	12,679,688.05	253.057	7,567,368.77			10.015	304,036.15
Hospital Admissions, Cardiovascular					34.094	1,325,206.91		
Hospital Admissions, Respiratory					12.619	404,403.71		
Lower Respiratory Symptoms					3,519.447	182,733.83		
Mortality			43.546	337,979,288.97	181.936	1,414,498,216.84		
School Loss Days			85,743.008	8,419,121.87				
Upper Respiratory Symptoms					2,800.939	125,746.08		
Work Loss Days					21,067.444	4,266,840.95		
Total	**263,018.450**	**33,733,342.14**	**250,260.016**	**368,033,902.79**	**265,423.239**	**1,473,880,655.48**	**2,802.296**	**514,000.05**

EPA Environmental Benefits Mapping and Analysis Program http://www.epa.gov/airquality/benmap/index.html
Incidence: the total number of adverse health effects avoided in a year due to a change in pollution concentration
Value: the economic value that is associated with the incidence of adverse health effects

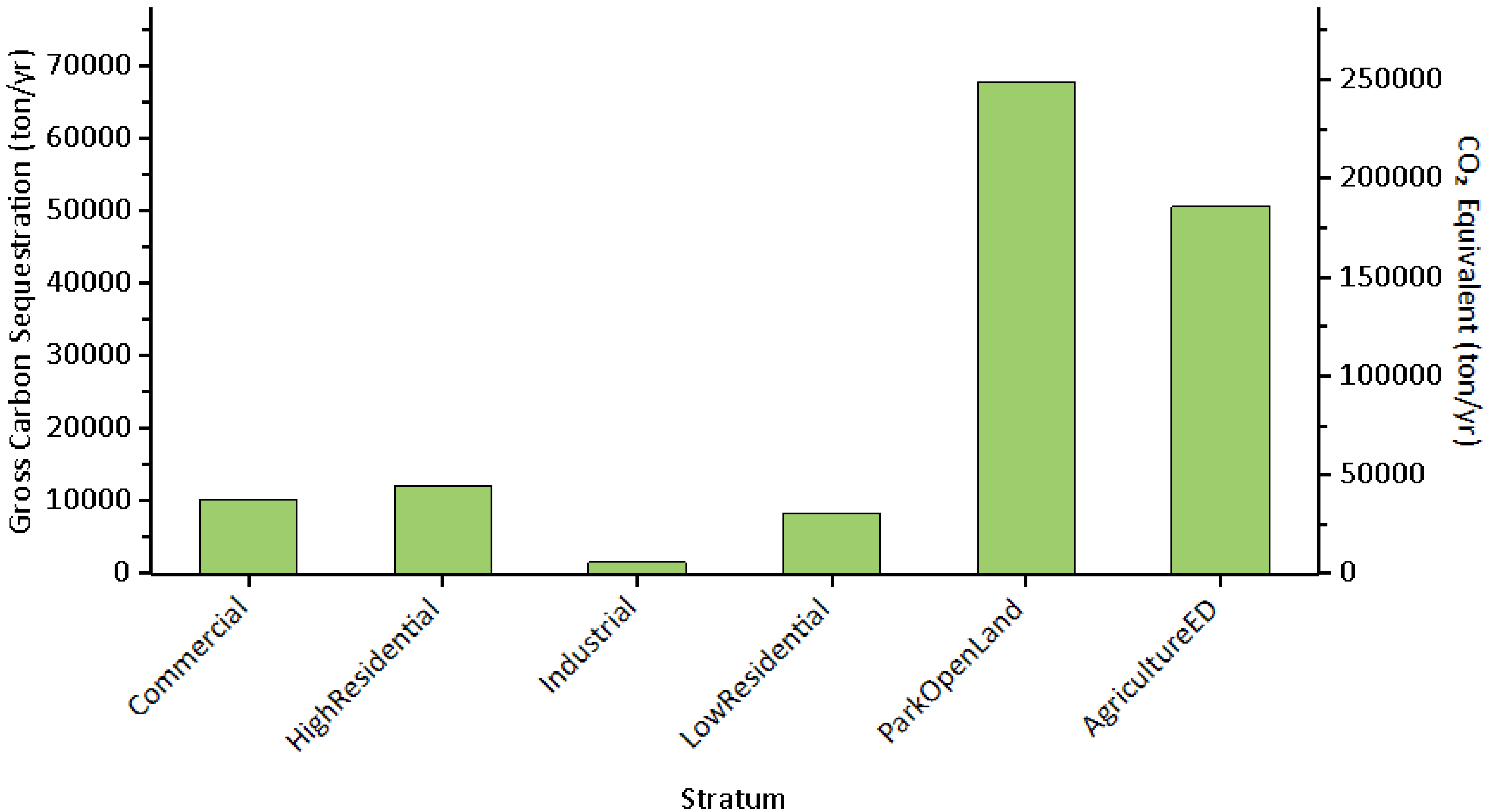
Annual Carbon Sequestration of Trees by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Stratum	Gross Carbon Sequestration (ton/yr)	CO_2 Equivalent (ton/yr)
Commercial	10,264.58	37,640.21
HighResidential	12,176.01	44,649.42
Industrial	1,566.08	5,742.82
LowResidential	8,410.00	30,839.47
ParkOpenLand	67,876.34	248,902.53
AgricultureED	50,626.95	185,649.03
Study Area	**150,919.96**	**553,423.48**

Annual Carbon Sequestration of Trees by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021



Avian Habitat Suitability by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

		Suitability Index		Index Change Due to Trees	
Stratum	Wildlife Name	With Trees	Without Trees	Relative (%)	Absolute
AgricultureED	American Robin	0.520	0.556	-7.011	-0.036
	Baltimore Oriole	0.281	0.052	81.680	0.230
	Carolina Chicakadee	0.407	0.062	84.675	0.344
	European Starling	0.182	0.183	-0.674	-0.001
	Northern Cardinal	0.278	0.402	-44.504	-0.124
	Red-bellied Woodpecker	0.450	0.020	95.582	0.430
	Scarlet Tanager	0.053	0.000	99.326	0.052
	Wood Thrush	0.264	0.000	99.872	0.263
Commercial	American Robin	0.392	0.455	-16.254	-0.064
	Baltimore Oriole	0.167	0.052	69.164	0.116
	Carolina Chicakadee	0.425	0.062	85.320	0.362
	European Starling	0.072	0.095	-32.012	-0.023
	Northern Cardinal	0.367	0.548	-49.061	-0.180
	Red-bellied Woodpecker	0.438	0.020	95.463	0.419
	Scarlet Tanager	0.037	0.000	99.053	0.037
	Wood Thrush	0.322	0.000	99.895	0.322
HighResidential	American Robin	0.495	0.516	-4.329	-0.021
	Baltimore Oriole	0.237	0.052	78.261	0.185
	Carolina Chicakadee	0.364	0.062	82.884	0.302
	European Starling	0.186	0.172	7.517	0.014
	Northern Cardinal	0.298	0.378	-26.908	-0.080
	Red-bellied Woodpecker	0.337	0.020	94.101	0.317
	Scarlet Tanager	0.032	0.000	98.904	0.032
	Wood Thrush	0.216	0.000	99.844	0.216
Industrial	American Robin	0.430	0.443	-3.035	-0.013
	Baltimore Oriole	0.089	0.052	42.300	0.038
	Carolina Chicakadee	0.216	0.062	71.127	0.154
	European Starling	0.091	0.089	1.831	0.002
	Northern Cardinal	0.348	0.406	-16.748	-0.058
	Red-bellied Woodpecker	0.147	0.020	86.452	0.127
	Scarlet Tanager	0.031	0.000	98.853	0.031

Avian Habitat Suitability by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

		Suitability Index		Index Change Due to Trees	
Stratum	**Wildlife Name**	**With Trees**	**Without Trees**	**Relative (%)**	**Absolute**
	Wood Thrush	0.118	0.000	99.713	0.117
LowResidential	American Robin	0.518	0.545	-5.308	-0.027
	Baltimore Oriole	0.168	0.052	69.317	0.116
	Carolina Chicakadee	0.293	0.062	78.720	0.231
	European Starling	0.245	0.281	-14.468	-0.035
	Northern Cardinal	0.290	0.380	-30.735	-0.089
	Red-bellied Woodpecker	0.263	0.020	92.443	0.243
	Scarlet Tanager	0.025	0.000	98.560	0.024
	Wood Thrush	0.121	0.000	99.720	0.120
ParkOpenLand	American Robin	0.315	0.440	-39.862	-0.125
	Baltimore Oriole	0.196	0.052	73.734	0.145
	Carolina Chicakadee	0.624	0.062	90.012	0.562
	European Starling	0.041	0.060	-44.178	-0.018
	Northern Cardinal	0.261	0.552	-111.719	-0.292
	Red-bellied Woodpecker	0.661	0.020	96.991	0.641
	Scarlet Tanager	0.132	0.000	99.730	0.131
Study Area	American Robin	0.439	0.503	-14.534	-0.064
	Baltimore Oriole	0.224	0.052	77.048	0.173
	Carolina Chicakadee	0.457	0.062	86.350	0.394
	European Starling	0.133	0.143	-7.361	-0.010
	Northern Cardinal	0.284	0.455	-60.552	-0.172
	Red-bellied Woodpecker	0.478	0.020	95.838	0.458
	Scarlet Tanager	0.072	0.000	99.506	0.071
	Wood Thrush	0.336	0.000	99.900	0.336

Suitability index is a unitless value meant to capture the ability of an area to sustain a population based on the habitat features that relate to and influence the patterns of abundance for each species.

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Research Paper

Using urban forest assessment tools to model bird habitat potential

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HIGHLIGHTS

- The i-Tree wildlife tool assesses the bird habitat potential within the urban forest.
- The i-Tree wildlife tool evaluates habitat improvement plans.
- The i-Tree wildlife tool provides detailed information of habitat requirements.

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ABSTRACT

The alteration of forest cover and the replacement of native vegetation with buildings, roads, exotic vegetation, and other urban features pose one of the greatest threats to global biodiversity. As more land becomes slated for urban development, identifying effective urban forest wildlife management tools becomes paramount to ensure the urban forest provides habitat to sustain bird and other wildlife populations. The primary goal of this study was to integrate wildlife suitability indices to an existing national urban forest assessment tool, i-Tree. We quantified available habitat characteristics of urban forests for ten northeastern U.S. cities, and summarized bird habitat relationships from the literature in terms of variables that were represented in the i-Tree datasets. With these data, we generated habitat suitability equations for nine bird species representing a range of life history traits and conservation status that predicts the habitat suitability based on i-Tree data. We applied these equations to the urban forest datasets to calculate the overall habitat suitability for each city and the habitat suitability for different types of land-use (e.g., residential, commercial, parkland) for each bird species. The proposed habitat models will help guide wildlife managers, urban planners, and landscape designers who require specific information such as desirable habitat conditions within an urban management project to help improve the suitability of urban forests for birds.

1. Introduction

The modification and destruction of wildlife habitat within urban areas via the replacement of forest cover and native vegetation with lawns, buildings, roads, and other impervious surfaces poses one of the greatest threats to bird populations on a global scale (Czech, Krausman, & Devers, 2000). Replacing native vegetation with ornamentals is one of the forms that habitat alterations take in the urban environment, and these esthetically pleasing landscapes are often at odds with ecological function (Lerman, Turner, & Bang, 2012). Thus, wildlife management tools aimed at assessing and improving urban habitat have an important role to play in reversing the loss of urban biodiversity.

Urban and community areas in the conterminous United States on average have 35% tree cover (Nowak & Greenfield, 2012), though the resulting urban landscape is a mix of contiguous (e.g., forest stands in parks or vacant areas) and fragmented (e.g., isolated trees along streets and in private yards) cover. Over the next 50 years, it is estimated that 118,300 km^2 of forested lands in the US will be consumed by urbanization (Nowak & Walton, 2005). Nonetheless, the urban forest provides essential ecosystem services that sustain environmental quality and human health (Nowak & Walton,

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2005). In particular, trees and other urban vegetation help mitigate the urban heat island effect through evapotranspiration and by providing shade, and they reduce air pollution through carbon sequestration (Akbari, Pomerantz, & Taha, 2001). Furthermore, the urban forest provides wildlife habitat resources including food, and nest and roosting sites for birds, mammals, and insects. And finally, the urban forest provides opportunities for urbanites to connect with the natural world (Miller, 2005). Currently we lack methods for a rapid assessment of the habitat potential of the urban forest (Shanahan, Possingham, & Martin, 2011). Therefore designing effective urban habitat assessment tools that can assist with the reconciliation between urban development and wildlife habitat becomes paramount to ensure that conservation efforts and plans for enhancing and protecting the urban forest will lead to sustainable bird and other desirable wildlife populations.

Few North American federal and Non-governmental Organization (NGO) programs have targeted improvement plans in urban habitats. The North American Landbird Conservation Plan (NALCP; Rich et al., 2004) aims to create and conserve landscapes that sustain bird populations. The NALCP calls for a thorough examination into how birds respond to and tolerate different land uses, including suburban areas, and recognizes the imminent threat of urbanization to most of the primary bird habitats in North America. Other than encouraging bird-friendly urban planning, the NALCP primarily characterizes urban areas as a threat to bird populations on a national scale without acknowledging the many opportunities for promoting conservation initiatives in urban and suburban landscapes (Goddard, Dougill, & Benton, 2010). The U.S. Fish and Wildlife Service's Urban Bird Treaty program (U.S. Fish and Wildlife Service, 2012) provides competitive challenge grants to individual cities for promoting education, hazard reduction, and habitat improvement projects aimed at supporting native urban bird populations. The National Wildlife Federation and the National Audubon Society have programs aimed at creating and certifying wildlife habitats in residential gardens and schoolyards with their respective Certified Wildlife Habitat and Healthy Yards programs. Although effective and innovative at the site level, these programs do not include management or monitoring programs for urban bird populations at regional scales. Recently Partners in Flight (PIF; an international cooperative effort that partners federal, state and local government agencies, NGOs, academia, and private landowners to conserve species at risk) recognized the extent of urban areas and the negative impact of urbanization on bird populations (Berlanga et al., 2010), though currently, PIF does not focus efforts toward conserving or enhancing urban habitats (Watts, 1999).

Scientists have studied urban bird populations since the 1970s (e.g., Emlen, 1974), however, our understanding of urban habitat and bird relationships trails behind that of habitat relationships in wildlands, thus hindering effective regional conservation plans aimed at improving bird habitat within the urban forest. Studying bird habitat relationships date back to the early 1900s (e.g., Adams, 1935; Grinnell, 1917; Lack, 1933). This research and other seminal works provided the foundation for understanding the habitat requirements for sustaining bird populations and have guided conservation planning, such as the NALCP (Fitzgerald et al., 2009). To date, the majority of urban bird studies conduct a bird monitoring protocol to document distribution patterns, measure habitat features at local and landscape scales, and design statistical models to identify the habitat features that relate to and influence patterns of bird abundance (Chace & Walsh, 2006). In addition, many urban bird studies correlate bird distribution with habitat features measured along an urban to rural gradient, within different land-use categories, or between urban and wildland sites (Beissinger & Osborne, 1982; Blair, 1996; Clergeau, Savard, Mennechez, & Falardeau, 1998; Croci, Butet, & Clergeau, 2008; Crooks, Suarez, & Bolger, 2004; DeGraaf & Wentworth, 1986; Emlen, 1974; Gering & Blair, 1999; Lerman & Warren, 2011; Melles, 2005). Additional variables identified as important in influencing urban bird populations include household density, human activities, and socio-economics (Fernandez-Juricic, 2000; Kinzig, Warren, Martin, Hope, & Katti, 2005; Lerman & Warren, 2011; Strohbach, Haase, & Kabisch, 2009).

Although these and other studies provide a solid foundation for understanding how birds respond to conditions within a particular city, they lack a means for non-specialists to apply these findings to conservation planning and management. In an effort to provide such tools, Tirpak and colleagues and Jones-Farrand and colleagues modeled how patch and landscape habitat features influence suitability for birds at an ecoregional scale (Tirpak, Jones-Farrand, Thompson, Twedt, & Uihlein, 2009; Jones-Farrand et al., 2011). Using the USDA Forest Service national forest census program Forest Inventory and Analysis (FIA) datasets, they described the forest structure and composition in the central and south-central U.S. and constructed Habitat Suitability Index (HSI) models that quantitatively relate forest characteristics to the abundance of forty bird species of conservation concern. They validated the models with Breeding Bird Survey data by testing whether the predicted suitability of landscapes based on the FIA and other data accorded with presence and relative abundance of a particular species (Tirpak, Jones-Farrand, Thompson, Twedt, Baxter, et al., 2009). These models have tremendous management potential in that they can assess the suitability at an ecoregional scale by leveraging existing forest and bird monitoring programs. Further, they assess habitat in terms of manageable characteristics such that they can be used to guide management prescriptions and predict the response of birds to various management scenarios.

Here we introduce the approach of integrating two existing bird habitat models (e.g., Tirpak, Jones-Farrand, Thompson, Twedt, Baxter, et al., 2009) and developing seven new models using the same model building procedure, and integrate these models into an urban forest assessment tool to evaluate the potential of the urban forest for supporting breeding bird populations, while also providing a platform for generating habitat improvement plans. This study aims to describe and validate the habitat models, and to demonstrate their applicability for improving urban bird diversity. Specifically we (1) identified the vegetation composition, configuration, and landscape features associated with the presence of a suite of representative bird species based on an extensive literature review, (2) quantified the characteristics of urban forests in ten northeastern cities using datasets from the i-Tree urban forest assessment program (Nowak et al., 2008), (3) modeled the habitat suitability for the representative bird species in urban forest monitoring plots, validated the models, and compared habitat suitability among ten cities and different land uses, and (4) tested whether habitat suitability changed over time for two cities for which we had habitat data for two points in time.

2. Methods

2.1. Study area

This study assesses the habitat potential for ten northeastern U.S. cities (Baltimore, MD, Boston, MA, Jersey City, NJ, Moorestown, NJ, New York, NY, Philadelphia, PA, Scranton, PA, Syracuse, NY, Washington D.C., and Woodbridge, NJ). These cities were selected because they had available urban forest data from i-Tree, and had a wide range of population sizes (19,000 – 8.4 million). Cities ranged from small municipalities such as Moorestown, NJ to large metropolitan areas such as Boston and Philadelphia, and thus were representative of urban areas in the region.

Table 1
Bird species list with associated life history traits, conservation status, and eBird frequencies (mean, minimum and maximum) included in the i-Tree wildlife habitat models. Forage and nest guilds include primary foraging and nesting locations. A conservation status of PIF indicates a Partners In Flight species of conservation concern.

Species	Summer frequency (ranges)	Forage guild	Nest guild	Conservation
American Robin	0.64 (0.50–0.79)	Lower canopy/ground	Tree branch	Flagship
Baltimore Oriole	0.25 (0.16–0.39)	Lower/upper canopy	Tree twig	PIF
Black-capped Chickadee	0.24 (0.03–0.56)	Lower canopy	Tree cavity	Flagship
Carolina Chickadee	0.28 (0.22–0.37)	Lower canopy	Tree cavity	PIF
European Starling	0.53 (0.38–0.70)	Ground	Buildings/cavities	Invasive
Northern Cardinal	0.49 (0.29–0.65)	Ground	Shrubs	Flagship
Red-bellied Woodpecker	0.19 (0.03–0.33)	Bark	Tree cavity	Flagship
Scarlet Tanager	0.08 (0.01–0.16)	Upper canopy	Tree twig	PIF
Wood Thrush	0.14 (0.03–0.25)	Ground	Tree branch	PIF

2.2. Bird species selection

In order to identify candidate bird species for this study, we first generated bird lists and average frequencies for all species recorded during the breeding season (mid-May through June in the northeast region) from 1990 to 2000, in the ten cities (i.e., their associated counties) using the Cornell Lab of Ornithology eBird database (eBird, 2012). The eBird database includes lists of birds seen during outings by amateur participants, and vetted by experts, and then uploaded with locality data, to an accessible interactive web-platform. Frequencies represented the percentage of submitted eBird checklists that record a particular species. We then identified the species recorded in all ten cities and calculated the mean, minimum and maximum frequency for each species. A total of 204 species were recorded in all ten cities, though only 57 species had frequencies >0.05. Species with few records (i.e., frequencies) are often not accurately placed in ecological space and hence we did not include species with frequencies <0.05 (McCune & Grace, 2002). Furthermore, the majority of species with low frequencies were forest interior species, species prone to local extinction within small and isolated forest fragments (Sherry & Holmes, 1985), and unlikely to penetrate the urban forest (Blair, 1996).

The urban forest could be important for birds in a number of ways. For instance, some forest interior species might penetrate the urban matrix when large tracts of forest exist. These rare species might be of particular concern because their populations might be vulnerable (Miller & Hobbs, 2002), and therefore we included species with differing levels of reporting frequencies (>0.05 frequency). The characteristic strata or substrate a bird uses for foraging or nesting could indicate the presence of resources needed by other species (Simberloff & Dayan, 1991), so we included species from a diversity of foraging and nesting guilds. Finally, species differed in their conservation significance. We included species recognized as high conservation priority, invasive or important for cultural reasons. Four of the selected species had a Partners in Flight (PIF) designation which ranks a species' conservation vulnerability based on "global measures, threats to breeding populations, area importance, and population trend for specific physiographic areas", and conservation initiatives and plans are directed toward species with high PIF scores (Rich et al., 2004). Invasive species included exotic birds that exploit the urban landscape (Blair, 1996). Urban flagship species were birds that urbanites recognize and embrace, following Caro and O'Doherty (1999). We ensured the species selected represented different foraging and nesting guilds with a focus on guilds reliant on forests (DeGraaf, Tilghman, & Anderson, 1985). Our final list included nine bird species with varying abundances, life history traits, and conservation status (Table 1).

2.3. i-Tree data

We used data from the above-mentioned 10 northeastern cities that were analyzed using the i-Tree model (www.itreetools.org; formerly known as the Urban Forest Effects [UFORE] model) for our habitat modeling. The i-Tree program is a free suite of tools developed by the US Forest Service to assess the ecosystem services and values provided by the urban forest. This program is designed to aid in the understanding and management of urban forests to help sustain environmental quality and human health in cities across the nation. The tool integrates local field data (e.g., species, tree height, canopy percentage) from either complete inventories or plot-based samples of trees with local air pollution and meteorological data to quantify forest structure and calculate the ecosystem services and values provided by the urban forest (Nowak et al., 2008). Data from i-Tree has provided information on the value of urban trees and their capacity to store carbon, mitigate energy costs, and remove air pollution (e.g., Nowak, Crane, & Stevens, 2006; Nowak, Greenfield, Hoehn, & Lapoint, 2013; Nowak, Hirabayshi, Bodine, & Hoehn, 2013). Information gathered via i-Tree has helped scientists to link urban forest management with environmental quality, and has assisted managers with planning for the future (Driscoll et al., 2012). Currently, the tool lacks the capacity to assess the habitat potential, an additional ecosystem service of the urban forest.

Each city included about 200 randomly selected plots (0.04 ha) located among all land-use categories (e.g., residential, commercial, parkland, and agricultural). Data collected at each plot included tree characteristics, percent cover of buildings, grass, shrubs and trees, the land use, and land cover. For each tree (woody plants with a minimum diameter of 2.54 cm at 1.4 m) numerous variables were collected including tree size, height, and condition (Table 2).

Table 2
List of i-Tree variables included in the i-Tree wildlife habitat models.

Variable	Description
PLOT ID	i-Tree plot identification
LANDUSE	Land-use category for each i-Tree plot
%BLDG	Percent of plot (0.04 ha) with land cover classification of building
%GRASS M	Percent of plot (0.04 ha) with land cover classification of lawn (maintained)
%SHRB	Percent of plot (0.04 ha) with shrub cover
%TREE	Percent of plot (0.04 ha) covered by tree canopy
TR_DENS_ALL	Number of all trees within plot (0.04 ha)
SAP DENS	Number of saplings (<10 cm dbh) within plot (0.04 ha)
23cm_DENS	Number of trees > 23 cm dbh within plot (0.04 ha)
DEAD_DENS	Number of trees within plot (0.04 ha) with fair, poor, dying, dead classification
BA_6 cm	Basal area of trees greater than 6 cm dbh per ha
MEAN_TOT HT_m	Mean tree height (m) per plot (0.04 ha)
FOR_AREA[a]	Amount of contiguous forest area (ha) surrounding i-Tree plot
FOR_1KM[a]	Percent forest land cover within 1 km of i-Tree plot

[a] These variables not collected using i-Tree but will be analyzed using plot location, forest cover maps and GIS analyses.

2.4. Bird habitat models

We conducted extensive literature reviews for each bird species using Web of Science and other databases as well as the literature-cited sections of papers. We identified habitat variables that were found to affect a species' abundance (Jones-Farrand et al., 2011) and also corresponded to measurements in the i-Tree datasets. Although i-Tree data did not always align with habitat variables representative of a particular species, we were able to extract this information from i-Tree and include these important local habitat variables. For example, basal area, a common forestry measurement, was listed in a number of publications describing habitat relationships but was not part of the i-Tree database. Thus we calculated the basal area based on the i-Tree data, and included this variable in two of our models. Similarly with dead wood, an important resource for cavity-nesting species, we extracted the tree condition data from i-Tree and assumed that trees with a rating of fair, poor, dying or dead had dead wood present. We assigned suitability index (SI) scores for each species, for each metric. The SI ranged between 0 and 1 whereby a score of 0 indicated unsuitable habitat conditions (i.e., strong likelihood the species not present) whereas a score of 1 indicated the habitat conditions have a strong likelihood of supporting the species. Often, published data consisted of a single mean value for a habitat feature (e.g., percent canopy cover) when the species was present, and we used this data point when building the models. In instances when published data were scant or not available, we estimated values by supplementing with iterative values which improved the predictability of our habitat models (Tirpak, Jones-Farrand, Thompson, Twedt, & Uihlein, 2009). These and the iterative values mentioned above were reviewed by a panel of experts and revised according to recommendations (Tirpak, Jones-Farrand, Thompson, Twedt, & Uihlein, 2009). Each habitat variable per species included at least three data points. We used CurveExpert Professional software (http://www.curveexpert.net/) to generate parameters for mathematical equations to predict the probability of a species occurrence for each habitat variable (e.g., percent canopy cover) based on the value of that variable. We selected the equation with the best fit to the data (r^2). We identified between two and five habitat variables that were associated with each species, and generated mathematical equations for each habitat variable. We then calculated the geometric mean for these two to five habitat variables used for each species for a final SI score for each plot. This assumes that each variable had equal weight in the model (Jones-Farrand et al., 2011).

These habitat models have various assumptions and limitations associated with their use. First, relying on expert opinion on the estimated values might have introduced observer bias (Jones-Farrand et al., 2011). However, we solicited opinions from at least three different wildlife biologists intimately familiar with our targeted species. Furthermore, we valued expert opinion and have confidence that the inclusion of the estimated values were more informative than having models without these values (Beaudry et al., 2010). We assumed the species were limited in their distribution by the habitat variables selected for the models, and the variables measured in i-Tree represented the suite of habitat variables a particular species used in the selection process (Jones-Farrand et al., 2011). We assumed that behavioral interactions (e.g., inter and intra-specific competition) were not the driving force birds used for selecting habitat (Sherry & Holmes, 1985). We assumed the models performed equally within the different land-uses, for generalist and specialist bird species, and that we built the models based on complete information on habitat relationships. In addition, since the majority of published habitat relationship studies were conducted in wildlands (i.e., not in urban land-uses), we assumed these relationships were applicable to urban landscapes (Beaudry et al., 2010; Roloff & Kernohan, 1999). And finally, the habitat models do not fully account for landscape variables that might indicate the permeability and connectivity throughout the urban landscape, essential factors for dispersal (Beaudry et al., 2010). We included the full description of habitat associations and subsequent models for the red-bellied woodpecker (*Melanerpes carolinus*) to illustrate the habitat model building process. See the online supplementary material for the remaining species accounts and models.

2.5. Validating the models

To test the validity of our habitat models, we used bird monitoring data from 82 sites located at the Baltimore Ecosystem Study Long-Term Ecological Research (BES LTER) project. To the best of our knowledge, Baltimore was the only city in the northeast with an extensive bird monitoring program. In addition, the bird monitoring sites coincided with the i-Tree collection sites and thus enabled us to directly test how the habitat models predicted species presence by comparing the HSI with the presence of a particular species. Each site was visited two times per year (2002, 2004–2007) during the breeding season (mid May to July) by a trained observer. Visits occurred between sunrise and 09:30, and all species heard and seen during the 5-min count were recorded (Nilon, Warren, & Wolf, 2011). Using the point count data, we calculated a mean abundance and categorized each species as present or absent at each i-Tree location. Five of the nine species were recorded at the BES LTER project: American robin (*Turdus migratorius*), Carolina chickadee (*Poecile carolinensis*), European starling (*Sturnus vulgaris*), northern cardinal (*Cardinalis cardinalis*), and red-bellied woodpecker. We compared the HSI scores with the BES LTER bird abundance data using Spearman Rank correlations. We assessed model sensitivity by removing one habitat variable at a time, and recalculated the HSI score to test whether the omission of the said variable altered the predictability of the model. For example, the red-bellied woodpecker model included four habitat variables: the number of large trees, basal area, percent canopy cover and dead wood density. To test whether the model was sensitive to the number of large trees, we generated a new HSI score by calculating the geometric mean of the three other habitat variables and then compared the new HSI score with the BES LTER bird abundance data using Spearman Rank correlations. Discrepancies between the two analyses (i.e., significant with all variables yet not significant with the omitted variable) suggested the omitted habitat variable had a greater influence to the model. Black-capped chickadee (*Poecile atricapillus*) range does not include Baltimore though we used Carolina chickadee model for validation. Tirpak, Jones-Farrand, Thompson, Twedt, and Uihlein (2009) used Breeding Bird Survey (BBS) data to validate the wood thrush (*Hylocichla mustelina*) model in their publication using Breeding Bird Survey (BBS) data. We were unable to validate the Baltimore oriole (*Icterus galbula*) and scarlet tanager (*Piranga olivacea*) model.

2.6. Illustrating applications

We applied the habitat model to each i-Tree plot, calculated an overall SI score (0–1) per species per i-Tree plot, calculated the mean SI score per species per city, and then calculated the mean SI score per land-use for each city. Although other land-uses were included in the i-Tree data collection, we focused on land-uses common for all ten cities: commercial, industrial, parks and forest, and residential. We also included vacant lots and transportation corridors, which were recorded in nine and eight of the ten cities, respectively. We describe the patterns of SI scores, land-uses, and management potential of i-Tree habitat models.

Although we did not directly test the effectiveness of habitat improvement plans, we demonstrated the potential of the i-Tree wildlife models to detect change in habitat conditions over time. For two cities (Baltimore, MD and Syracuse, NY), i-Tree data were collected at the same plot in 2001 and 2009. We used *t*-tests to determine whether the suitability for each land-use per city changed during the two data collection periods.

3. Results

3.1. Suitability index summaries

We developed 27 variable functions that were incorporated to form habitat models for nine species (Table 3). Overall, Moorestown, NJ had the highest quality habitat for birds (city-wide score for all species combined: 0.28), Jersey City, NJ the lowest (city-wide score: 0.14), and the remaining eight cities falling in between these SI scores (Table 4). On average, Philadelphia, PA had the highest SI score for Carolina chickadee, red-bellied woodpecker, and wood thrush while Jersey City had the lowest SI score for Baltimore oriole, Carolina chickadee, European starling, red-bellied woodpecker, scarlet tanager, and wood thrush (Table 4). Suitability within different land-uses varied for each species. Vacant lots, parks and forested land-uses had high SI scores for wood thrush, scarlet tanager, red-bellied woodpecker, and black-capped and Carolina chickadee. American robin had high SI scores for a variety of different land-uses and we did not discern any clear land-use signals. Industrial and commercial land-uses tended to score poorly with most species (Table 4).

3.2. Habitat model example: red-bellied woodpecker

The habitat suitability index model for the red-bellied woodpecker included four variables: tree density per 0.04 ha, basal area per ha, density of dead wood per 0.04 ha, and percent canopy cover per 0.04 ha. The species relies on forested areas and we included three variables to describe these habitat needs. Adkins Giese and Cuthbert (2003) observed 24 trees per 0.04 ha and a basal area of 34 m^2/ha in oak forests of the Upper Midwest, while Conner (1980) observed 30 trees/0.04 ha and a basal area of 14 m^2/ha in oak-hickory forests around Blacksburg, VA. However, these studies did not discern tree size. We wanted the model to reflect the mean diameter of the cavity limb (21.6 cm; Jackson, 1976) so only included trees greater than 23 cm dbh and adjusted the densities to reflect these conditions (Table 5). We fit a rational function $(0 - 0.0035 + (0.1606 \times \text{tree density}))/(1 + (-0.1417 \times \text{tree density}) + (0.0233 \times \text{tree density}^2))$ where tree density represents the density of trees greater than 23 cm dbh within a 0.04 ha plot, through these data points to predict how habitat suitability varied with large tree density (Fig. 1). We assumed suitability was the lowest when trees were absent. Our inclusion of basal area for all trees greater than 6 cm dbh reflects the propensity for this species to prefer relatively dense forests (Shackelford, Brown, & Conner, 2000; Table 6). We fit a logistic function $0.9906/(1 + (47.9216 \times \exp(-0.9689 \times \text{basal area})))$ where basal area is m^2/ha and calculated for all trees greater than 6 cm dbh, through these data points to quantify the relationship between basal area and the SI score (Fig. 2).

Canopy coverage has the potential to predict habitat suitability. DeGraaf, Yamasaki, Leak, and Lester (2006) suggested that when canopy coverage exceeds 35%, the site provided suitable conditions for red-bellied woodpeckers. We based our assumed values for canopy cover on qualitative accounts and personal observations of the species in forested suburban and riparian areas, with lack of observations in areas with little to no canopy cover and areas with an extremely dense canopy cover (Table 7). We fit a rational function $(-0.0371 + (0.0124 \times \text{percent canopy}))/(1 + (-0.0363 \times \text{percent canopy}) + (0.0005 \times \text{percent}$

Table 3
Habitat suitability equations for nine bird species in northeastern cities. Species codes as follows: AMRO, American robin; BAOR, Baltimore oriole; BCCH, black-capped chickadee; CACH, Carolina chickadee; EUST, European starling; NOCA, northern cardinal; RBWO, red-bellied woodpecker; SCTA, scarlet tanager; WOTH, wood thrush. Models with exp used base e.

Species	Variable (x)	Equation
AMRO	%TREE	$(0.6439054 + (-0.0023519694 \times x))/(1 + (-0.031238306 \times x) + (0.00059471346 \times x^2))$
AMRO	%GRASS M	$1/(4.19182 + (-0.083072 \times x) + (0.000538 \times x^2))$
BAOR	%TREE	$1.012735 \times \exp(0 - ((x - 35.4635207)^2)/(2 \times 15.3507889^2))$
BAOR	23cm_DENS	$(0.0377801 + (0.27942563 \times x))/(1 + (-0.4470676 \times x) + (0.13110269 \times x))$
BCCH	%TREE	$1.002 \times \exp((0 - ((x) - 63.568198)^2)/1795)$
BCCH	DEAD_DENS	$1.007/(1 + (32.567 \times \exp(-1.403x)))$
BCCH	MEAN_TOT HT_m	$0.97572/(1 + (11.742599 \times \exp(-0.48523169 \times)))$
CACH	%TREE	$1.002 \times \exp((0 - ((x) - 63.568198)^2)/1795)$
CACH	DEAD_DENS	$1.007/(1 + (32.567 \times \exp(-1.403x)))$
CACH	MEAN_TOT HT_m	$0.97572/(1 + (11.742599 \times \exp(-0.48523169 \times)))$
EUST	%BLDG	$(-0.00035052 + (0.0148132 \times x))/(1 + (-0.0378391 \times x) + (0.00065325 \times x^2)) \times -0.1$
EUST	DEAD_DENS	$0.800547 \times (1.2498289 - \exp(-2.42900485 \times x))$
EUST	%GRASS M	$1.02247/(1 + (40.643183849 \times \exp(-0.104376 \times x)))$
EUST	TR_DENS_ALL	$(0.81293 + (-0.0879822662 \times x))/(1 + (-0.3167288645 \times x) + (0.0546857954 \times x^2))$
NOCA	%TREE	$(0.63133686 + (-0.005359156 \times x))/(1 + (-0.036974589 \times x) + (0.0006728828 \times x^2))$
NOCA	%SHRB	$(0.00949075 + (0.021340335 \times x))/(1 + (-0.02120201 \times x) + (0.000432969 \times x^2))$
RBWO	BA_6 cm	$0.9906/(1 + (47.9216 \times \exp(-0.9689 \times x)))$
RBWO	%TREE	$(-0.0371 + (0.0124 \times x))/(1 + (-0.0335 \times x) + (0.0005 \times x^2)) \times -0.1$
RBWO	DEAD_DENS	$1/(1 + (15.67 \times \exp(-5.338 \times x)))$
RBWO	23cm_DENS	$(0 - 0.00347415 + (0.160609 \times x))/(1 + (-0.141679 \times x) + (0.0233308 \times x^2)) \times -0.1$
SCTA	BA_6 cm	$1.0363/(1 + (49.295 \times \exp(-0.1088 \times x)))$
SCTA	%TREE	$1.00545/(1 + (19{,}171.9801 \times \exp(-0.16936 \times x)))$
SCTA[a]	FOR_AREA	$((-0.0009840608 \times 4.3992415) + (1.6780139 \times x^{0.25391}))/(4.3992 + x^{0.2539122})$
SCTA	23cm_DENS	$1.01622702/(1 + (24{,}569.22035 \times \exp(-0.6493929 \times x)))$
WOTH[a]	FOR_1KM	$1.003/(1 + (224.7853 \times \exp(-0.1081 \times (x))))$
WOTH	%TREE	$1.03163/(1 + (141{,}241.64 \times \exp(-0.1531 \times x)))$
WOTH	SAP DENS	$(1.0401978/(1 + (65.800186 \times \exp(-0.758149 \times (x)))))$

[a] These models that used landscape variables were not included in the SI calculations but will be incorporated into the i-Tree program, and analyzed when spatial data is available.

Table 4
The suitability index (SI) scores for nine bird species in ten northeastern cities, for different urban land-uses. City SI score is the mean score per species and per city. Species codes as follows: AMRO, American robin; BAOR, Baltimore oriole; BCCH, black-capped chickadee; CACH, Carolina chickadee; EUST, European starling; NOCA, northern cardinal; RBWO, red-bellied woodpecker; SCTA, scarlet tanager; WOTH, wood thrush.

Land use	City	*n*	AMRO	BAOR	CACH	EUST	NOCA	RBWO	SCTA	WOTH	MEAN
CITY SI SCORE	Baltimore, MD	195	0.52	0.25	0.25	0.25	0.24	0.20	0.01	0.10	0.22
Commercial	Baltimore, MD	41	0.43	0.08	0.11	0.18	0.10	0.06	0.00	0.01	0.12
Industrial	Baltimore, MD	14	0.63	0.13	0.15	0.25	0.24	0.06	0.00	0.01	0.18
Park	Baltimore, MD	22	0.43	0.24	0.43	0.18	0.20	0.37	0.04	0.44	0.26
Residential	Baltimore, MD	90	0.57	0.33	0.26	0.35	0.32	0.22	0.01	0.06	0.27
Transportation	Baltimore, MD	16	0.45	0.23	0.32	0.09	0.16	0.29	0.03	0.15	0.20
Vacant	Baltimore, MD	5	0.51	0.49	0.26	0.07	0.55	0.26	0.00	0.02	0.24
CITY SI SCORE	Boston, MA	220	0.49	0.29	0.27	0.19	0.21	0.26	0.01	0.06	0.21
Commercial	Boston, MA	13	0.63	0.26	0.31	0.38	0.22	0.26	0.01	0.09	0.25
Industrial	Boston, MA	23	0.51	0.26	0.21	0.25	0.20	0.16	0.01	0.02	0.20
Park	Boston, MA	35	0.60	0.28	0.25	0.27	0.14	0.27	0.01	0.06	0.22
Residential	Boston, MA	62	0.47	0.41	0.36	0.13	0.30	0.41	0.01	0.09	0.26
Transportation	Boston, MA	10	0.51	0.11	0.13	0.12	0.11	0.07	0.00	0.00	0.12
Vacant	Boston, MA	28	0.34	0.24	0.50	0.01	0.21	0.49	0.03	0.22	0.23
CITY SI SCORE	Jersey City, NJ	230	0.47	0.11	0.15	0.18	0.16	0.04	0.00	0.01	0.14
Commercial	Jersey City, NJ	29	0.43	0.06	0.07	0.09	0.10	0.01	0.00	0.00	0.09
Industrial	Jersey City, NJ	4	0.39	0.05	0.06	0.01	0.08	0.01	0.00	0.00	0.07
Park	Jersey City, NJ	33	0.57	0.08	0.16	0.28	0.09	0.06	0.00	0.03	0.15
Residential	Jersey City, NJ	64	0.47	0.17	0.21	0.26	0.29	0.07	0.00	0.02	0.19
Transportation	Jersey City, NJ	25	0.46	0.08	0.16	0.06	0.10	0.02	0.00	0.00	0.10
Vacant	Jersey City, NJ	13	0.42	0.09	0.17	0.01	0.10	0.02	0.00	0.00	0.09
CITY SI SCORE	Moorestown, NJ	206	0.49	0.17	0.33	0.21	0.47	0.32	0.03	0.17	0.28
Commercial	Moorestown, NJ	31	0.50	0.18	0.20	0.20	0.66	0.14	0.01	0.03	0.25
Industrial	Moorestown, NJ	4	0.56	0.09	0.11	0.17	0.66	0.02	0.00	0.00	0.22
Park	Moorestown, NJ	45	0.44	0.07	0.41	0.18	0.35	0.41	0.08	0.33	0.28
Residential	Moorestown, NJ	103	0.56	0.25	0.34	0.28	0.50	0.33	0.02	0.10	0.31
Transportation	Moorestown, NJ	1	0.81	0.05	0.06	0.41	0.63	0.01	0.00	0.00	0.28
CITY SI SCORE	New York City	214	0.46	0.20	0.20	0.20	0.21	0.17	0.01	0.06	0.18
Commercial	New York City	6	0.84	0.20	0.13	0.42	0.22	0.05	0.00	0.00	0.21
Industrial	New York City	12	0.48	0.22	0.18	0.24	0.15	0.13	0.00	0.03	0.18
Park	New York City	33	0.45	0.13	0.26	0.17	0.19	0.29	0.02	0.13	0.19
Residential	New York City	76	0.50	0.35	0.25	0.32	0.28	0.27	0.01	0.03	0.26
Vacant	New York City	53	0.38	0.10	0.20	0.03	0.17	0.19	0.02	0.10	0.13
CITY SI SCORE	Philadelphia, PA	213	0.42	0.19	0.48	0.25	0.22	0.39	0.03	0.21	0.26
Commercial	Philadelphia, PA	3	0.75	0.41	0.30	0.54	0.20	0.29	0.00	0.00	0.29
Industrial	Philadelphia, PA	19	0.49	0.14	0.25	0.34	0.14	0.17	0.00	0.05	0.19
Park	Philadelphia, PA	53	0.28	0.13	0.74	0.10	0.17	0.69	0.07	0.54	0.30
Residential	Philadelphia, PA	62	0.57	0.33	0.40	0.52	0.26	0.30	0.00	0.02	0.31
Transportation	Philadelphia, PA	10	0.44	0.17	0.20	0.08	0.24	0.09	0.00	0.00	0.14
Vacant	Philadelphia, PA	50	0.31	0.10	0.54	0.03	0.26	0.42	0.03	0.29	0.22
CITY SI SCORE	Scranton, PA	191	0.50	0.20	0.25	0.23	0.23	0.22	0.01	0.16	0.22
Commercial	Scranton, PA	32	0.47	0.15	0.10	0.16	0.20	0.05	0.00	0.01	0.14
Industrial	Scranton, PA	11	0.49	0.15	0.10	0.19	0.15	0.04	0.00	0.00	0.14
Park	Scranton, PA	9	0.54	0.29	0.33	0.25	0.25	0.35	0.01	0.29	0.26
Residential	Scranton, PA	94	0.56	0.18	0.19	0.44	0.22	0.13	0.01	0.06	0.23
Transportation	Scranton, PA	13	0.44	0.16	0.16	0.05	0.18	0.10	0.00	0.03	0.13
Vacant	Scranton, PA	29	0.26	0.10	0.53	0.02	0.17	0.48	0.03	0.61	0.25
CITY SI SCORE	Syracuse, NY	200	0.58	0.18	0.29	0.30	0.25	0.14	0.00	0.12	0.23
Commercial	Syracuse, NY	15	0.45	0.11	0.14	0.22	0.18	0.07	0.00	0.00	0.15
Industrial	Syracuse, NY	18	0.57	0.11	0.27	0.27	0.16	0.08	0.00	0.22	0.21
Park	Syracuse, NY	7	0.67	0.26	0.17	0.42	0.12	0.19	0.00	0.01	0.21
Residential	Syracuse, NY	113	0.64	0.20	0.24	0.38	0.26	0.12	0.00	0.03	0.24
Transportation	Syracuse, NY	9	0.50	0.13	0.22	0.07	0.51	0.04	0.00	0.01	0.17
Vacant	Syracuse, NY	30	0.40	0.11	0.50	0.10	0.17	0.21	0.01	0.46	0.23
CITY SI SCORE	Washington, DC	201	0.50	0.31	0.26	0.23	0.22	0.31	0.07	0.06	0.23
Commercial	Washington, DC	10	0.43	0.15	0.12	0.17	0.21	0.09	0.00	0.00	0.15
Industrial	Washington, DC	7	0.46	0.19	0.10	0.16	0.21	0.08	0.00	0.00	0.15
Park	Washington, DC	53	0.46	0.24	0.33	0.15	0.24	0.41	0.17	0.15	0.24
Residential	Washington, DC	91	0.50	0.44	0.27	0.20	0.30	0.36	0.03	0.03	0.26
CITY SI SCORE	Woodbridge, NJ	215	0.52	0.23	0.27	0.21	0.07	0.24	0.01	0.12	0.20
Commercial	Woodbridge, NJ	20	0.45	0.19	0.16	0.14	0.08	0.14	0.01	0.06	0.15
Industrial	Woodbridge, NJ	5	0.43	0.09	0.09	0.01	0.09	0.01	0.00	0.00	0.08
Park	Woodbridge, NJ	29	0.32	0.10	0.56	0.13	0.03	0.59	0.07	0.48	0.25
Residential	Woodbridge, NJ	98	0.64	0.35	0.27	0.32	0.08	0.24	0.01	0.04	0.24
Transportation	Woodbridge, NJ	22	0.50	0.11	0.13	0.13	0.08	0.04	0.00	0.05	0.12

Table 5
Relationship between large tree density (trees larger than 23 cm dbh) per 0.04 ha and suitability index (SI) for red-bellied woodpecker (RBWO) habitat, and associated references.

Large tree density (per 0.04 ha)	SI score (RBWO)	Reference
0	0	Assumed value
3	0.6	Assumed value
6	1	Adkins Giese and Cuthbert (2003)
8	0.9	Conner (1980)
11	0.8	Assumed value

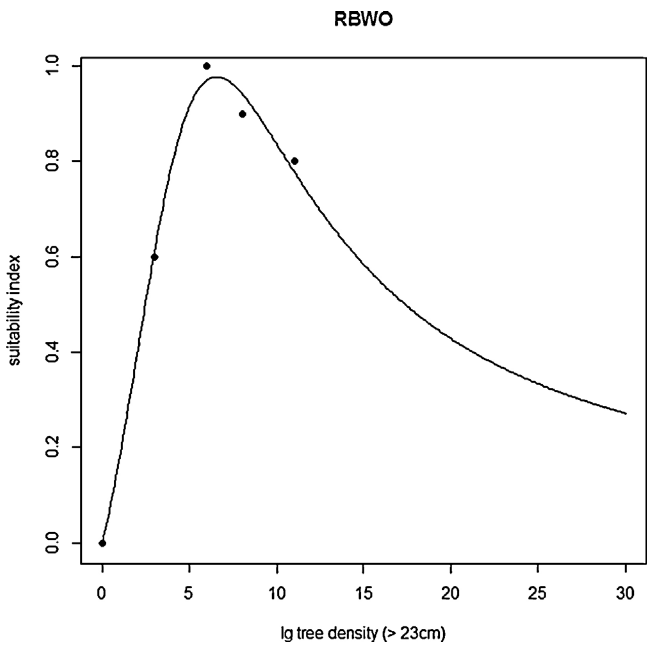

Fig. 1. Relationship between large tree density (trees larger than 23 cm dbh) per 0.04 ha and suitability index (SI) for red-bellied woodpecker (RBWO) habitat, and associated references.

Table 6
Relationship between basal area (trees > 6 cm dbh) per ha and suitability index (SI) for red-bellied woodpecker (RBWO) habitat, and associated references.

Basal area (per ha)	SI score (RBWO)	Reference
0	0	Assumed value
4	0.5	Assumed value
8	0.95	Conner, 1980 (based on SD)
14	1	Conner, 1980
34	1	Adkins Giese and Cuthbert (2003)

canopy^2)), where percent canopy represents the percent of a 0.04 ha plot with tree canopy cover, through these data points to predict how habitat suitability varied with canopy coverage (Fig. 3). We assumed suitability was the lowest when trees were absent.

Table 7
Relationship between canopy percent per 0.04 ha and suitability index (SI) for red-bellied woodpecker (RBWO) habitat, and associated references.

Canopy percent (per 0.04 ha)	SI score (RBWO)	Reference
0	0	Assumed value
15	0.1	Assumed value
20	0.3	Assumed value
25	0.5	Assumed value
35	0.9	DeGraaf et al. (2006)
62	1	Straus et al. (2011)

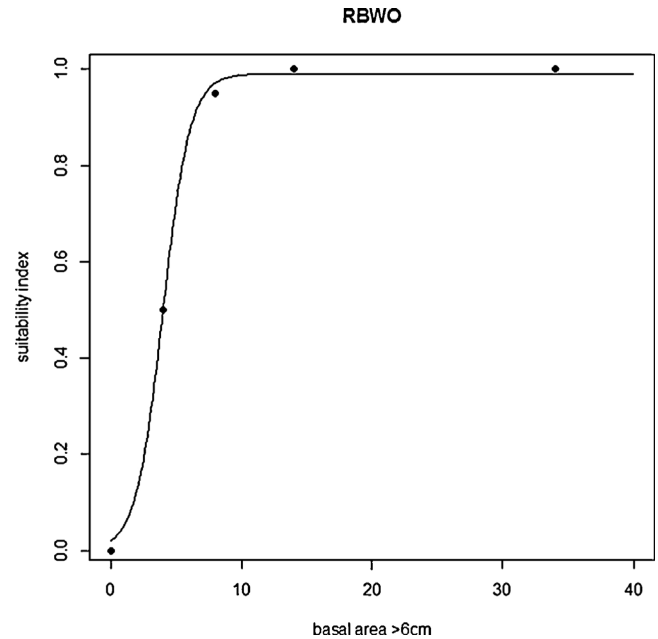

Fig. 2. Relationship between basal area (trees > 6 cm dbh) per ha and suitability index (SI) for red-bellied woodpecker (RBWO) habitat, and associated references.

Although dead wood is necessary for foraging and nesting, it is not essential for detecting red-bellied woodpeckers. Of 42 nests in southwest Ontario, Straus, Bavrlic, Nol, Burke, and Elliott (2011) observed 93% of the nests in dead and declining trees and 6% of nests in healthy trees. Adkins Giese and Cuthbert (2003) observed three dead or declining trees per 0.04 ha in the Midwest (Table 8). We fit a logistic function $1/(1+(15.67 \times \exp(-5.338 \times \text{dead wood density per 0.04 ha})))$ (where dead wood is recorded as trees with a condition of fair, poor, dying or dead) through these data points to quantify the relationship between trees with dead wood and the SI score (Fig. 4). We calculated the geometric mean of these habitat models to generate a final SI score for this species.

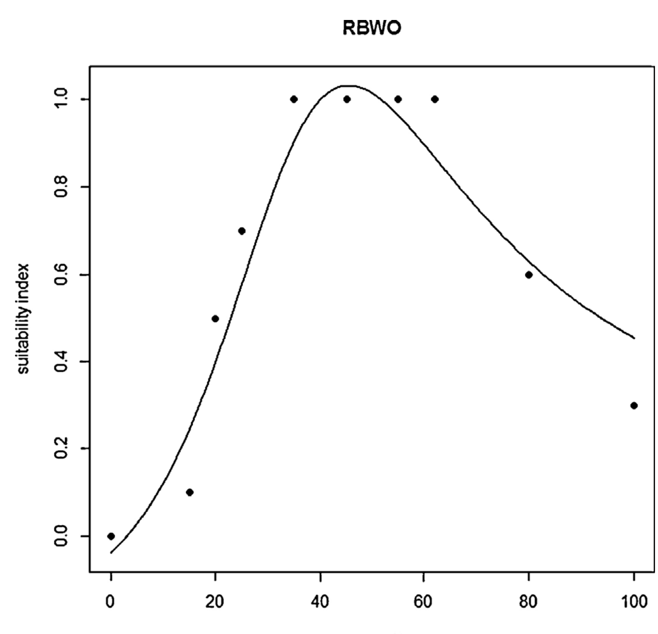

Fig. 3. Relationship between canopy percent per 0.004 ha and suitability index (SI) for red-bellied woodpecker (RBWO) habitat, and associated references.

Table 8
Relationship between dead wood density per ha and suitability index (SI) for red-bellied woodpecker (RBWO) habitat, and associated references.

Dead wood density (per 0.04 ha)	SI score (RBWO)	Reference
0	0.06	Straus et al. (2011)
1	0.93	Straus et al. (2011)
3	1	Adkins Giese and Cuthbert (2003)

3.3. Model validations

At the BES LTER sites, the American robin was recorded in 72 of the 83 bird monitoring/i-Tree locations, Carolina chickadee in 19 of the 83 locations, European starling in 62 of the 83 locations, northern cardinal in 60 of the 83 locations, and red-bellied woodpecker in 12 of the 83 locations. Spearman rank correlation identified a significant and positive relationship between the HSI score and mean bird abundance at the BES LTER i-Tree locations for American robin ($P = 0.0043$, $r_s = 0.31$), Carolina chickadee ($P = 0.0011$, $r_s = 0.3515$), northern cardinal ($P = 0.0022$, $r_s = 0.3311$), red-bellied woodpecker ($P = 0.0008$, $r_s = 0.3596$), and European starling ($P = 0.0349$, $r_s = 0.2333$). When testing the sensitivity of the models by subsequently removing individual variables from whole models, we found no discrepancies between these partial and full models in their ability to predict mean bird abundance better than chance for Carolina chickadee, European starling and red-bellied woodpecker. The spearman rank correlation did not detect a significant relationship between the HSI score and mean bird abundance in the American robin model when lawn percent was omitted ($P = 0.5976$, $r_s = 0.0593$). However, when the model omitted canopy cover and included lawn percent, we found a significant relationship between the HSI score and mean abundance ($P = 0.0071$, $r_s = 0.2950$). Similarly, when the percent shrub cover was removed from the northern cardinal model, the model failed to predict presence when this species was recorded, though a model with just percent shrubs was significant ($P = 0.0140$, $r_s = 0.2705$).

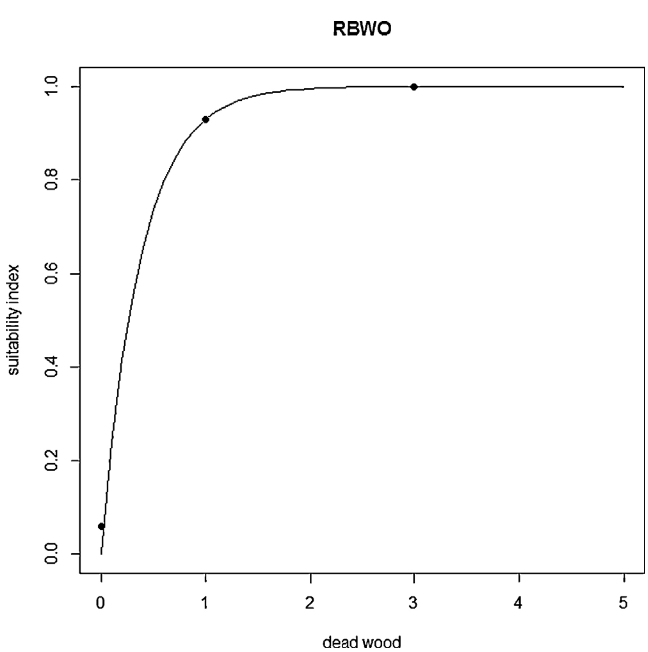

Fig. 4. Relationship between deadwood density per ha and suitability index (SI) for red-bellied woodpecker (RBWO) habitat, and associated references.

3.4. Illustrating applications

For the most part, habitat suitability in Baltimore and Syracuse declined from 2001 to 2009 (Table 9). Important resources such as canopy cover in Baltimore declined by 33.8% in vacant lots, and large tree density in Syracuse declined by 0.8 and 3.4 trees in residential and vacant lots between the two time periods (*unpublished i-Tree dataset*). Habitat suitability scores significantly decreased for Baltimore oriole, northern cardinal, and red-bellied woodpecker between 2001 and 2009 in Syracuse residential areas and vacant lots, and for scarlet tanagers in vacant lots only. Habitat suitability also differed for red-bellied woodpecker in Baltimore residential areas and for Carolina chickadee, red-bellied woodpecker, and wood thrush in Baltimore vacant lots. In contrast, habitat suitability increased for wood thrushes (Syracuse) and northern cardinals (Baltimore) in residential areas during this time period (Table 9). We failed to find a significant change in commercial, cemetery, golf course or institutional land-use plots in Baltimore and Syracuse.

4. Discussion

Integrating validated bird habitat suitability models into i-Tree can provide a more comprehensive assessment of the ecosystem services provided by the urban forest. Essentially, our models translate the i-Tree raw data's detailed information on the forest composition and structure into relative assessments of habitat value for birds. The bird habitat models suggest which species specifically, and guilds broadly, can be supported by an urban forest. By selecting which bird models to focus on (e.g., native or rare species), other societal values can be included in this assessment and guide general forest planning in urban areas. In addition, the bird habitat models have the capacity to provide specific targets (i.e., canopy percent or dead wood density) geared toward urban foresters and planners when determining how to manage the urban forest for wildlife.

Our validation efforts support the efficacy of using the habitat models to predict the habitat quality of urban areas for a variety of species. Although we were unable to validate the Baltimore oriole and scarlet tanager model at this time, we agree with Brooks (1997) that these untested models still have greater value than no information about these species' habitat relationships. In several cases, sensitivity analyses helped to identify particularly influential habitat parameters. For example, percent lawn for American robin and percent shrub cover for northern cardinal have strong influences on the habitat suitability for the respective species. Although the models with insignificant results highlight the unequal effect of these particular variables, the models that included all the habitat variables had a higher rank scores, suggesting the model had stronger predictive power when these variables were included.

The i-Tree habitat models link habitat features with an SI score reflecting the suitability of a site for that species. Each habitat variable has an optimal value for a particular species (i.e., when the suitability index score is 1.0, the site has the greatest potential to support said species). Less than optimal values result in lower SI scores and provide a baseline for habitat improvement recommendations. Compared with the other cities, Jersey City had the lowest mean SI scores for all but one species (Table 3). The i-Tree program assessed canopy coverage at 13%, well below the national average of 35.1% (Nowak & Greenfield, 2012). Eight species included canopy percent as an important limiting variable with optimal values ranging between 25% and 100% (Supplementary material).

Urban parks, vacant lots, and residential land-uses had high SI scores for most of the species modeled (Table 3), and species of conservation concern in particular (Dettmers & Rosenberg, 2000). For example, urban parks and vacant lots had the highest SI score for

Table 9
A comparison of suitability index (SI) scores for six bird species and mean values for two habitat variables at the same i-Tree monitoring plot in 2001 and 2009 in Syracuse, NY and Baltimore, MD for residential and vacant lot land-uses. The SI scores for American robin and European starling did not exhibit any significant changes. Species habitat models in commercial and institutional land-uses, and golf courses failed to show significant relationships.

	Residential				Vacant lot			
	2001	2009	*F*	*P*	2001	2009	*F*	*P*
BALTIMORE	*n* = 87	*n* = 90			*n* = 18	*n* = 5		
American robin	0.54	0.57	1.22	0.27	0.39	0.51	1.62	0.22
Baltimore oriole	0.35	0.33	0.09	0.75	0.35	0.49	0.58	0.45
Carolina chickadee	0.3	0.26	1.34	0.25	0.65	0.26	5.28	0.032
European starling	0.34	0.3	0.88	0.35	0.07	0.04	0.24	0.63
Northern cardinal[a]	0.35	0.33	0.47	0.49	0.22	0.55	16.71	0.0005
Red-bellied woodpecker	0.34	0.24	4.28	0.04	0.66	0.26	5.53	0.029
Scarlet tanager	0.01	0.01	0.97	0.33	0.1	0.01	2.05	0.17
Wood thrush	0.03	0.06	2.19	0.14	0.3	0.14	3.30	0.084
Tree canopy	25.31	24.74	0.02	0.88	52.22	18.4	5.50	0.03
SYRACUSE	*n* = 117	*n* = 113			*n* = 33	*n* = 30		
American robin	0.61	0.64	1.24	0.27	0.37	0.4	0.27	0.6
Baltimore oriole	0.46	0.22	46.37	<0.001	0.22	0.11	3.62	0.06
Black-capped chickadee	0.23	0.27	2.64	0.11	0.48	0.5	0.03	0.86
European starling	0.28	0.32	2.38	0.12	0.05	0.02	1.05	0.31
Northern cardinal	0.39	0.29	11.92	0.0007	0.32	0.17	6.81	0.01
Red-bellied woodpecker	0.24	0.16	7.57	0.0064	0.5	0.21	14.53	0.0003
Scarlet tanager	0.01	0	0.42	0.52	0.07	0.01	5.24	0.026
Wood thrush[a]	0.01	0.04	6.01	0.015	0.36	0.46	0.83	0.37
Large tree density	1.16	0.39	24.88	<0.0001	3.85	0.4	22.46	<0.0001

[a] An increase in suitability.

scarlet tanager and wood thrush, suggesting that when managed for wildlife, these urban land-uses have the potential to support rare species. Residential land-uses had the highest SI score for Baltimore oriole (Table 3) and although this land-use scored low for wood thrush, the patterns suggest the existence of potential habitat and the conservation value of residential areas (Lerman & Warren, 2011).

The active management of dead wood in urban areas has the potential to stabilize populations for a guild that often adapts well to cities (Chace & Walsh, 2006). Urban parks in Boston, MA and New York City had low SI scores compared to urban parks in Philadelphia, PA for red-bellied woodpecker, an obligate cavity nester. Boston and New York also had low densities of dead wood, an important nesting resource for the species (Shackelford et al., 2000). On average, Boston had 0.66 trees with dead wood (Dead Dens) per plot (6% of trees had some dead wood; *unpublished i-Tree dataset*) and New York City had 0.85 trees with dead wood per plot (6% of trees had some dead wood; Nowak, Hoehn, Crane, Stevens, & Walton, 2007). The model for dead wood density calculated an SI score of 1 (i.e., most suitable) when at least three trees with dead wood were present in a 0.04 ha plot. The model calculated an SI score of 0.93 with at least one tree with dead wood. Based on the dead wood present, these two cities failed to reach a suitability threshold that had a high likelihood of supporting species requiring dead wood (i.e., areas with at least one tree with dead wood) whereas Philadelphia, with an average nine trees per plot with dead wood (57% of all trees; *unpublished i-Tree dataset*), had a greater potential to support this species because of the presence of an important resource for cavity nesting species. Black-capped chickadee, an additional species belonging to this nesting guild, had similar patterns.

The differences in dead wood densities might be the result of different management regimes for these cities. Perhaps the former two cities have a more active urban forestry department and remove a greater degree of dead wood due to the hazards and esthetics associated with dead and dying limbs (Harris, Clark, & Matheny, 2004). Alternatively, the differences could also be due to different tree population structures (e.g., age or size distribution) among cities. By delineating a threshold of suitability for each habitat variable, the models provide specific targets for improving the habitat conditions for a particular species, which is necessary for identifying management goals (Kroll & Haufler, 2006). For example, the city of New York had low scores for red-bellied woodpecker, particularly in commercial and industrial land-uses. Based on the habitat model description for this species (see model example), the optimal values for key habitat features are as follows: six large trees (> 23 cm dbh) per 0.04 ha, 14 m^2/ha basal area, 35–62% canopy coverage per 0.04 ha, and at least three trees with dead wood within 0.04 ha (Tables 1–4, respectively). Managers can then review the i-Tree data and assess how well the actual habitat values accord with the optimal values. In New York City forest patches, the canopy percentage reached optimal values though the amount of deadwood fell below the threshold (*unpublished i-Tree dataset*). Thus incorporating management initiatives that encourage dead wood would improve the habitat conditions for this and other cavity nesting species. In sum, when cities or land-uses have low SI scores, the manager can pinpoint the sub-optimal variables and develop management plans that target these low scoring habitat features.

Our example of how the i-Tree habitat module can document SI changes over time demonstrated the potential for assessing the effectiveness of management plans (or lack thereof). For example, in the Baltimore i-Tree dataset, we noted a sharp decline of trees with dead wood between 2001 (3.59 trees per i-Tree plot) and 2009 (0.73 trees per i-Tree plot). The deadwood density threshold for a suitable site for red-bellied woodpecker was three. Therefore this loss of deadwood might explain why the suitability index for species that rely on this resource also declined. An effective management strategy would include more selective criteria for removing dead wood (e.g., only when posing a strong hazard risk), or perhaps encouraging the development and retention of snags in areas not frequented by people.

The models provide a substantial initial assessment of the habitat potential in the urban forest, while assisting decision makers with the ultimate goal of improving urban bird habitat (Beaudry et al., 2010). Although the number of studies focusing on urban birds has increased over the past 20 years (Ramalho & Hobbs, 2012), and many of these studies included recommendations on how to improve urban habitat, the recommendations are often for a specific city (Lerman & Warren, 2011), and not necessarily accessible to managers. The i-Tree tool was designed for urban managers and thus the wildlife component expands the capacity of the tool to allow for a more comprehensive assessment of the ecosystem services provided by the urban forest. With rapid habitat suitability assessment capabilities and ease of use for non-professional scientists, the wildlife component of i-Tree delivers a valuable tool that is applicable on a regional scale.

We recognize the importance of local and landscape features in limiting urban bird distribution (Chamberlain, Cannon, & Toms, 2004; McCaffrey & Mannan, 2012). We did not have spatial locations available for the majority of the i-Tree plots and thus did not incorporate these landscape variables into the SI calculations. However, landscape variables are known to influence the distribution for two of our modeled species: scarlet tanager and wood thrush (Hoover & Brittingham, 1998; Robinson, Thompson, Donovan, Whitehead, & Faaborg, 1995). We describe these models based on landscape features (e.g., percent forest cover within 1 km radius of i-Tree plot; Table 3), and will include the models in the i-Tree program when spatial data are available.

Although currently limited to the local scale, the i-Tree habitat models have the advantage of calculating SI for specific land-uses, a known feature that influences urban bird distribution (Blair, 1996), and thus enabling managers to target low-scoring land-uses independently. By discriminating among the land-use differences, the tool recognizes the different jurisdictions and land ownership, and the associated management strategies. For example, the strategy for increasing canopy coverage in city-owned open space might differ from residential lands, since the latter might require participation from private households and the former might require public support for urban forestry programs (Warren, Ryan, Lerman, & Tooke, 2011). This local scale also provides greater opportunities for intervention. For example, mangers can affect canopy percentage through tree planting efforts but have little opportunity to significantly increase the area of forest tracts embedded within the urban matrix. Thus, although protecting large tracts of contiguous forest is essential for forest interior species (Robinson et al., 1995), once the land becomes developed, there is little chance to effectively manage and incorporate management improvement plans at this scale.

Similar to other habitat models, the i-Tree habitat models were not as robust for generalist species compared with habitat specialists (Tirpak, Jones-Farrand, Thompson, Twedt, Baxter, et al., 2009). For example, the European starling, an urban exploiter (Blair, 1996), scored lower than expected for each city in all the urban land-uses (Table 4), indicating that the ten cities used in the habitat model demonstration supported few starlings. Based on personal observations and the numerous studies documenting starlings as one of the most abundant urban birds (Chace & Walsh, 2006), we can assume that the model did not accurately reflect starling habitat suitability. This was further supported during the validation process. The results from our models also suggested that variables other than those measured using i-Tree might better explain the habitat suitability of this ubiquitous species. Habitat specialists by their very nature are more restricted to a few key habitat features (Kilgo et al., 2002). The i-Tree habitat models also had the tendency to overestimate the suitability of potential habitat. The model calculated a high likelihood of occupancy (>0.5) for more sites than will be occupied since the models did not account for interspecific competition, an additional factor that limits distribution (Fielding & Bell, 1997; Shochat et al., 2010).

Future directions include integrating these models into the i-Tree program which involves coding the equations in i-Tree Eco. We plan to generate GIS range maps for each species to identify the regions these equations should be activated (based on Breeding Bird Survey data). We plan to model additional species in other regions, identify additional variables for the i-Tree data collection protocol that will help improve the estimation of the SI, and collect bird abundance data at i-Tree plots to further validate the models. We also urge future urban bird studies to adapt a habitat assessment protocol that includes the i-Tree variables and data collection at the same spatial scale (0.04 ha). These studies will enable us to further model validation efforts as well as compare urban bird habitats among cities.

The i-Tree habitat models provide a tool for local or regional initial assessments of the current state of the urban forest for providing bird habitat. The assessment can be the basis for an extensive and comprehensive conservation plan specifically geared toward urban land-uses. Results from this study will help guide urban foresters, planners, and landscape designers who require specific information such as how many trees and shrubs are necessary within an urban greening project to reach conservation goals targeted at improving the suitability of urban bird habitat. Given that more than 80% of Americans live in urban environments (US Census, 2012), it becomes imperative that urban forests provide opportunities for urban dwellers to connect with nature. This connection can improve and enhance health and well-being (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007) while generating interest and support for conservation initiatives that aim to improve urban biodiversity (Miller, 2005).

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2013.10.006.

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Benefits Summary of Trees by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Species	Trees		Carbon Storage			Gross Carbon Sequestration		
	Number	SE	(ton)	SE	($)	(ton/yr)	SE	($/yr)
Freeman maple	33,950	±20,972	4,842.44	±3,442.76	825,882.80	476.31	±387.30	81,235.16
Boxelder	1,174,313	±666,136	37,104.93	±18,779.31	6,328,280.92	3,292.14	±1,604.80	561,477.27
Japanese maple	24,342	±17,372	2,256.42	±2,208.18	384,833.96	24.82	±18.21	4,233.41
Red maple	4,148,190	±641,265	571,217.88	±120,877.87	97,421,743.15	21,211.45	±3,472.51	3,617,633.17
Silver maple	24,154	±17,259	47,546.28	±33,630.73	8,109,061.72	829.54	±589.90	141,478.24
Sugar maple	22,864	±16,520	16,422.90	±16,245.71	2,800,941.45	581.07	±546.50	99,102.22
Tree of heaven	315,323	±117,564	32,043.75	±24,485.41	5,465,091.01	1,247.10	±547.06	212,693.74
European alder	10,318	±10,317	200.28	±200.27	34,158.06	22.87	±22.87	3,900.78
Persian silk tree	274,627	±274,607	801.82	±801.77	136,751.90	113.25	±113.24	19,314.89
Downy serviceberry	6,866	±6,865	1,253.04	±1,252.95	213,707.15	51.08	±51.07	8,711.43
Smooth service berry	10,318	±10,317	28.44	±28.43	4,849.80	9.44	±9.44	1,610.28
Devils walking stick	72,298	±62,673	141.69	±123.31	24,165.14	93.24	±82.76	15,902.83
Pawpaw	313,592	±163,430	2,515.83	±1,314.35	429,076.60	432.54	±248.34	73,769.86
River birch	59,516	±37,341	25,287.20	±14,941.29	4,312,755.52	1,116.19	±807.76	190,367.09
hickory spp	24,238	±17,289	978.00	±945.65	166,797.98	13.99	±13.99	2,385.40
American hornbeam	1,631,060	±530,457	19,118.38	±6,217.81	3,260,658.10	1,385.39	±397.57	236,279.87
Bitternut hickory	194,402	±73,716	4,730.88	±2,624.85	806,856.05	272.90	±152.67	46,543.33
Pignut hickory	745,293	±211,127	72,699.82	±27,712.93	12,399,022.67	907.40	±251.78	154,758.67
Red hickory	31,142	±17,884	915.07	±583.21	156,065.80	94.07	±54.94	16,043.92
Mockernut hickory	1,193,932	±285,129	83,302.35	±23,327.90	14,207,294.26	1,627.18	±478.81	277,517.53
Eastern redbud	307,402	±129,719	2,553.27	±1,245.77	435,461.96	175.83	±72.20	29,987.38
Northern hackberry	206,921	±77,450	3,068.03	±1,190.36	523,254.58	262.14	±97.12	44,708.13
Fringe tree	70,211	±39,100	167.58	±90.42	28,580.89	35.02	±20.09	5,972.61
American hazlenut	20,636	±20,635	104.93	±104.93	17,896.38	0.58	±0.58	98.19
Flowering dogwood	853,939	±214,200	15,487.91	±3,920.81	2,641,477.39	1,667.72	±435.73	284,431.45
Leyland cypress	162,375	±79,182	89,425.40	±55,335.47	15,251,585.33	4,540.78	±2,349.35	774,434.44
Common persimmon	218,686	±70,805	11,589.04	±5,741.90	1,976,521.78	294.96	±174.50	50,305.69

Benefits Summary of Trees by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Avoided Runoff		Pollution Removal		Structural Value	
(ft³/yr)	($/yr)	(ton/yr)	($/yr)	($)	SE
362,878.59	24,256.93	3.54	1,566,610.29	23,220,361.43	±15,570,516.47
4,171,189.16	278,826.67	40.65	18,007,752.78	78,157,970.32	±37,547,969.98
183,189.47	12,245.46	1.79	790,860.97	27,450,755.62	±26,785,912.23
40,095,986.44	2,680,250.13	390.77	173,101,382.60	2,700,431,308.20	±510,161,355.26
2,791,337.20	186,589.30	27.20	12,050,690.64	178,018,044.17	±125,887,848.65
1,869,920.05	124,996.39	18.22	8,072,771.73	106,586,369.50	±104,539,761.99
2,027,275.76	135,514.96	19.76	8,752,103.84	95,227,506.17	±76,479,643.30
91,898.39	6,143.03	0.90	396,741.43	2,317,199.04	±2,317,086.75
191,934.30	12,830.01	1.87	828,613.91	4,486,642.79	±4,486,316.03
24,763.32	1,655.33	0.24	106,907.60	9,792,723.33	±9,792,010.14
3,022.88	202.07	0.03	13,050.29	424,104.53	±424,083.97
12,906.23	862.73	0.13	55,718.46	4,145,648.21	±3,682,595.61
405,822.65	27,127.56	3.96	1,752,007.34	15,369,633.80	±9,157,025.49
3,243,690.04	216,827.20	31.61	14,003,576.94	140,723,059.55	±94,270,081.93
3,949.30	263.99	0.04	17,049.80	798,816.58	±798,758.41
5,361,221.14	358,375.36	52.25	23,145,328.83	155,083,984.36	±54,443,037.31
1,362,545.28	91,080.49	13.28	5,882,346.17	52,615,453.68	±29,523,346.40
8,473,854.57	566,441.98	82.59	36,583,111.50	612,940,267.03	±201,221,538.91
235,441.74	15,738.30	2.29	1,016,443.17	5,069,068.19	±3,108,161.07
13,576,573.33	907,537.53	132.32	58,612,440.38	750,140,294.85	±228,367,341.19
346,970.00	23,193.50	3.38	1,497,930.16	38,380,211.65	±18,010,127.93
2,026,353.92	135,453.34	19.75	8,748,124.10	71,535,092.50	±31,148,166.87
28,163.22	1,882.59	0.27	121,585.53	1,008,379.25	±584,776.62
4,495.66	300.52	0.04	19,408.54	935,954.82	±935,909.46
1,038,854.79	69,443.13	10.12	4,484,917.75	115,212,644.47	±32,452,592.22
1,589,111.50	106,225.50	15.49	6,860,472.13	351,003,692.31	±227,348,752.24
558,551.35	37,336.84	5.44	2,411,363.81	35,578,345.37	±16,256,144.19

Benefits Summary of Trees by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Species	Trees		Carbon Storage			Gross Carbon Sequestration		
	Number	SE	(ton)	SE	($)	(ton/yr)	SE	($/yr)
Autumn olive	552,355	±215,395	7,610.54	±3,588.98	1,297,984.44	1,600.95	±618.40	273,043.27
American beech	6,036,002	±996,235	373,197.48	±73,337.01	63,649,179.44	12,282.48	±1,961.03	2,094,788.59
ash spp	90,469	±38,160	32,591.25	±19,367.44	5,558,468.65	0.00	±0.00	0.00
White ash	1,378,704	±372,338	86,417.07	±32,705.66	14,738,512.38	1,282.86	±418.56	218,793.64
Green ash	505,414	±207,548	24,279.05	±11,713.20	4,140,814.13	466.74	±195.41	79,602.60
Honeylocust	13,731	±13,730	5,320.82	±5,320.43	907,470.03	4.96	±4.96	846.47
Kentucky coffeetree	10,506	±10,506	536.31	±536.29	91,468.84	50.72	±50.72	8,649.91
Chinese holly	57,402	±43,028	4,886.19	±3,906.83	833,343.77	398.26	±288.76	67,924.08
American holly	1,304,446	±309,285	14,994.22	±3,146.02	2,557,278.82	1,086.32	±237.21	185,273.20
Savannah holly	30,915	±23,035	427.54	±390.32	72,917.52	40.65	±35.61	6,933.04
Chinese juniper	13,836	±13,835	531.26	±531.24	90,607.06	130.02	±130.02	22,175.38
Black walnut	341,996	±116,113	41,761.40	±16,496.30	7,122,446.27	3,121.57	±1,322.20	532,386.66
Eastern red cedar	5,348,192	±1,617,839	261,625.41	±69,482.12	44,620,458.86	8,193.59	±2,338.09	1,397,425.22
Mountain laurel	1,637,422	±694,324	7,942.46	±3,843.58	1,354,593.38	81.72	±33.80	13,937.29
Common crapemyrtle	28,374	±16,188	2,008.67	±1,916.00	342,580.29	41.87	±27.37	7,141.14
Spicebush	236,019	±119,067	1,450.21	±813.11	247,334.44	257.84	±140.55	43,975.31
Chinese privet	21,013	±21,012	225.44	±225.43	38,449.39	59.14	±59.13	10,085.83
privet spp	55,862	±44,243	264.10	±223.84	45,041.75	71.81	±71.81	12,247.08
Sweetgum	864,429	±322,160	26,928.04	±16,647.98	4,592,602.37	2,225.60	±1,071.14	379,577.82
Tulip tree	2,225,470	±425,012	677,669.74	±138,527.35	115,577,207.87	13,287.09	±2,254.47	2,266,125.00
Common privet	9,028	±9,028	69.14	±69.14	11,792.61	4.57	±4.57	779.06
Amur honeysuckle	73,168	±56,437	257.03	±218.34	43,836.43	68.09	±51.17	11,612.11
honeysuckle spp	27,501	±21,747	77.11	±61.68	13,150.74	27.20	±21.63	4,639.12
apple spp	19,535	±13,852	4,959.33	±4,934.87	845,819.12	7.61	±7.61	1,298.53
Hardwood	196,638	±52,085	17,103.18	±8,917.50	2,916,963.68	7.25	±7.25	1,236.42
Southern magnolia	13,836	±13,835	475.77	±475.75	81,143.16	86.83	±86.83	14,809.60
White mulberry	27,567	±16,737	3,335.55	±3,309.81	568,881.07	162.42	±154.05	27,700.66

Benefits Summary of Trees by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Avoided Runoff		Pollution Removal		Structural Value	
(ft^3/yr)	($/yr)	(ton/yr)	($/yr)	($)	SE
736,067.68	49,203.07	7.17	3,177,732.84	21,630,403.15	±8,527,825.17
70,472,269.32	4,710,778.45	686.82	304,241,105.90	2,188,213,859.60	±409,932,883.63
0.00	0.00	0.00	0.00	0.00	±0.00
1,354,123.67	90,517.54	13.20	5,845,988.59	61,852,597.42	±22,817,242.30
821,500.01	54,913.86	8.01	3,546,559.16	35,645,151.94	±23,527,831.23
4,147.33	277.23	0.04	17,904.76	82,130.74	±82,124.76
162,305.26	10,849.43	1.58	700,700.17	11,743,157.36	±11,742,598.49
133,130.74	8,899.24	1.30	574,748.67	36,657,089.86	±28,899,276.86
2,929,529.69	195,826.89	28.55	12,647,291.79	149,157,289.25	±31,904,606.05
19,376.54	1,295.24	0.19	83,651.90	3,405,225.01	±2,503,970.42
29,686.91	1,984.45	0.29	128,163.57	5,407,032.32	±5,406,836.92
5,193,193.30	347,143.40	50.61	22,419,923.30	393,055,811.58	±154,629,847.17
13,324,706.06	890,701.25	129.86	57,525,085.33	1,483,445,358.10	±451,748,900.21
672,760.39	44,971.24	6.56	2,904,424.21	79,453,394.66	±38,258,041.18
122,321.04	8,176.65	1.19	528,081.29	15,379,553.66	±13,771,139.01
164,089.93	10,968.73	1.60	708,404.92	6,832,089.33	±4,016,163.51
17,275.67	1,154.81	0.17	74,582.07	789,672.31	±789,634.73
27,884.79	1,863.98	0.27	120,383.50	2,138,868.63	±2,138,766.84
5,215,653.77	348,644.79	50.83	22,516,889.05	243,650,744.92	±110,488,199.84
55,848,629.92	3,733,248.91	544.30	241,108,298.25	4,440,278,157.80	±871,378,728.82
4,731.01	316.25	0.05	20,424.58	149,197.27	±149,189.01
70,722.65	4,727.52	0.69	305,322.04	3,700,653.08	±2,764,889.30
8,935.84	597.32	0.09	38,577.59	1,326,817.27	±1,223,418.88
5,360.88	358.35	0.05	23,143.85	426,549.46	±426,525.84
3,452.99	230.82	0.03	14,907.15	162,492.16	±162,484.28
78,256.32	5,231.11	0.76	337,846.22	5,450,133.36	±5,449,936.40
316,345.08	21,146.35	3.08	1,365,716.99	35,377,960.55	±34,453,057.94

Benefits Summary of Trees by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Species	Trees		Carbon Storage			Gross Carbon Sequestration		
	Number	SE	(ton)	SE	($)	(ton/yr)	SE	($/yr)
Red mulberry	103,744	±54,238	37,812.45	±36,922.39	6,448,948.31	192.38	±123.74	32,811.25
Black tupelo	4,154,291	±750,892	93,687.84	±16,191.89	15,978,547.92	8,156.22	±1,364.66	1,391,051.40
Eastern hophornbeam	175,402	±175,394	1,071.69	±1,071.64	182,778.27	132.10	±132.10	22,530.49
Royal paulownia	6,866	±6,865	650.75	±650.71	110,986.79	15.63	±15.63	2,666.20
pine spp	31,142	±17,884	16,972.29	±11,387.33	2,894,640.54	0.00	±0.00	0.00
Softwood	31,331	±18,002	1,227.24	±737.24	209,306.32	0.00	±0.00	0.00
Shortleaf pine	48,892	±33,787	6,350.61	±6,204.01	1,083,103.14	370.51	±357.93	63,191.31
White spruce	27,085	±14,909	489.54	±287.05	83,490.95	69.48	±38.74	11,850.26
Eastern white pine	182,795	±97,490	33,266.65	±18,800.25	5,673,658.12	1,610.12	±899.46	274,606.98
Loblolly pine	10,506	±10,506	245.61	±245.60	41,889.01	59.18	±59.18	10,093.37
Virginia pine	4,188,548	±1,313,676	230,739.45	±62,798.42	39,352,828.12	10,602.39	±3,517.89	1,808,247.85
American sycamore	282,332	±112,602	39,255.81	±24,335.53	6,695,115.69	2,171.93	±955.55	370,423.99
Eastern cottonwood	20,824	±14,725	728.53	±519.08	124,251.25	147.60	±113.24	25,173.67
Bigtooth aspen	138,253	±85,514	8,300.64	±5,400.27	1,415,681.70	204.75	±139.05	34,920.21
plum spp	12,983	±9,856	53.92	±40.93	9,195.71	14.24	±14.24	2,428.90
Sweet cherry	66,948	±46,251	53,676.31	±53,616.67	9,154,544.29	38.91	±24.98	6,635.50
Kanzan cherry	31,040	±27,370	2,894.05	±2,376.57	493,583.01	305.57	±240.02	52,114.85
Black cherry	595,925	±144,745	38,309.80	±13,245.41	6,533,771.54	3,680.01	±1,106.69	627,629.50
Higan cherry	72,226	±44,477	3,098.95	±2,594.62	528,528.20	168.64	±96.41	28,761.53
Yoshino flowering cherry	39,069	±27,704	3,567.55	±3,351.95	608,449.42	242.97	±181.54	41,439.34
Callery pear	189,657	±122,240	29,303.56	±26,543.82	4,997,748.80	890.03	±581.68	151,795.93
'Bradford' callery pear	9,028	±9,028	40.20	±40.20	6,855.87	10.03	±10.03	1,710.41
oak spp	116,192	±39,189	106,679.68	±47,796.09	18,194,318.26	0.00	±0.00	0.00
White oak	2,066,401	±361,352	860,002.38	±169,812.37	146,674,208.26	11,459.17	±2,240.55	1,954,371.96
Swamp white oak	10,506	±10,506	56.56	±56.56	9,646.38	15.85	±15.85	2,703.32
Scarlet oak	199,901	±73,007	58,057.64	±19,890.61	9,901,784.45	1,563.56	±706.09	266,665.87
Southern red oak	294,869	±127,130	110,251.60	±57,706.80	18,803,513.93	1,511.96	±626.31	257,866.64

Benefits Summary of Trees by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Avoided Runoff		Pollution Removal		Structural Value	
(ft^3/yr)	($/yr)	(ton/yr)	($/yr)	($)	SE
646,968.86	43,247.18	6.31	2,793,077.68	120,447,197.43	±113,947,615.23
10,742,995.67	718,124.63	104.70	46,379,390.26	959,295,849.09	±178,184,283.64
699,489.76	46,757.98	6.82	3,019,819.55	15,525,102.18	±15,524,349.81
51,031.92	3,411.27	0.50	220,313.73	1,491,457.50	±1,491,348.88
0.00	0.00	0.00	0.00	0.00	±0.00
0.00	0.00	0.00	0.00	0.00	±0.00
308,350.69	20,611.96	3.01	1,331,203.84	67,828,889.19	±66,739,865.32
16,497.93	1,102.82	0.16	71,224.44	6,591,562.40	±3,770,341.07
5,237,978.72	350,137.12	51.05	22,613,269.76	364,098,125.05	±210,247,135.08
30,865.93	2,063.26	0.30	133,253.63	4,330,257.43	±4,330,051.35
12,560,471.74	839,615.36	122.41	54,225,752.17	1,340,788,123.70	±365,373,181.90
5,327,298.98	356,107.81	51.92	22,998,880.97	303,141,962.64	±221,108,767.88
128,623.44	8,597.94	1.25	555,289.86	5,241,918.66	±3,726,484.73
792,333.83	52,964.23	7.72	3,420,643.67	23,113,830.62	±14,371,414.14
5,423.67	362.55	0.05	23,414.93	101,567.30	±101,561.67
297,617.08	19,894.47	2.90	1,284,864.97	80,213,855.03	±79,711,133.52
165,691.91	11,075.82	1.61	715,320.95	10,780,400.72	±8,559,484.38
3,693,830.86	246,917.25	36.00	15,946,913.56	152,311,199.29	±50,984,329.59
427,656.42	28,587.05	4.17	1,846,267.51	18,206,464.10	±16,082,468.18
133,080.58	8,895.88	1.30	574,532.14	17,623,438.05	±15,952,447.08
1,819,300.64	121,612.69	17.73	7,854,238.90	144,817,564.59	±122,867,962.18
5,593.12	373.88	0.05	24,146.47	502,451.30	±502,423.47
0.00	0.00	0.00	0.00	0.00	±0.00
61,358,909.62	4,101,588.21	598.00	264,897,138.95	4,746,666,405.20	±858,445,043.21
4,649.96	310.83	0.05	20,074.69	462,284.96	±462,262.96
5,793,065.82	387,242.38	56.46	25,009,677.82	274,334,353.14	±100,532,994.35
7,755,567.24	518,427.45	75.59	33,482,139.50	601,325,838.42	±338,741,696.47

Benefits Summary of Trees by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Species	Trees		Carbon Storage			Gross Carbon Sequestration		
	Number	SE	(ton)	SE	($)	(ton/yr)	SE	($/yr)
Shingle oak	20,636	±20,635	512.03	±512.01	87,327.48	65.24	±65.23	11,125.93
Blackjack oak	152,258	±69,901	5,595.21	±3,792.83	954,268.16	169.24	±97.97	28,864.48
Swamp chestnut oak	41,271	±41,269	25,488.62	±25,487.39	4,347,108.75	201.71	±201.70	34,401.65
Pin oak	312,139	±107,782	73,208.40	±38,725.51	12,485,761.16	2,656.30	±1,214.32	453,034.37
Willow oak	269,295	±124,474	77,375.79	±36,968.11	13,196,513.40	1,923.08	±788.23	327,982.89
Chestnut oak	512,670	±164,161	259,830.47	±99,917.79	44,314,329.34	2,244.78	±779.49	382,849.50
Northern red oak	744,933	±141,188	386,080.45	±127,680.42	65,846,380.64	3,423.50	±912.44	583,880.65
Post oak	42,210	±24,977	16,883.93	±14,938.33	2,879,570.88	80.74	±51.59	13,769.77
Black oak	213,166	±64,565	95,966.09	±41,981.53	16,367,105.82	1,637.31	±629.60	279,244.21
Catawba rosebay	10,506	±10,506	226.60	±226.59	38,647.12	3.00	±3.00	510.96
Shining sumac	6,866	±6,865	7.17	±7.16	1,222.06	3.08	±3.08	526.02
Smooth sumac	54,925	±54,921	105.32	±105.32	17,963.00	44.89	±44.88	7,655.34
Multiflora rose	10,318	±10,317	86.00	±86.00	14,667.49	0.55	±0.55	94.53
Black locust	157,408	±61,454	16,006.83	±10,124.70	2,729,980.49	694.03	±365.14	118,367.14
Sassafras	175,961	±73,981	4,879.20	±2,373.22	832,152.26	506.21	±247.57	86,334.54
Black willow	185,870	±121,519	7,014.77	±4,568.23	1,196,376.16	944.68	±570.17	161,115.35
lilac spp	9,028	±9,028	57.24	±57.23	9,761.48	10.36	±10.36	1,766.70
Baldcypress	6,866	±6,865	247.74	±247.72	42,252.04	51.75	±51.74	8,825.65
Northern white cedar	20,702	±15,445	1,170.73	±908.59	199,669.74	87.21	±62.76	14,873.83
Oriental arborvitae	17,372	±12,550	1,005.70	±918.38	171,523.34	119.19	±94.44	20,328.29
Littleleaf linden	41,508	±41,506	239.53	±239.52	40,852.19	102.78	±102.77	17,528.95
Eastern hemlock	52,014	±42,815	6,704.68	±6,113.25	1,143,490.20	194.00	±138.95	33,086.12
American elm	1,031,120	±344,202	65,780.51	±23,586.02	11,218,927.93	4,449.05	±1,663.61	758,789.97
Slippery elm	163,071	±87,718	5,475.05	±3,286.12	933,774.98	791.77	±483.05	135,036.96
elm spp	104,813	±67,540	12,799.18	±10,896.86	2,182,912.29	497.74	±337.60	84,890.84
Highbush blueberry	72,224	±72,221	266.91	±266.90	45,521.49	76.13	±76.12	12,983.59
Black haw	367,818	±116,582	5,942.87	±2,901.25	1,013,562.08	346.66	±184.80	59,122.56

Benefits Summary of Trees by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Avoided Runoff		Pollution Removal		Structural Value	
(ft^3/yr)	($/yr)	(ton/yr)	($/yr)	($)	SE
28,397.41	1,898.25	0.28	122,596.56	1,663,905.90	±1,663,825.26
509,163.37	34,035.46	4.96	2,198,147.28	17,541,073.67	±10,654,945.82
1,773,668.28	118,562.36	17.29	7,657,236.03	56,291,967.81	±56,289,239.83
4,274,259.75	285,716.51	41.66	18,452,726.51	339,431,998.37	±194,019,225.91
7,358,065.24	491,856.09	71.71	31,766,053.90	596,502,710.90	±254,155,825.82
11,463,364.47	766,278.29	111.72	49,489,348.33	902,696,013.01	±357,751,342.29
22,546,745.11	1,507,156.25	219.74	97,338,240.02	1,902,525,273.80	±551,424,558.25
1,725,926.56	115,371.02	16.82	7,451,126.66	125,430,751.88	±105,085,100.85
4,447,470.91	297,294.96	43.34	19,200,509.40	344,414,047.02	±147,563,189.75
18,541.99	1,239.46	0.18	80,049.03	924,152.98	±924,109.00
899.98	60.16	0.01	3,885.38	373,035.04	±373,007.87
12,320.11	823.55	0.12	53,188.05	3,495,720.34	±3,495,465.76
6,903.09	461.44	0.07	29,801.86	631,511.66	±631,481.06
428,351.31	28,633.51	4.17	1,849,267.47	37,975,750.27	±21,453,620.70
361,738.56	24,180.72	3.53	1,561,688.61	16,204,771.05	±6,173,126.96
878,794.46	58,743.76	8.56	3,793,909.30	38,114,728.75	±20,715,082.92
1,398.26	93.47	0.01	6,036.54	203,190.85	±203,179.60
32,190.93	2,151.83	0.31	138,973.88	6,644,542.13	±6,644,058.22
23,484.27	1,569.83	0.23	101,385.70	7,947,550.85	±5,813,099.04
18,805.09	1,257.04	0.18	81,184.85	9,718,222.31	±9,070,229.90
28,923.54	1,933.42	0.28	124,867.96	5,814,725.19	±5,814,515.06
814,914.55	54,473.65	7.94	3,518,128.55	59,642,489.29	±51,304,253.18
8,310,372.19	555,513.86	80.99	35,877,329.48	297,117,530.53	±108,973,171.53
899,277.63	60,112.97	8.76	3,882,338.72	64,340,733.61	±39,258,257.69
871,308.84	58,243.38	8.49	3,761,592.59	49,172,477.18	±36,580,642.18
22,750.74	1,520.79	0.22	98,218.94	3,668,446.89	±3,668,269.11
463,258.17	30,966.88	4.51	1,999,966.48	27,484,890.71	±16,180,268.56

Benefits Summary of Trees by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Species	Trees		Carbon Storage			Gross Carbon Sequestration		
	Number	SE	(ton)	SE	($)	(ton/yr)	SE	($/yr)
Japanese zelkova	18,056	±18,055	2,197.02	±2,196.90	374,704.11	134.59	±134.58	22,953.82
Total	**51,192,519**	**±4,158,166**	**5,450,693.22**	**±380,833.57**	**929,620,819.20**	**150,919.96**	**±9,551.43**	**25,739,539.38**

Carbon storage and gross carbon sequestration value is calculated based on the price of $170.55 per ton.
Due to limits of available models, i-Tree Eco will limit carbon storage to a maximum of 7,500 kg (16,534.7 lbs) and not estimate additional storage for any tree beyond a diameter of 254 cm (100 in). Whichever limit results in lower carbon storage is used.
Avoided runoff value is calculated by the price $0.067/ft^3. The user-designated weather station reported 38.9 inches of total annual precipitation. Eco will always use the hourly measurements that have the greatest total rainfall or user-submitted rainfall if provided.
Pollution removal value is calculated based on the prices of $1,327.00 per ton (CO), $125,615.84 per ton (O3), $37,096.74 per ton (NO2), $13,956.79 per ton (SO2), $5,718,057.33 per ton (PM2.5).
Structural value is the estimated local cost of having to replace a tree with a similar tree.
A value of zero may indicate that ancillary data (pollution, weather, energy, etc.) is not available for this location or that the reported amounts are too small to be shown.

Benefits Summary of Trees by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Avoided Runoff		Pollution Removal		Structural Value	
(ft^3/yr)	($/yr)	(ton/yr)	($/yr)	($)	SE
333,138.94	22,268.95	3.25	1,438,219.05	51,070,577.18	±51,067,748.71
433,476,085.18	**28,976,075.56**	**4,224.65**	**1,871,392,035.47**	**29,028,347,810.00**	**±2,060,209,868.10**

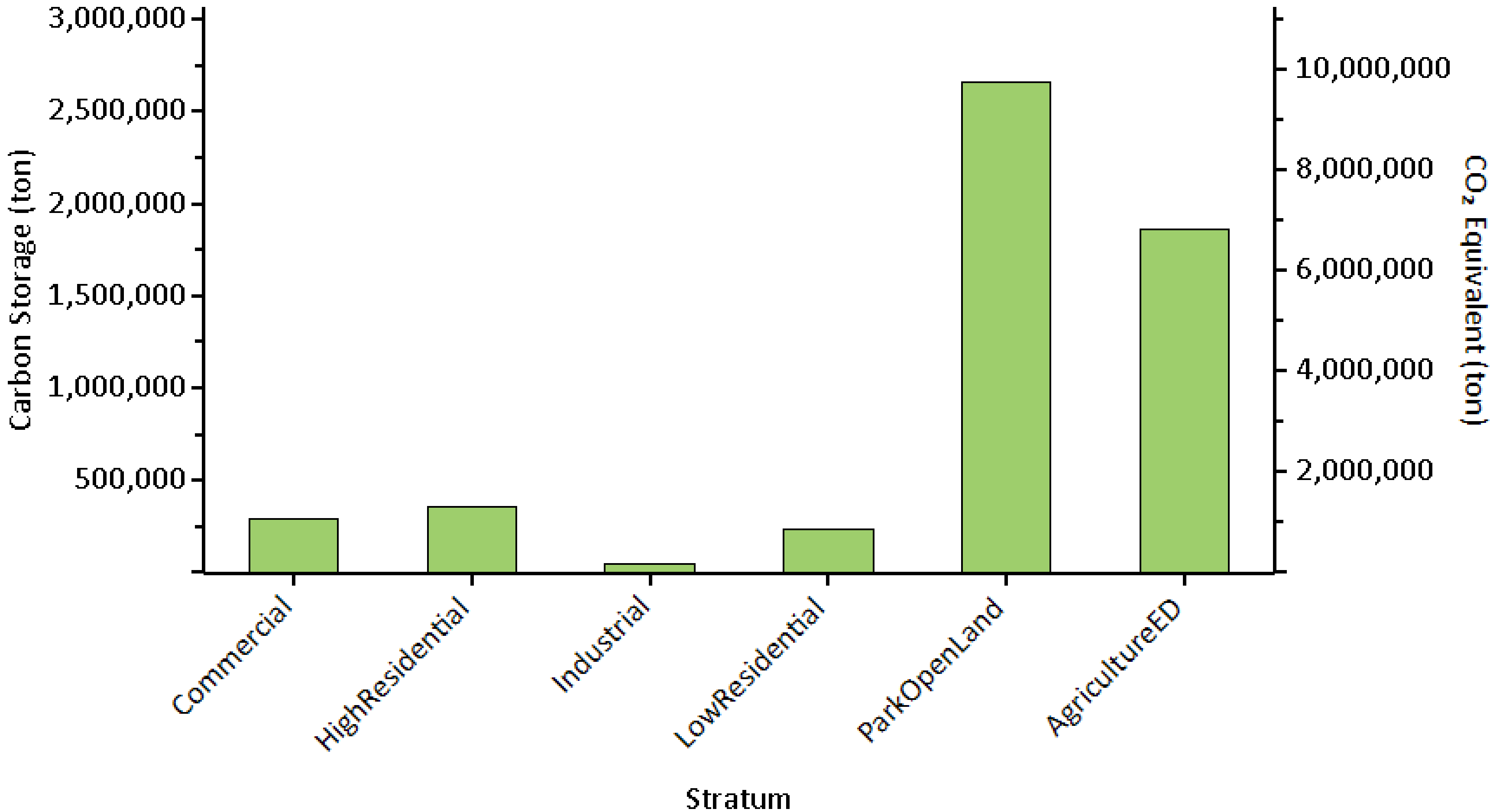
Carbon Storage of Trees by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Stratum	Carbon Storage (ton)	Carbon Storage (%)	CO_2 Equivalent (ton)
Commercial	292,713.0	5.4%	1,073,378.6
HighResidential	356,124.9	6.5%	1,305,910.2
Industrial	48,930.3	0.9%	179,427.5
LowResidential	235,632.7	4.3%	864,065.0
ParkOpenLand	2,662,216.3	48.8%	9,762,347.1
AgricultureED	1,855,076.0	34.0%	6,802,563.7
Study Area	**5,450,693.2**	**100%**	**19,987,692.0**

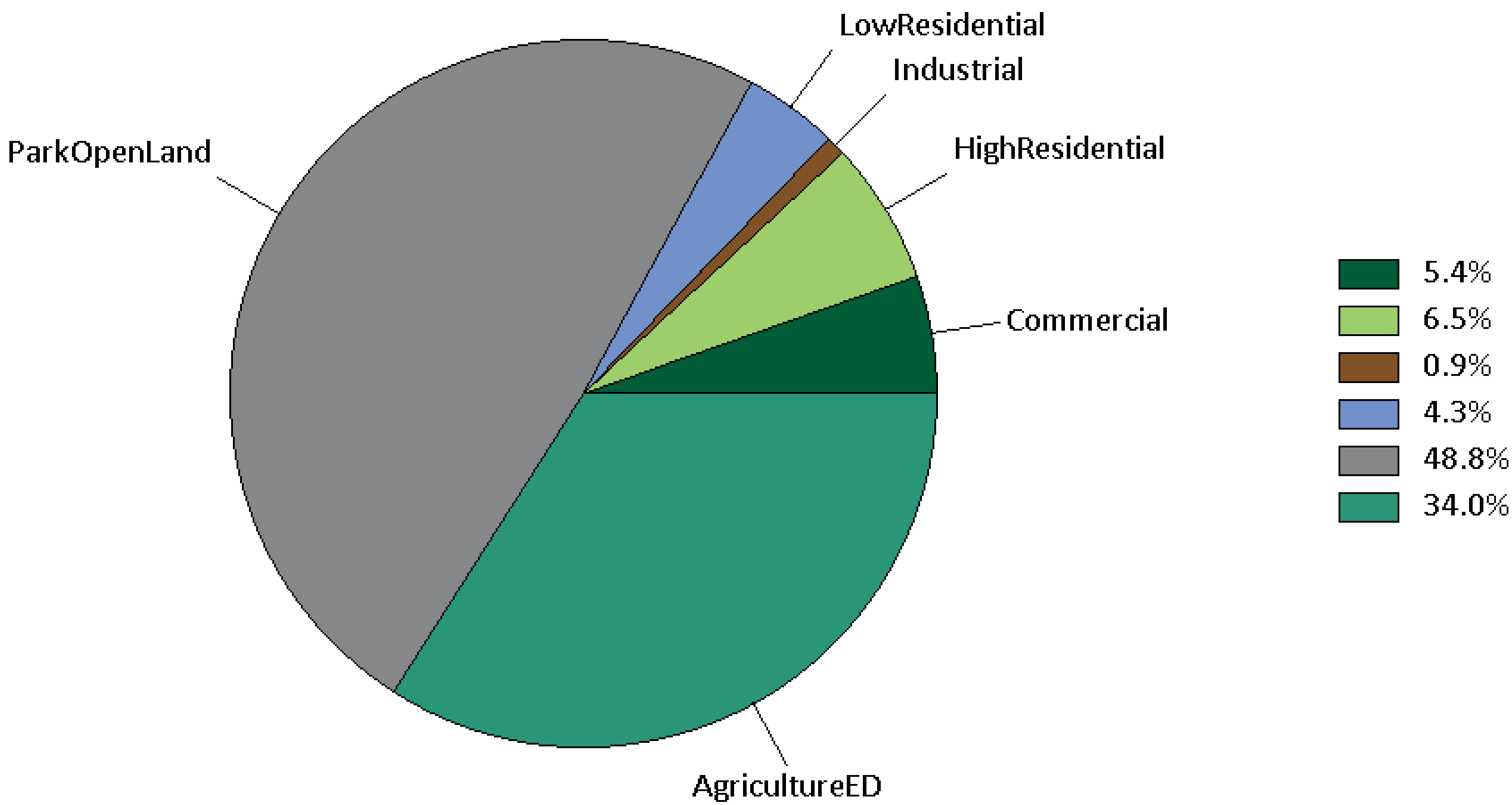
Carbon Storage of Trees by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021



Carbon Storage of Trees by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021



Carbon Storage of Trees by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Due to limits of available models, i-Tree Eco will limit carbon storage to a maximum of 7,500 kg (16,534.7 lbs) and not estimate additional storage for any tree beyond a diameter of 254 cm (100 in). Whichever limit results in lower carbon storage is used.

Diversity Indices by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Stratum	Richness	SPP/ac	Shannon	Menhinick	Simpson	Evenness	Rarefaction
Commercial	52	28.9	3.0	2.3	14.4	0.8	26.8
HighResidential	49	21.3	3.3	2.7	20.1	0.9	33.3
Industrial	21	12.4	2.3	1.7	7.1	0.8	18.7
LowResidential	31	22.1	2.6	2.6	8.0	0.8	26.1
ParkOpenLand	66	10.5	3.3	1.4	15.2	0.8	31.1
AgricultureED	64	8.9	3.1	1.7	13.7	0.8	29.0
Study Area	**105**	**12.5**	**3.4**	**1.5**	**19.1**	**0.7**	**N/A**

Richness: is the number of species sampled in each stratum or city (i.e. species richness)
SPP/ac: is the number of species found per acre of area sampled
Shannon: is the Shannon-Wiener diversity index
Menhinick: is Menhinick's diversity index
Simpson: is Simpson's diversity index
Evenness: is Shannon-Wiener's evenness index
Rarefaction: is the results of Sanders' Rarefaction technique

Energy Effects of Trees

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Amounts

Type	Heating	Cooling	Total
MBTU	174,825.627	N/A	174,825.627
MWH	2,765.234	51,095.311	53,860.545
Carbon Avoided (ton)	4,560.736	7,797.974	12,358.710

Energy Values ($)

Type	Heating	Cooling	Total
MBTU	2,358,452	N/A	2,358,452
MWH	308,485	5,700,108	6,008,593
Carbon Avoided	777,838	1,329,952	2,107,789

Carbon is calculated based on the price of $170.55 per ton.
Energy saving value is calculated based on the prices of $111.56 per MWH and $13.49 per MBTU. Trees less than or equal to 10ft/3m tall or further than 60ft/18m away from buildings do not provide energy benefits to nearby buildings.

Ground Cover Composition by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

	Building		Cement		Tar		Rock		Bare soil		Duff/mulch	
Stratum	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**
Commercial	9.4	±6.1	6.1	±2.4	15.0	±5.7	1.7	±1.6	1.1	±0.6	38.4	±8.6
HighResidential	6.6	±2.7	12.0	±4.3	17.6	±4.7	1.0	±0.5	2.7	±1.2	23.8	±6.3
Industrial	7.8	±5.9	2.9	±2.3	19.1	±7.5	17.8	±6.3	4.4	±1.9	13.1	±7.0
LowResidential	19.1	±4.7	3.6	±1.3	13.1	±6.7	1.1	±0.7	2.9	±2.1	18.9	±7.0
ParkOpenLand	0.4	±0.3	0.7	±0.4	2.7	±1.3	2.2	±0.7	5.2	±1.7	47.8	±4.8
AgricultureED	1.5	±0.6	1.1	±0.6	7.4	±2.0	0.7	±0.3	3.8	±1.1	27.9	±3.8
Study Area	**4.1**	**±0.7**	**2.7**	**±0.6**	**8.4**	**±1.3**	**1.9**	**±0.4**	**3.9**	**±0.7**	**33.2**	**±2.4**

	Herbs		Grass		Unmaintained grass		Water		Other Impervious		PLANTABLE SPACE	
Stratum	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**	**%**	**SE**
Commercial	10.0	±3.0	12.4	±3.7	5.0	±3.7	0.8	±0.8			3.8	±1.4
HighResidential	5.2	±1.3	23.6	±4.2	5.0	±3.7			2.6	±1.2	13.6	±3.1
Industrial	14.4	±5.5	9.9	±3.7	5.3	±3.4	0.3	±0.3	5.0	±3.5	1.1	±0.6
LowResidential	4.9	±1.7	31.8	±6.6					4.5	±2.8	17.0	±3.9
ParkOpenLand	18.7	±2.6	9.5	±2.8	6.3	±1.5	6.3	±2.2	0.1	±0.1	4.0	±1.1
AgricultureED	13.9	±2.1	34.6	±4.2	5.8	±1.9	2.9	±1.3	0.2	±0.1	25.7	±4.0
Study Area	**13.5**	**±1.2**	**22.8**	**±2.0**	**5.3**	**±1.0**	**3.2**	**±0.9**	**1.0**	**±0.3**	**14.4**	**±1.6**

Ground Cover Composition by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

	TREE		SHRUB	
Stratum	**%**	**SE**	**%**	**SE**
Commercial	43.6	±9.1	19.3	±2.6
HighResidential	34.6	±6.9	14.0	±3.8
Industrial	15.6	±7.2	14.0	±3.4
LowResidential	33.1	±9.1	12.7	±3.9
ParkOpenLand	67.2	±4.3	30.4	±3.4
AgricultureED	40.2	±4.3	17.8	±2.7
Study Area	**47.1**	**±2.5**	**21.0**	**±1.6**

Hydrology Effects of Trees by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Stratum	Number of Trees	Leaf Area (ac)	Potential Evapotranspiration (ft^3/yr)	Evaporation (ft^3/yr)	Transpiration (ft^3/yr)	Water Intercepted (ft^3/yr)	Avoided Runoff (ft^3/yr)	Avoided Runoff Value ($/yr)
ParkOpenLand	23,772,131	825,548.14	3,386,708,141.92	991,469,693.02	438,327,845.55	993,020,688.57	221,575,963.11	14,811,432.67
AgricultureED	17,262,141	516,093.52	2,117,209,205.13	619,819,799.26	274,021,767.03	620,789,408.07	138,518,776.66	9,259,404.79
HighResidential	3,349,464	103,622.83	425,099,727.00	124,449,311.30	55,018,926.84	124,643,992.32	27,812,222.81	1,859,131.56
Commercial	3,995,828	83,137.59	341,061,566.99	99,846,869.87	44,142,209.96	100,003,064.31	22,314,011.72	1,491,598.99
LowResidential	2,199,922	69,312.60	284,346,303.01	83,243,294.06	36,801,784.26	83,373,514.86	18,603,405.82	1,243,560.40
Industrial	613,035	17,331.33	71,099,622.73	20,814,643.06	9,202,134.68	20,847,204.24	4,651,705.06	310,947.16
Total	**51,192,519**	**1,615,046.01**	**6,625,524,566.78**	**1,939,643,610.57**	**857,514,668.32**	**1,942,677,872.36**	**433,476,085.18**	**28,976,075.56**

Avoided runoff value is calculated by the price $0.067/$ft^3$. The user-designated weather station reported 38.9 inches of total annual precipitation. Eco will always use the hourly measurements that have the greatest total rainfall or user-submitted rainfall if provided.

Land Use Composition by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

	Stratum			
Land Use	**AgricultureED (%)**	**Commercial (%)**	**HighResidential (%)**	**Industrial (%)**
Agriculture	29.1	0.0	0.0	5.9
Commercial/Indu	0.0	46.9	4.3	64.7
Golf course	1.4	0.0	4.3	0.0
Institutional	0.6	0.0	4.3	0.0
Multi-family re	0.0	5.6	26.1	0.0
Park	0.1	11.1	4.3	0.0
Residential	53.6	0.0	34.8	0.0
Transportation	0.0	3.3	0.0	5.9
Utility	1.4	2.2	4.3	11.8
Vacant	12.5	27.8	17.4	11.8
Water/wetland	1.4	3.1	0.0	0.0
Total	**100.0**	**100.0**	**100.0**	**100.0**

Land Use Composition by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Land Use	Stratum LowResidential (%)	ParkOpenLand (%)
Agriculture	0.0	9.8
Commercial/Indu	0.0	1.6
Golf course	7.1	1.6
Institutional	7.1	4.8
Multi-family re	0.0	2.3
Park	0.0	45.3
Residential	78.6	12.7
Transportation	0.0	0.0
Utility	0.0	2.2
Vacant	7.1	13.7
Water/wetland	0.0	6.1
Total	**100.0**	**100.0**

Pollution Removal by Trees and Shrubs - Monthly Removal

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

i-Tree Eco

		Removal (pounds)			Value ($)		
Pollutant	**Month**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
CO	1	771.621	N/A	N/A	511.97	N/A	N/A
	2	681.237	N/A	N/A	452.00	N/A	N/A
	3	756.688	N/A	N/A	502.06	N/A	N/A
	4	7,764.835	N/A	N/A	5,151.98	N/A	N/A
	5	20,882.319	N/A	N/A	13,855.46	N/A	N/A
	6	17,356.757	N/A	N/A	11,516.24	N/A	N/A
	7	30,942.665	N/A	N/A	20,530.52	N/A	N/A
	8	34,682.554	N/A	N/A	23,011.95	N/A	N/A
	9	30,711.315	N/A	N/A	20,377.02	N/A	N/A
	10	23,442.902	N/A	N/A	15,554.41	N/A	N/A
	11	1,755.307	N/A	N/A	1,164.65	N/A	N/A
	12	1,253.111	N/A	N/A	831.44	N/A	N/A
	Annual	**171,001.309**	**N/A**	**N/A**	**113,459.72**	**N/A**	**N/A**
NO2	1	60,452.769	60,452.769	60,452.769	1,121,300.34	1,121,300.34	1,121,300.34
	2	56,374.536	56,374.536	56,374.536	1,045,655.75	1,045,655.75	1,045,655.75
	3	74,108.842	74,108.842	74,108.842	1,374,598.23	1,374,598.23	1,374,598.23
	4	198,302.401	205,313.740	129,786.684	3,678,186.32	3,808,235.22	2,407,331.44
	5	340,066.491	362,698.871	88,129.591	6,307,679.11	6,727,472.86	1,634,660.27
	6	316,304.735	333,870.388	77,065.189	5,866,937.27	6,192,751.49	1,429,433.64
	7	257,641.010	272,121.636	65,660.465	4,778,820.78	5,047,412.80	1,217,894.59
	8	296,063.948	315,481.514	84,366.566	5,491,503.66	5,851,667.86	1,564,862.29
	9	356,038.728	376,409.538	97,084.507	6,603,938.08	6,981,783.40	1,800,759.36
	10	268,512.260	284,695.404	114,315.578	4,980,464.76	5,280,635.69	2,120,367.65
	11	98,685.178	98,685.178	98,685.178	1,830,449.20	1,830,449.20	1,830,449.20
	12	79,737.765	79,737.765	79,737.765	1,479,005.57	1,479,005.57	1,479,005.57

Pollution Removal by Trees and Shrubs - Monthly Removal

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

		Removal (pounds)			Value ($)		
Pollutant	Month	Mean	Max	Min	Mean	Max	Min
	Annual	**2,402,288.664**	**2,519,950.181**	**1,025,767.671**	**44,558,539.07**	**46,740,968.42**	**19,026,318.34**
O3	1	289,270.658	289,270.658	289,270.658	18,168,487.96	18,168,487.96	18,168,487.96
	2	278,780.117	278,780.117	278,780.117	17,509,598.91	17,509,598.91	17,509,598.91
	3	417,586.896	417,586.896	417,586.896	26,227,763.81	26,227,763.81	26,227,763.81
	4	726,679.651	772,307.111	492,051.135	45,641,236.41	48,507,002.24	30,904,707.64
	5	1,020,561.807	1,116,944.458	182,646.133	64,099,362.96	70,152,956.68	11,471,623.44
	6	1,497,143.348	1,658,064.843	306,660.181	94,032,457.63	104,139,601.80	19,260,687.72
	7	1,187,461.050	1,284,518.614	176,286.400	74,581,957.08	80,677,940.62	11,072,181.90
	8	977,327.041	1,080,201.198	161,687.785	61,383,877.32	67,845,188.99	10,155,273.23
	9	968,297.778	1,054,193.731	172,408.486	60,816,768.11	66,211,714.14	10,828,618.16
	10	628,764.756	690,885.921	240,046.279	39,491,405.67	43,393,106.72	15,076,807.16
	11	0.000	0.000	0.000	0.00	0.00	0.00
	12	0.000	0.000	0.000	0.00	0.00	0.00
	Annual	**7,991,873.103**	**8,642,753.547**	**2,717,424.069**	**501,952,915.86**	**542,833,361.88**	**170,675,749.93**
PM2.5	1	12,560.065	31,922.292	2,037.041	35,909,586.94	91,266,748.73	5,823,958.18
	2	15,059.108	35,725.609	2,115.394	43,054,421.42	102,140,540.43	6,047,972.90
	3	12,020.313	28,068.820	1,468.942	34,366,419.73	80,249,560.42	4,199,746.35
	4	42,700.766	94,491.875	5,179.152	122,082,713.18	270,154,978.06	14,807,345.32
	5	149,433.435	306,548.583	19,365.490	427,234,472.50	876,431,184.26	55,366,492.39
	6	118,524.342	245,790.957	15,051.548	338,864,490.66	702,723,390.49	43,032,806.78
	7	94,393.875	216,905.548	13,378.665	269,874,793.01	620,139,179.55	38,249,985.83
	8	62,020.815	135,978.700	8,216.150	177,319,287.31	388,767,000.01	23,490,207.84
	9	63,382.749	151,447.491	7,312.205	181,213,097.09	432,992,716.57	20,905,804.73
	10	36,522.155	78,872.071	4,489.993	104,417,888.09	225,497,511.32	12,837,018.88
	11	4,782.043	9,989.158	711.250	13,671,996.58	28,559,289.85	2,033,484.69

Pollution Removal by Trees and Shrubs - Monthly Removal

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

		Removal (pounds)			Value ($)		
Pollutant	**Month**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
	12	9,614.785	22,392.838	1,243.682	27,488,946.13	64,021,764.74	3,555,721.49
	Annual	**621,014.450**	**1,358,133.941**	**80,569.512**	**1,775,498,112.63**	**3,882,943,864.44**	**230,350,545.38**
SO2	1	5,952.400	5,952.400	5,952.400	41,538.21	41,538.21	41,538.21
	2	4,295.522	4,295.522	4,295.522	29,975.86	29,975.86	29,975.86
	3	6,204.333	6,204.333	6,204.333	43,296.29	43,296.29	43,296.29
	4	4,780.474	5,023.112	4,482.644	33,360.04	35,053.27	31,281.67
	5	4,019.899	5,329.639	1,309.257	28,052.45	37,192.33	9,136.52
	6	2,817.036	3,812.422	1,085.672	19,658.39	26,604.59	7,576.25
	7	10,243.797	13,617.560	3,458.287	71,485.28	95,028.73	24,133.30
	8	14,599.576	18,837.323	5,192.322	101,881.63	131,454.31	36,234.08
	9	23,183.592	29,326.398	8,662.601	161,784.30	204,651.23	60,451.06
	10	12,173.902	15,506.690	6,261.465	84,954.32	108,211.83	43,694.99
	11	5,982.298	5,982.298	5,982.298	41,746.85	41,746.85	41,746.85
	12	6,691.548	6,691.548	6,691.548	46,696.27	46,696.27	46,696.27
	Annual	**100,944.377**	**120,579.245**	**59,578.349**	**704,429.89**	**841,449.78**	**415,761.35**

Pollution removal value is calculated based on the prices of $0.66 per pound (CO), $62.81 per pound (O3), $18.55 per pound (NO2), $6.98 per pound (SO2), $2,859.03 per pound (PM2.5). Min and max values for CO are not calculated.
A value of zero may indicate that ancillary data (pollution, weather, energy, etc.) is not available for this location or that the reported amounts are too small to be shown.

Structure Summary by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Species	Trees Number	SE	Leaf Area (ac)	SE	Leaf Biomass (ton)	SE	Tree Dry Weight Biomass (ton)	SE	Average Condition (%)
American beech	6,036,002	±996,235	262,565.713	±45,884.906	49,911.734	±8,722.370	746,394.968	±146,674.020	98.22
Eastern red cedar	5,348,192	±1,617,839	49,645.215	±12,905.302	61,534.370	±15,995.895	523,250.830	±138,964.247	73.96
Virginia pine	4,188,548	±1,313,676	46,797.829	±12,888.973	20,121.475	±5,541.820	461,478.893	±125,596.840	69.84
Black tupelo	4,154,291	±750,892	40,026.273	±7,280.930	6,175.743	±1,123.391	187,375.672	±32,383.785	81.42
Red maple	4,148,190	±641,265	149,389.701	±25,255.368	44,882.280	±7,587.662	1,142,435.763	±241,755.730	84.11
Tulip tree	2,225,470	±425,012	208,080.930	±36,405.853	54,717.498	±9,573.377	1,355,339.489	±277,054.701	91.32
White oak	2,066,401	±361,352	228,611.140	±40,569.224	74,189.640	±13,165.658	1,720,004.750	±339,624.744	94.35
Mountain laurel	1,637,422	±694,324	2,506.572	±1,148.644	1,347.338	±617.422	15,884.913	±7,687.157	86.37
American hornbeam	1,631,060	±530,457	19,974.848	±6,829.431	5,368.139	±1,835.375	38,236.766	±12,435.613	90.90
White ash	1,378,704	±372,338	5,045.196	±1,642.868	1,278.829	±416.425	172,834.144	±65,411.314	55.55
American holly	1,304,446	±309,285	10,914.847	±2,323.881	6,509.360	±1,385.908	29,988.447	±6,292.039	99.12
Mockernut hickory	1,193,932	±285,129	50,583.622	±13,799.418	12,931.137	±3,527.667	166,604.708	±46,655.795	96.26
Boxelder	1,174,313	±666,136	15,541.024	±7,832.808	6,342.230	±3,196.538	74,209.865	±37,558.623	82.00
American elm	1,031,120	±344,202	30,962.800	±12,355.735	10,045.957	±4,008.849	131,561.026	±47,172.033	78.31
Sweetgum	864,429	±322,160	19,432.493	±8,559.404	3,979.724	±1,752.944	53,856.080	±33,295.965	95.08
Flowering dogwood	853,939	±214,200	3,870.567	±1,008.317	1,341.585	±349.495	30,975.819	±7,841.611	74.33
Pignut hickory	745,293	±211,127	31,571.903	±10,119.324	7,442.742	±2,385.524	145,399.646	±55,425.855	97.58
Northern red oak	744,933	±141,188	84,004.705	±20,604.002	29,859.470	±7,323.692	772,160.892	±255,360.836	87.60
Black cherry	595,925	±144,745	13,762.482	±4,430.102	4,761.363	±1,532.669	76,619.593	±26,490.818	88.65

Structure Summary by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Species	Trees Number	SE	Leaf Area (ac)	SE	Leaf Biomass (ton)	SE	Tree Dry Weight Biomass (ton)	SE	Average Condition (%)
Autumn olive	552,355	±215,395	2,742.442	±1,140.007	634.630	±263.809	15,221.077	±7,177.961	94.32
Chestnut oak	512,670	±164,161	42,710.225	±16,163.936	14,973.744	±5,666.902	519,660.940	±199,835.578	88.09
Green ash	505,414	±207,548	3,060.746	±1,470.995	890.593	±428.019	48,558.094	±23,426.403	67.33
Black haw	367,818	±116,582	1,726.008	±808.552	403.118	±188.841	11,885.741	±5,802.506	94.32
Black walnut	341,996	±116,113	19,348.809	±7,117.801	6,917.773	±2,544.825	83,522.806	±32,992.596	92.24
Tree of heaven	315,323	±117,564	7,553.228	±5,694.563	2,443.554	±1,842.256	64,087.494	±48,970.816	83.79
Pawpaw	313,592	±163,430	1,512.015	±756.139	1,131.702	±565.950	5,031.653	±2,628.701	95.91
Pin oak	312,139	±107,782	15,925.045	±7,610.743	6,429.540	±3,072.743	146,416.802	±77,451.021	93.92
Eastern redbud	307,402	±129,719	1,292.741	±659.402	369.311	±188.378	5,106.533	±2,491.548	83.27
Southern red oak	294,869	±127,130	28,895.707	±14,702.102	10,051.527	±5,114.205	220,503.207	±115,413.591	97.50
American sycamore	282,332	±112,602	19,848.461	±8,362.642	4,289.615	±1,807.320	78,511.627	±48,671.057	93.40
Persian silk tree	274,627	±274,607	715.109	±715.057	138.697	±138.687	1,603.649	±1,603.532	71.14
Willow oak	269,295	±124,474	27,414.693	±12,130.823	10,849.373	±4,800.777	154,751.582	±73,936.215	95.42
Spicebush	236,019	±119,067	611.367	±289.110	155.266	±73.424	2,900.417	±1,626.212	81.93
Common persimmon	218,686	±70,805	2,081.052	±880.746	622.001	±263.244	23,178.082	±11,483.796	77.30
Black oak	213,166	±64,565	16,570.395	±7,006.519	5,224.315	±2,209.016	191,932.175	±83,963.063	94.09
Northern hackberry	206,921	±77,450	7,549.793	±3,088.999	1,752.282	±716.946	6,136.051	±2,380.721	98.50
Scarlet oak	199,901	±73,007	21,583.815	±8,589.310	7,016.190	±2,792.103	116,115.277	±39,781.229	98.01
Hardwood	196,638	±52,085	12.865	±12.865	4.345	±4.345	34,206.364	±17,835.009	5.22
Bitternut hickory	194,402	±73,716	5,076.574	±2,876.972	1,423.565	±806.756	9,461.761	±5,249.691	98.10
Callery pear	189,657	±122,240	6,778.354	±4,762.617	2,274.868	±1,598.371	58,607.112	±53,087.646	99.50
Black willow	185,870	±121,519	3,274.214	±2,087.587	925.246	±589.922	14,029.547	±9,136.460	97.61
Eastern white pine	182,795	±97,490	19,515.671	±11,531.573	5,598.907	±3,308.326	66,533.299	±37,600.496	89.36
Sassafras	175,961	±73,981	1,347.766	±593.897	295.718	±130.309	9,758.402	±4,746.437	90.83

Structure Summary by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Species	Trees Number	SE	Leaf Area (ac)	SE	Leaf Biomass (ton)	SE	Tree Dry Weight Biomass (ton)	SE	Average Condition (%)
Eastern hophornbeam	175,402	±175,394	2,606.160	±2,606.034	758.964	±758.927	2,143.386	±2,143.283	97.91
Slippery elm	163,071	±87,718	3,350.530	±1,881.477	669.131	±375.748	10,950.101	±6,572.239	91.57
Leyland cypress	162,375	±79,182	5,920.715	±3,883.034	6,191.209	±4,060.435	178,850.798	±110,670.946	97.50
Black locust	157,408	±61,454	1,595.952	±990.719	383.298	±237.940	32,013.668	±20,249.410	78.18
Blackjack oak	152,258	±69,901	1,897.042	±1,253.738	831.533	±549.552	11,190.418	±7,585.662	98.01
Bigtooth aspen	138,253	±85,514	2,952.079	±2,155.665	671.884	±490.622	16,601.278	±10,800.537	64.47
oak spp	116,192	±39,189	0.000	±0.000	0.000	±0.000	213,359.351	±95,592.178	0.00
elm spp	104,813	±67,540	3,246.324	±2,477.484	986.345	±752.745	25,598.362	±21,793.727	96.15
Red mulberry	103,744	±54,238	2,410.478	±1,814.954	1,068.027	±804.164	75,624.896	±73,844.780	91.61
ash spp	90,469	±38,160	0.000	±0.000	0.000	±0.000	65,182.506	±38,734.879	0.00
Amur honeysuckle	73,168	±56,437	263.499	±236.436	57.903	±51.957	514.057	±436.683	99.50
Devils walking stick	72,298	±62,673	48.086	±40.309	16.168	±13.553	283.377	±246.612	99.50
Higan cherry	72,226	±44,477	1,593.363	±1,472.906	549.971	±508.394	6,197.893	±5,189.242	96.75
Highbush blueberry	72,224	±72,221	84.765	±84.761	28.114	±28.112	533.817	±533.791	81.93
Fringe tree	70,211	±39,100	104.931	±65.580	36.322	±22.701	335.160	±180.838	79.01
Sweet cherry	66,948	±46,251	1,108.862	±1,066.307	382.739	±368.050	107,352.614	±107,233.340	80.04
River birch	59,516	±37,341	12,085.346	±7,338.303	4,178.861	±2,537.432	50,574.399	±29,882.576	98.63
Chinese holly	57,402	±43,028	496.019	±467.206	295.814	±278.631	9,772.374	±7,813.659	99.50
privet spp	55,862	±44,243	103.893	±103.888	42.136	±42.134	528.191	±447.679	74.86
Smooth sumac	54,925	±54,921	45.902	±45.899	11.291	±11.290	210.647	±210.631	99.50
Eastern hemlock	52,014	±42,815	3,036.210	±2,602.689	1,258.055	±1,078.425	13,409.369	±12,226.495	98.49
Shortleaf pine	48,892	±33,787	1,148.854	±1,113.947	493.968	±478.959	12,701.228	±12,408.021	89.16
Post oak	42,210	±24,977	6,430.460	±5,064.340	2,441.537	±1,922.844	33,767.870	±29,876.666	98.28
Littleleaf linden	41,508	±41,506	107.763	±107.759	36.012	±36.010	479.062	±479.044	99.50

Structure Summary by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Species	Trees Number	Trees SE	Leaf Area (ac)	Leaf Area SE	Leaf Biomass (ton)	Leaf Biomass SE	Tree Dry Weight Biomass (ton)	Tree Dry Weight Biomass SE	Average Condition (%)
Swamp chestnut oak	41,271	±41,269	6,608.337	±6,608.016	1,774.995	±1,774.909	50,977.249	±50,974.779	90.25
Yoshino flowering cherry	39,069	±27,704	495.832	±364.411	171.143	±125.781	7,135.105	±6,703.906	98.16
Freeman maple	33,950	±20,972	1,352.014	±933.101	339.460	±234.281	9,684.882	±6,885.525	99.50
Softwood	31,331	±18,002	0.000	±0.000	0.000	±0.000	2,454.473	±1,474.485	0.00
Red hickory	31,142	±17,884	877.209	±580.955	262.856	±174.083	1,830.137	±1,166.428	99.50
pine spp	31,142	±17,884	0.000	±0.000	0.000	±0.000	33,944.587	±22,774.653	0.00
Kanzan cherry	31,040	±27,370	617.335	±598.102	213.082	±206.443	5,788.101	±4,753.150	99.50
Savannah holly	30,915	±23,035	72.193	±60.186	43.054	±35.894	855.082	±780.634	99.50
Common crapemyrtle	28,374	±16,188	455.744	±433.345	263.175	±250.240	4,017.337	±3,831.994	93.32
White mulberry	27,567	±16,737	1,178.639	±1,133.338	384.622	±369.840	6,671.099	±6,619.614	99.50
honeysuckle spp	27,501	±21,747	33.293	±26.058	7.316	±5.726	154.215	±123.358	99.50
White spruce	27,085	±14,909	61.468	±38.030	44.049	±27.252	979.074	±574.093	93.83
Japanese maple	24,342	±17,372	682.528	±659.706	171.367	±165.638	4,512.833	±4,416.361	94.50
hickory spp	24,238	±17,289	14.714	±14.713	3.693	±3.693	1,955.990	±1,891.300	56.37
Silver maple	24,154	±17,259	10,399.969	±7,575.153	2,441.876	±1,778.619	95,092.551	±67,261.456	99.50
Sugar maple	22,864	±16,520	6,966.952	±6,888.950	1,872.333	±1,851.370	32,845.806	±32,491.419	99.50
Chinese privet	21,013	±21,012	64.366	±64.363	26.105	±26.104	450.884	±450.863	91.00
Eastern cottonwood	20,824	±14,725	479.225	±370.439	154.252	±119.236	1,457.057	±1,038.153	99.50
Northern white cedar	20,702	±15,445	87.498	±72.825	75.061	±62.474	2,341.468	±1,817.174	97.84
American hazlenut	20,636	±20,635	16.750	±16.749	5.189	±5.189	209.865	±209.855	97.00
Shingle oak	20,636	±20,635	105.803	±105.798	46.377	±46.375	1,024.063	±1,024.014	99.50
apple spp	19,535	±13,852	19.974	±19.972	7.682	±7.681	9,918.669	±9,869.748	45.99
Japanese zelkova	18,056	±18,055	1,241.210	±1,241.141	358.562	±358.542	4,394.043	±4,393.800	99.50
Oriental arborvitae	17,372	±12,550	70.064	±67.408	73.265	±70.487	2,011.403	±1,836.769	99.50
Chinese juniper	13,836	±13,835	110.608	±110.604	137.096	±137.091	1,062.522	±1,062.484	99.50
Southern magnolia	13,836	±13,835	291.568	±291.557	175.669	±175.663	951.542	±951.507	99.50

Structure Summary by Species

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Species	**Number**	**SE**	**(ac)**	**SE**	**(ton)**	**SE**	**(ton)**	**SE**	**(%)**
Honeylocust	13,731	±13,730	15.452	±15.451	7.219	±7.218	10,641.631	±10,640.856	41.25
plum spp	12,983	±9,856	20.208	±20.206	6.975	±6.975	107.835	±81.860	69.19
Kentucky coffeetree	10,506	±10,506	604.717	±604.688	233.153	±233.142	1,072.628	±1,072.577	99.50
Loblolly pine	10,506	±10,506	115.000	±114.995	41.613	±41.611	491.220	±491.197	99.50
Swamp white oak	10,506	±10,506	17.325	±17.324	7.594	±7.594	113.120	±113.115	99.50
Catawba rosebay	10,506	±10,506	69.084	±69.081	61.647	±61.645	453.203	±453.182	99.50
European alder	10,318	±10,317	342.395	±342.379	111.358	±111.353	400.561	±400.542	99.50
Smooth service berry	10,318	±10,317	11.263	±11.262	3.806	±3.806	56.872	±56.869	82.50
Multiflora rose	10,318	±10,317	25.720	±25.718	8.632	±8.631	172.001	±171.993	99.50
Common privet	9,028	±9,028	17.627	±17.626	7.149	±7.149	138.288	±138.281	37.50
'Bradford' callery pear	9,028	±9,028	20.839	±20.838	6.994	±6.993	80.397	±80.392	99.50
lilac spp	9,028	±9,028	5.210	±5.209	2.242	±2.242	114.470	±114.464	37.50
Downy serviceberry	6,866	±6,865	92.263	±92.257	25.096	±25.094	2,506.080	±2,505.898	99.50
Royal paulownia	6,866	±6,865	190.135	±190.121	62.393	±62.389	1,301.509	±1,301.414	37.50
Shining sumac	6,866	±6,865	3.353	±3.353	1.428	±1.428	14.331	±14.330	94.50
Baldcypress	6,866	±6,865	119.937	±119.928	30.229	±30.227	495.477	±495.441	99.50
Study Area	**51,192,519**	**±4,158,166**	**1,615,046.009**	**±111,271.810**	**518,615.582**	**±32,828.070**	**10,901,386.438**	**±761,667.133**	**84.68**

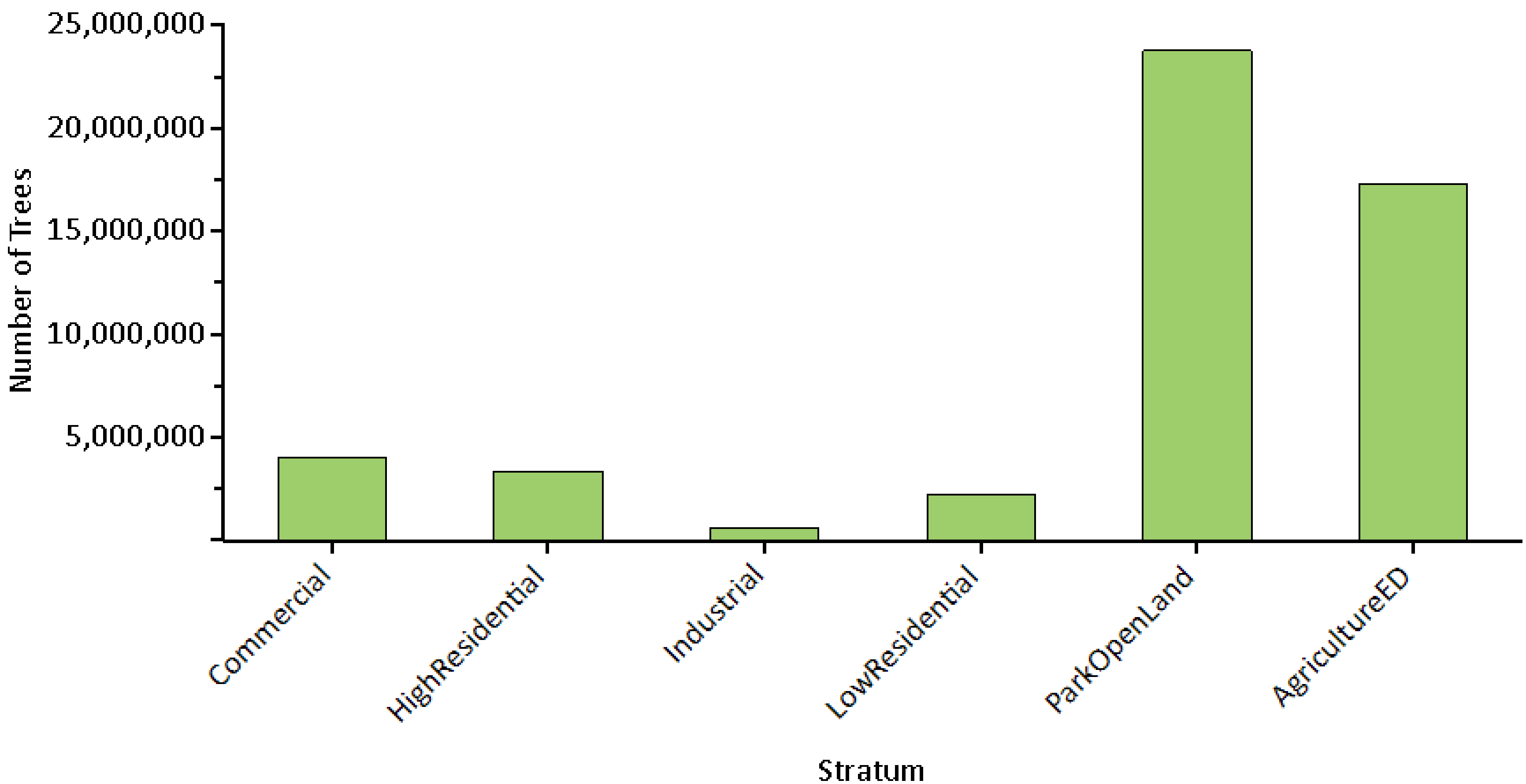
Population Summary by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021

Stratum	Number of Trees	Percent of Population
Commercial	3,995,828	7.8%
HighResidential	3,349,464	6.5%
Industrial	613,035	1.2%
LowResidential	2,199,922	4.3%
ParkOpenLand	23,772,131	46.4%
AgricultureED	17,262,141	33.7%
Study Area	**51,192,519**	**100.0%**

Population Summary by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
Generated: 4/19/2021



Population Summary by Stratum

Location: County Center, Prince William, Virginia, United States of America
Project: Prince William County, Series: County Wide 2019-2020, Year: 2019
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