i-Tree
Ecosystem Analysis

Charlottesville

Urban Forest Effects and Values
February 2012

VirginiaTech
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Acknowledgements

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Report layout and content adapted from the automated report generated by i-Tree Eco assessment software and authored by the i-Tree Development Team.

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Funding:

This project was made possible through support from the Virginia Department of Forestry and the USDA Forest Service – Urban and Community Forestry Program.

Technical Support:

We thank Eric Kuehler with the USDA Forest Service Southern Research Station for his assistance with field data processing. We also want to thank the City of Charlottesville staff along with Chris Gensic (Parks Department Trails Planner) for providing GIS data and facilitating access to public property for field data collection. We are also grateful for the cooperation of numerous citizens and businesses that permitted access to their properties for field data collection and for assistance with data collection from the Rivanna Chapter of Virginia Master Naturalists.

Disclaimer:

Information about urban forest structure, function, and value in this report includes estimates based on statistical sampling, which has an associated margin of error. Therefore, all results should be interpreted with caution. To facilitate reading, statistical error rates are not reported for all forest attributes and model outputs in the main report.

Summary

Trees provide a long list of ecologic and economic benefits that improve environmental conditions and human well-being. Trees in urban settings are especially important. Understanding an urban forest's structure, function, and value can promote management decisions that will improve human health and environmental quality. An assessment of the urban forest in the City of Charlottesville, Virginia was conducted during 2011 using i-Tree Eco sampling protocols and analysis tools. Data from 74 field plots located throughout Charlottesville in three land-use classes (Forested Residential Use, Forested Mixed Use, and Urbanized Mixed Use) were analyzed using the Urban Forest Effects (UFORE) model developed by the U.S. Forest Service, Northern Research Station.

Key findings

- Number of trees: 357,985 (SE: 57,447)
- Tree canopy cover: 27% (SE: 0.57)
- Most common tree species: flowering dogwood, red maple, and spicebush
- Percentage of trees less than 6" trunk diameter: 63%
- Carbon storage: 90,300 tons (valued at $1.66 million)
- Annual gross carbon sequestration: 4,140 tons per year (valued at $76,200)
- Annual avoided carbon emissions: 476 tons per year (valued at $8,766)
- Annual pollution removal: 71 tons per year (valued at $555 thousand)
- Annual building energy savings: $1.03 million
- Structural value of trees: $592 million (SE: 89 million)

Ton: short ton (U.S.) (2,000 lbs)

Carbon storage: the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation

Carbon sequestration: the removal of carbon dioxide from the air by plants through photosynthesis

Structural value: value based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree)

Monetary values ($) reported in US Dollar throughout report except where noted

SE: standard error of the total

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Assessment Methods

UFORE Model and Field Measurements

UFORE is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure (e.g., species composition, tree health, leaf area, etc.) and its numerous effects[5], including:

- Amount of pollution removed hourly by the urban forest and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter <10 microns (PM_{10}).
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants.
- Structural value of the forest as well as the value for air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by Asian longhorned beetle, emerald ash borer, gypsy moth, and Dutch elm disease.

In the City of Charlottesville, 74 one-tenth-acre plots were sampled using a stratified random sampling method across three land use types: forested residential use (28 plots), forested mixed use (32 plots), and urbanized mixed use (14 plots). Plots were assigned proportionate to tree canopy cover and land area within each stratum based on existing canopy data and land use zoning. Plots on both public and private property were assessed. All field data were collected during the 2011 leaf-on season to properly assess tree canopies. At each field plot, two to four crew members collected data on ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback, and distance and direction to residential buildings[11].

To calculate current **carbon storage**, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations[12]. To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

To estimate the gross amount of **carbon sequestered annually**, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1.

Air pollution removal estimates were derived from calculated hourly tree-canopy resistances for ozone, sulfur dioxide, and nitrogen dioxide based on a hybrid of big-leaf and multi-layer canopy deposition models[13,14]. As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature[15,16] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent re-suspension rate of particles back to the atmosphere[17]. Recent updates (2011) to air quality modeling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values[27,28,29].

Seasonal effects of trees on **residential building energy use** were calculated based on procedures described in the literature[4] using distance and direction of trees from residential structures, tree height, and tree condition data.

Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers[8], which uses tree species, diameter, condition, and location information[18].

For modeling and analysis of urban forest structure, function, and value, Charlottesville's human population was set at 43,475 as estimated by the U.S. Census Bureau in 2010 (http://quickfacts.census.gov/qfd/states/51/51540.html).

Structure of Charlottesville's Urban Forest

Tree Characteristics of the Urban Forest

The urban forest of Charlottesville comprises about 358,000 trees with a tree canopy cover of about 27 percent (see Appendix III for comparable values from other cities). The three most common tree species are flowering dogwood (~12 percent), red maple (~5 percent), and spicebush (~5 percent) as shown in Figure 1. There were 84 unique taxa of woody plants catalogued in the field survey. With the exception of the top three species mentioned above, all other species had relative abundance less than 5 percent – a positive indication of species diversity in the forest. A complete listing of tree abundance by species and land use is provided in Appendix I. The overall tree density in Charlottesville averages about 55 trees per acre, which is comparable to other localities along the East Coast (Appendix III). Among the land use strata, the highest tree densities occur in Forested Residential lands followed by Forest Mixed Use lands and Urbanized Mixed Use lands (Fig. 2). Trees that have diameters less than 6-inches constitute about 63 percent of the tree population (Fig. 3), which suggests that there are plentiful young trees to help sustain forest cover into the future.

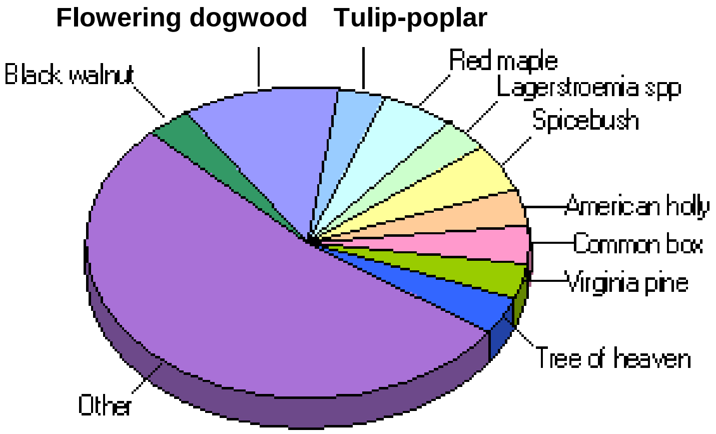

Figure 1. Tree species composition (percent of total) in City of Charlottesville

Urban forests are composed of a mix of native and exotic tree species. Thus, urban forests often have higher species diversity than surrounding native landscapes. High species diversity helps minimize forest vulnerability to species-specific pests and disorders, but may also pose a risk to forest health if exotic species are invasive plants that can potentially out-compete and displace native species. In Charlottesville, about 67 percent of the trees are species native to North America, while 66 percent are native to the state (Fig. 4). Species exotic to Virginia make up 30 percent of the population. Most of Charlottesville's exotic tree species are indigenous to Asia (~18 percent of the species).

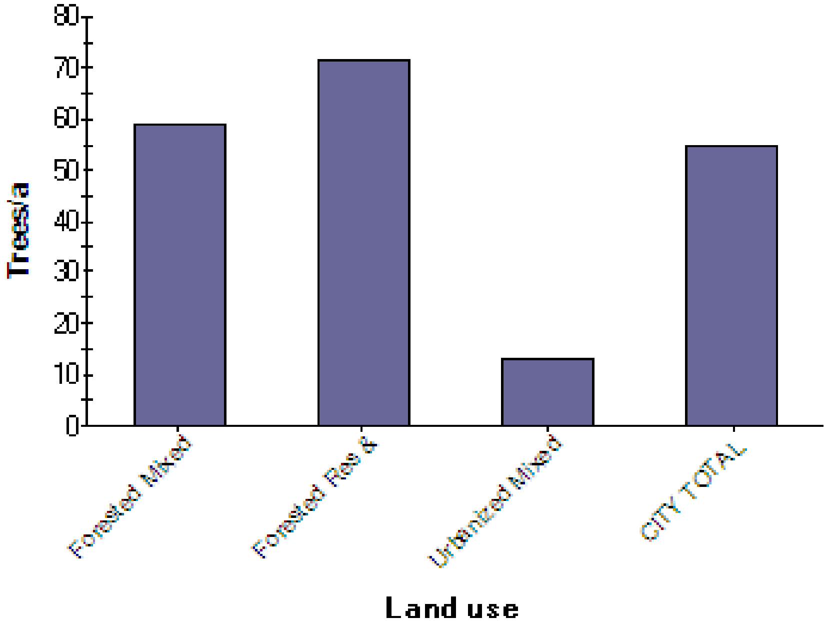

Figure 2. Trees per acre (a) in City of Charlottesville by land use

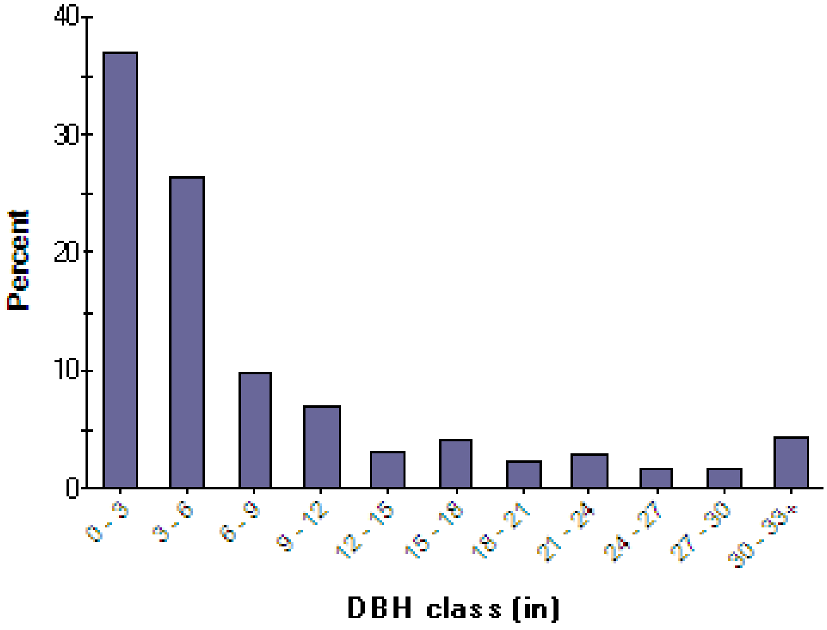

Figure 3. Trunk diameter distribution (DBH=stem diameter at 4.5 feet above ground line) of trees in City of Charlottesville.

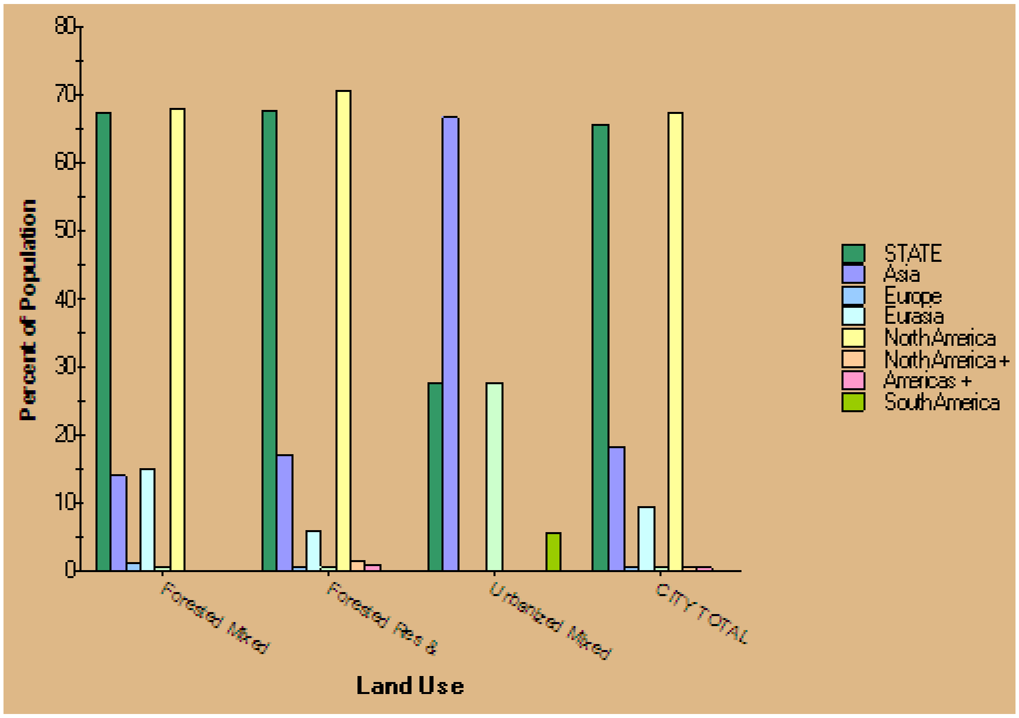

Figure 4. Species composition of live trees in City of Charlottesville by geographic origin

"North America +" = native to North America and at least one other continent except South America

Urban Forest Cover and Leaf Area

Tree canopy covers about 27 percent of Charlottesville's land area. Many tree benefits are directly proportional to the amount of healthy leaf surface area. In Charlottesville, the three most dominant tree species in terms of leaf area are tulip-poplar, white oak, and red maple (Table 1). Tulip-poplar is the only species that accounts for more than 10 percent of total leaf area. Importance Value (IV) is a metric that documents species dominance by summing relative abundance and relative leaf area for each tree species. An IV over 10 may indicate that an urban forest is over-reliant on a particular species for structural and functional benefits, depending on the local ecosystem. Charlottesville's ten most important species are listed in Table 1 below. Tulip-poplar, black locust, and red maple are the three most important species, each having an IV exceeding 10.

The two most dominant ground cover types in Charlottesville are grass (29 percent) and building (19 percent) as shown in Figure 5. The three impervious ground cover classes (Building, Cement, and Tar) make up 42 percent of total ground cover. Ground space permissible for tree planting (not covered by impervious surface and free of overhead obstructions such as existing tree canopy and utility lines) exists on about 20 percent of the land area (data not shown), which suggests moderate potential for increasing Charlottesville's tree canopy cover.

Table 1. Ten most important tree species in City of Charlottesville. Importance Value (IV) is the sum of relative abundance and relative leaf area.

Species Name	*Percent of Population*	*Percent of Leaf Area*	*Importance Value (IV)*
Flowering dogwood	11.7	5.5	17.2
Tulip tree	3.4	13.8	17.2
Red maple	5.3	6.3	11.6
White oak	1.9	7.5	9.4
Green ash	2.4	5.0	7.4
Silver maple	1.0	5.6	6.6
Eastern red cedar	3.2	3.4	6.5
American holly	3.6	2.6	6.2
Spicebush	5.2	1.0	6.1
Eastern white pine	2.0	4.1	6.1

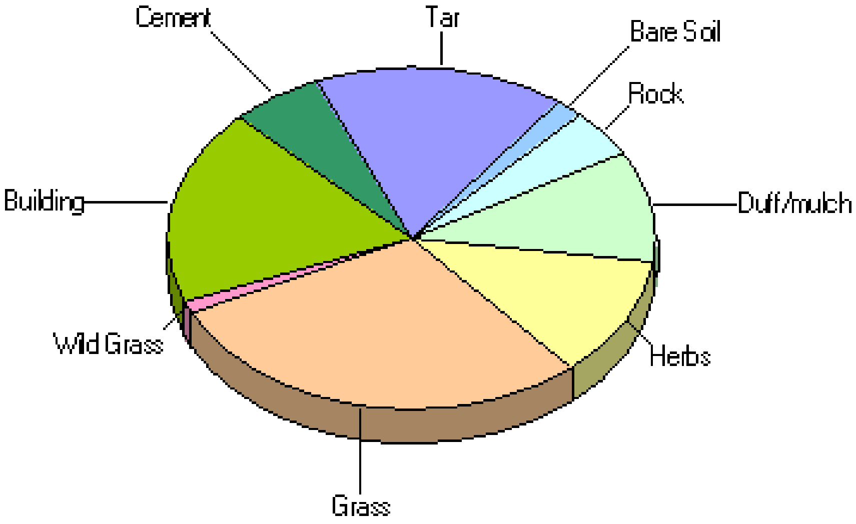

Figure 5. Ground cover composition (percent of total) in City of Charlottesville

Structural and Functional Values of Charlottesville's Urban Forest

Overview of Urban Forest Values

Urban forests have monetary value as structural assets much like any other infrastructure found in a municipality. This value is commonly calculated based on the cost that would be incurred to replace existing trees with trees of similar type and size. In addition, the carbon stored in woody tree parts has structural value as a carbon offset resource. Urban forests also have monetary value as functional assets based on the ecosystem services that they provide. These services (carbon sequestration, air pollution removal, and energy conservation) are rendered through tree interactions with the natural and built environment and may have positive or negative value depending on the nature of these interactions.

The structural and functional values of an urban forest tend to increase with an increase in the number and size of healthy trees[6]. However, inappropriate species selection, improper tree placement, and tree neglect can diminish both structural and functional values.

The structural value of Charlottesville's urban forest exceeds $590 million. The most valuable species in Charlottesville's urban forest is tulip-poplar at nearly $82 million (Fig. 6). The ten most valuable species alone have a combined value of over $413 million. A summary of annual functional values are shown below and summarized in the subsequent sections of this report.

<ins>Structural values of trees in Charlottesville's urban forest:</ins>

- Structural value: $592 million
- Carbon storage: $1.66 million

<ins>Functional values of trees in Charlottesville's urban forest (annual basis):</ins>

- Carbon sequestration (removal): $76.2 thousand
- Pollution removal: $555 thousand
- Energy savings and carbon emission reductions: $1.04 million

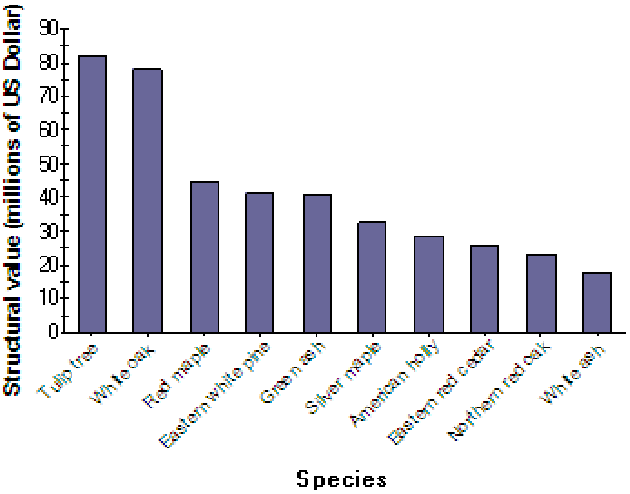

Figure 6. Structural value of the ten most valuable tree species in City of Charlottesville

Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering (removing) atmospheric carbon (as carbon dioxide through photosynthesis) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power plants[3].

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered increases with the size and health of the trees. The gross sequestration of Charlottesville's trees is about 4,140 tons of carbon per year with an associated value of $76,200. Net carbon sequestration (accounting for losses from carbon dioxide release through tree respiration) in Charlottesville's urban forest is about 3,350 tons annually. Tulip-poplar sequesters the most carbon annually (~401 tons), which accounts for about 12% of all sequestered carbon in the urban forest (Fig. 7).

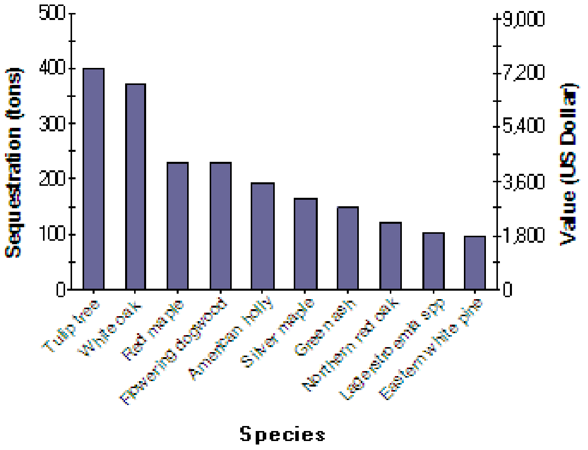

Figure 7. Annual carbon sequestration quantity and value for top ten tree species in Charlottesville

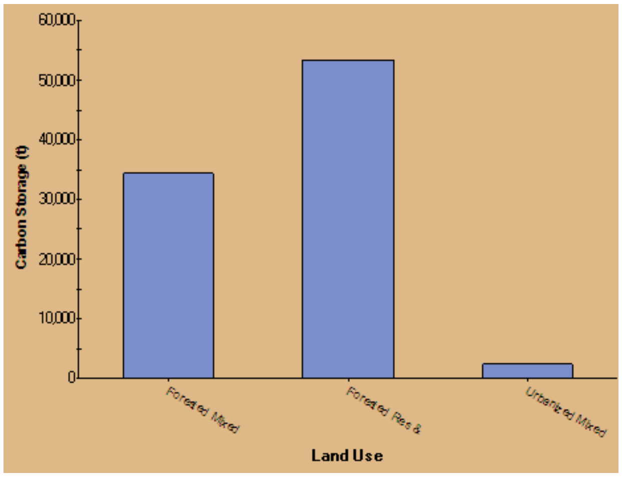

Figure 8. Carbon storage in Charlottesville's urban forest by land use

As trees grow, they accumulate carbon as wood. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in Charlottesville are estimated to store 90,300 tons of carbon, which is valued at $1.66 million (Fig. 8). Of all the species sampled, white oak stores the most carbon (~16% of the total; data not shown).

Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damaged landscape plants and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by directly removing pollutants from the air, reducing ambient air temperature, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power plants. Trees also emit volatile organic compounds (VOCs) that can contribute to ground-based ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation overall despite VOC emissions[1].

Pollution removal by trees in Charlottesville was estimated using field data and recent pollution and weather data available. Pollution removal is greatest for ozone (O_3) as shown in Figure 9. It is estimated that Charlottesville's trees remove 71 tons of air pollution (CO, NO_2, O_3, PM_{10}, and SO_2) per year with an associated value of $555 thousand (based on estimated national median externality costs associated with pollutants[2]).

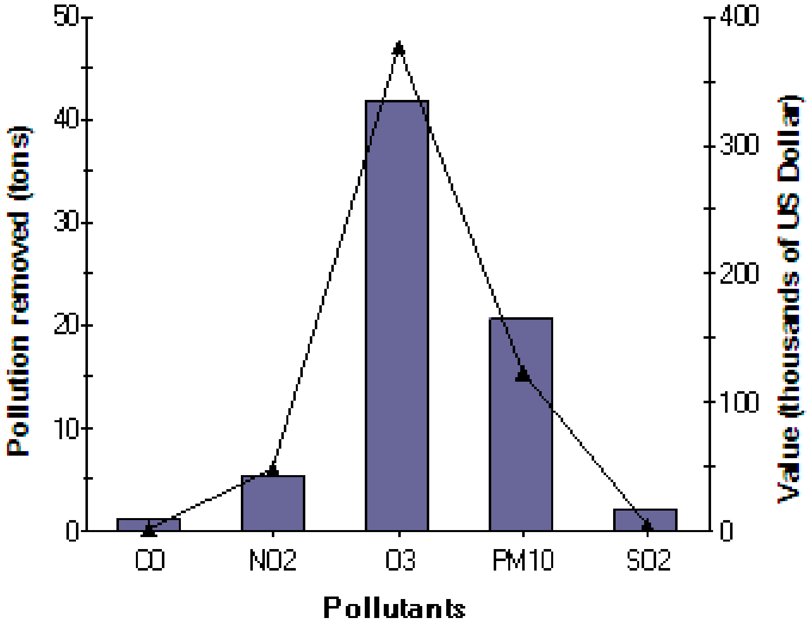

Figure 9. Pollution removal (bars) and associated monetary value (line) for trees in City of Charlottesville

Trees and Building Energy Use

Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months, depending on the location of trees around the building. Estimates of tree effects on energy use are based on field measurements of tree distance and direction to space conditioned residential buildings[4].

Based on 2002 prices, trees in Charlottesville are estimated to reduce energy-related costs from residential buildings by $1.03 million annually (Tables 2 and 3). Trees also provide an additional $8,766 in value[5] by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 476 tons of carbon emissions).

Table 2. Annual energy conservation and carbon avoidance due to trees near residential buildings. Note: negative numbers indicate an increased energy use or carbon emission.

	Heating	*Cooling*	*Total*
MBTU[1]	24,519	n/a	24,519
MWH[2]	502	6,358	6,860
Carbon avoided (tons)	472	4	476

[1] One million British Thermal Units
[2] Megawatt-hour

Table 3. Annual savings[1] in residential energy expenditure during heating and cooling seasons. Note: negative numbers indicate a cost due to increased energy use or carbon emission.

	Heating ($)	*Cooling ($)*	*Total ($)*
MBTU[2]	300,603	n/a	300,603
MWH[3]	53,262	674,584	727,846
Carbon avoidance	8,692	74	8,766

[1] Based on state-wide energy costs for Virginia.
[2] One million British Thermal Units
[3] Megawatt-hour

Potential Pest Impacts

Various insects and diseases can infest trees, potentially killing trees and reducing the health, value, and sustainability of the urban forest. As pests tend to have differing tree hosts, the potential risk of each pest will differ. Four exotic pests were analyzed for their potential impact (Fig. 10): Asian longhorned beetle (ALB), gypsy moth (GM), emerald ash borer (EAB), and Dutch elm disease (DED).

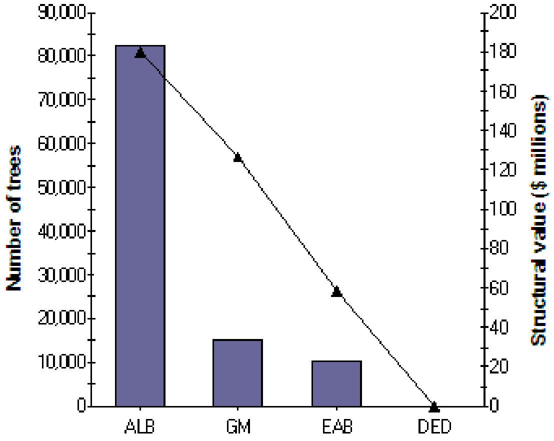

Figure 10. Susceptible trees (bars) and potential structural value loss (line) by pest for City of Charlottesville's urban forest

The Asian longhorned beetle (ALB)[7] is an insect that bores into and kills a wide range of hardwood tree species. ALB poses a threat to about 23 percent of Charlottesville's urban forest, which represents a potential loss of $180 million in structural value of the urban forest.

The gypsy moth (GM)[8] caterpillar is an insect that feeds on many tree species, causing widespread defoliation and tree death if outbreak conditions persist over several years. This pest threatens about 4 percent of the tree population, representing a potential loss of $127 million in structural value.

Emerald ash borer (EAB)[9] is a wood-boring insect has killed thousands of native ash trees in parts of the United States. EAB has the potential to affect about 3 percent of Charlottesville's tree population ($58.3 million in potential structural value loss).

American elm, one of the most important street trees in the twentieth century, has been devastated by the Dutch elm disease (DED)[10]. Since the 1930s, DED has killed over 50 percent of the native elm population in the United States. Although American elms are known to inhabit Charlottesville, there was no measurable vulnerability to DED in terms of potential loss of trees or their structural value in this assessment.

Appendix I. Tree count and structural value by land use and tree species

		Number of Trees		Structural Value ($)	
Land Use	**Species**	**Value**	**SE**	**Value**	**SE**
Forested Mixed	Spicebush	18,473	18,463	316,477	316,297
Forested Mixed	Virginia pine	12,315	10,638	3,476,796	2,650,063
Forested Mixed	Black walnut	11,436	9,772	3,909,076	2,716,341
Forested Mixed	Flowering dogwood	9,676	4,821	3,642,666	1,974,149
Forested Mixed	Common box	8,797	5,270	1,822,021	1,120,411
Forested Mixed	European hornbeam	7,917	7,913	3,190,332	3,188,518
Forested Mixed	Eastern red cedar	7,037	5,357	16,037,400	11,373,765
Forested Mixed	Lagerstroemia spp	7,037	3,990	7,033,606	3,949,976
Forested Mixed	Red maple	6,158	3,274	5,924,399	4,051,695
Forested Mixed	Tree of heaven	6,158	5,319	916,504	844,678
Forested Mixed	Eastern white pine	5,278	5,275	34,341,062	34,321,538
Forested Mixed	American holly	4,398	2,224	22,178,156	13,311,369
Forested Mixed	Sassafras	4,398	4,396	90,372	90,321
Forested Mixed	Tulip tree	4,398	2,853	35,139,333	28,441,849
Forested Mixed	Black locust	3,519	2,752	224,291	192,561
Forested Mixed	Northern hackberry	3,519	2,752	5,692,817	5,648,102
Forested Mixed	Autumn olive	2,639	1,940	364,555	342,238
Forested Mixed	Black cherry	2,639	1,940	663,193	649,673
Forested Mixed	Eastern redbud	2,639	2,638	203,456	203,340
Forested Mixed	Silver maple	2,639	1,471	27,225,508	15,398,095
Forested Mixed	Sugar maple	2,639	1,940	2,397,568	1,920,311
Forested Mixed	Amur honeysuckle	1,759	1,758	494,998	494,716
Forested Mixed	Black oak	1,759	1,758	156,182	156,093
Forested Mixed	Chaste tree	1,759	1,222	196,553	138,700
Forested Mixed	Green ash	1,759	1,222	7,023,964	6,812,412
Forested Mixed	Kwanzan cherry	1,759	1,758	181,185	181,082
Forested Mixed	White ash	1,759	1,758	17,573,949	17,563,957
Forested Mixed	American sycamore	880	879	4,224,721	4,222,319
Forested Mixed	Black willow	880	879	1,292,734	1,291,999
Forested Mixed	Cherry plum	880	879	1,985,585	1,984,456
Forested Mixed	Deodar cedar	880	879	112,785	112,721
Forested Mixed	Fraser photinia	880	879	775,624	775,183
Forested Mixed	Higan cherry	880	879	37,111	37,090
Forested Mixed	Leyland cypress	880	879	2,644,526	2,643,022
Forested Mixed	Mimosa	880	879	13,881	13,874
Forested Mixed	Mock orange spp	880	879	41,644	41,621
Forested Mixed	Mockernut hickory	880	879	42,884	42,860
Forested Mixed	Northern red oak	880	879	1,318,890	1,318,140
Forested Mixed	Norway maple	880	879	3,412,655	3,410,714

Forested Mixed	Norway spruce	880	879	1,519,688	1,518,824
Forested Mixed	Pignut hickory	880	879	2,248,126	2,246,848
Forested Mixed	Sawara false cypress	880	879	2,675,423	2,673,902
Forested Mixed	Scotch pine	880	879	1,155,253	1,154,596
Forested Mixed	Shortleaf pine	880	879	759,907	759,475
Forested Mixed	Sweet cherry	880	879	449,483	449,227
Forested Mixed	Winged burningbush	880	879	82,092	82,045
Forested Mixed	**Total**	**160,981**	**42,380**	**225,209,428**	**56,467,501**
Forested Res	Flowering dogwood	31,146	12,670	12,279,654	4,372,523
Forested Res	Red maple	12,978	7,833	38,574,441	19,571,321
Forested Res	American holly	8,652	4,534	6,421,163	5,054,237
Forested Res	Tulip tree	7,787	4,147	46,778,750	28,794,982
Forested Res	American beech	6,921	4,803	1,561,822	1,292,899
Forested Res	Green ash	6,921	4,469	33,680,550	32,221,665
Forested Res	White oak	6,921	3,497	78,100,788	37,604,675
Forested Res	Black cherry	6,056	2,379	6,767,637	4,271,699
Forested Res	Common box	5,191	3,602	828,865	512,450
Forested Res	Lagerstroemia spp	5,191	2,886	1,887,831	935,013
Forested Res	Amur privet	4,326	2,510	306,676	188,212
Forested Res	Eastern red cedar	4,326	2,802	9,524,311	9,315,151
Forested Res	Eastern redbud	3,461	2,054	1,108,733	668,911
Forested Res	Fraser photinia	3,461	2,705	1,007,067	707,858
Forested Res	Chinese privet	2,596	1,906	160,998	118,705
Forested Res	Common cherry laurel	2,596	2,594	146,005	145,921
Forested Res	Eastern hemlock	2,596	2,594	3,591,008	3,588,932
Forested Res	Mimosa	2,596	1,443	64,304	41,423
Forested Res	Northern hackberry	2,596	2,594	118,550	118,482
Forested Res	Pignut hickory	2,596	2,594	8,512,112	8,507,191
Forested Res	Shortleaf pine	2,596	2,594	5,202,344	5,199,337
Forested Res	Western redcedar	2,596	2,594	354,926	354,721
Forested Res	White mulberry	2,596	1,443	6,348,375	5,722,966
Forested Res	Apple spp	1,730	1,201	228,040	166,377
Forested Res	Black locust	1,730	1,201	6,078,368	5,473,517
Forested Res	Camellia spp	1,730	1,729	147,582	147,497
Forested Res	Higan cherry	1,730	1,201	1,374,511	1,349,144
Forested Res	Nannyberry	1,730	1,729	184,533	184,426
Forested Res	Northern white cedar	1,730	1,201	5,242,955	5,145,163
Forested Res	Norway maple	1,730	1,729	91,564	91,511
Forested Res	Red mulberry	1,730	1,729	38,910	38,887
Forested Res	Rosebay rhododendron	1,730	1,729	217,927	217,801
Forested Res	Southern magnolia	1,730	1,201	6,209,559	5,622,465
Forested Res	Topal holly	1,730	1,201	1,751,532	1,460,994
Forested Res	Autumn olive	865	865	40,958	40,934
Forested Res	Azalea	865	865	79,316	79,270

Forested Res	Black oak	865	865	7,332,853	7,328,614
Forested Res	Black tupelo	865	865	49,315	49,286
Forested Res	Boxelder	865	865	894,496	893,979
Forested Res	Callery pear	865	865	40,958	40,934
Forested Res	Chinese holly	865	865	657,510	657,129
Forested Res	Creeping strawberry bush	865	865	40,958	40,934
Forested Res	Eastern white pine	865	865	1,096,099	1,095,465
Forested Res	Fire thorn	865	865	84,567	84,518
Forested Res	Japanese maple	865	865	546,673	546,357
Forested Res	Kousa dogwood	865	865	48,246	48,218
Forested Res	Leyland cypress	865	865	45,422	45,395
Forested Res	Ligustro	865	865	40,958	40,934
Forested Res	Lilac spp	865	865	25,394	25,379
Forested Res	Mockernut hickory	865	865	859,194	858,697
Forested Res	Northern red oak	865	865	21,735,224	21,722,659
Forested Res	Plum spp	865	865	29,200	29,183
Forested Res	Privet spp	865	865	68,485	68,446
Forested Res	Rosemallow spp	865	865	43,760	43,735
Forested Res	Rose-of-sharon	865	865	82,817	82,769
Forested Res	Silver maple	865	865	5,321,126	5,318,050
Forested Res	Sourwood	865	865	551,174	550,856
Forested Res	Star magnolia	865	865	43,798	43,773
Forested Res	Sugar maple	865	865	8,094,295	8,089,616
Forested Res	Sweet cherry	865	865	80,646	80,599
Forested Res	Viburnum spp	865	865	152,068	151,980
Forested Res	Virginia pine	865	865	2,311,174	2,309,838
Forested Res	**Total**	**179,956**	**37,687**	**335,289,072**	**65,812,963**
Urbanized Mixed	Tree of heaven	7,577	7,573	260,788	260,650
Urbanized Mixed	Sugar maple	1,894	1,893	653,008	652,663
Urbanized Mixed	Callery pear	947	947	3,431,797	3,429,985
Urbanized Mixed	Chinese juniper	947	947	371,989	371,792
Urbanized Mixed	Eastern white pine	947	947	5,539,463	5,536,538
Urbanized Mixed	Flowering dogwood	947	947	948,392	947,891
Urbanized Mixed	Japanese zelkova	947	947	2,331,316	2,330,085
Urbanized Mixed	Ligustro	947	947	300,374	300,216
Urbanized Mixed	Purpleleaf plum	947	947	859,907	859,453
Urbanized Mixed	Sweetgum	947	947	16,728,538	16,719,705
Urbanized Mixed	**Total**	**17,049**	**9,155**	**31,425,571**	**18,032,485**
CITY TOTAL	**Total**	**357,985**	**57,447**	**591,924,071**	**88,572,543**

Appendix II. Relative Tree Effects

The urban forest in City of Charlottesville provides benefits that include carbon storage, carbon sequestration, and air pollutant removal. To estimate the relative value of these benefits, tree benefits were compared to estimates of average municipal carbon emissions[19], average passenger automobile emissions[20], and average household emissions[21].

Carbon storage is equivalent to:
- Amount of carbon emitted in Charlottesville in 125 days
- Annual carbon (C) emissions from 54,200 automobiles
- Annual C emissions from 27,200 single-family houses

Carbon monoxide removal is equivalent to:
- Annual carbon monoxide emissions from 5 automobiles
- Annual carbon monoxide emissions from 20 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 344 automobiles
- Annual nitrogen dioxide emissions from 229 single-family houses

Sulfur dioxide removal is equivalent to:
- Annual sulfur dioxide emissions from 2,960 automobiles
- Annual sulfur dioxide emissions from 50 single-family houses

Particulate matter less than 10 micron (PM10) removal is equivalent to:
- Annual PM10 emissions from 54,700 automobiles
- Annual PM10 emissions from 5,290 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in Charlottesville in 5.7 days
- Annual C emissions from 2,500 automobiles
- Annual C emissions from 1,200 single-family houses

Note: estimates above are partially based on the user-supplied information on human population total for study area

Appendix III. Comparison of Urban Forests

A common question asked is, "How does this city compare to other cities?" Although comparison among cities should be made with caution as there are many attributes of a city that affect urban forest structure and functions, summary data are provided from other cities analyzed using the UFORE model.

I. City totals for trees

City	*% Tree Cover*	*Number of trees*	*Carbon storage (tons)*	*Carbon Sequestration (tons/yr)*	*Pollution removal (tons/yr)*	*Pollution Value (USD)*
Calgary, Canada	7.2	11,889,000	445,000	21,422	326	1,611,000
Atlanta, GA	36.8	9,415,000	1,345,000	46,433	1,662	2,534,000
Toronto, Canada	20.5	7,542,000	992,000	40,345	1,212	6,105,000
New York, NY	21.0	5,212,000	1,351,000	42,283	1,677	8,071,000
Baltimore, MD	21.0	2,627,000	596,000	16,127	430	2,129,000
Philadelphia, PA	15.7	2,113,000	530,000	16,115	576	2,826,000
Washington, DC	28.6	1,928,000	523,000	16,148	418	1,956,000
Boston, MA	22.3	1,183,000	319,000	10,509	284	1,426,000
Woodbridge, NJ	29.5	986,000	160,000	5561.00	210	1,037,000
Minneapolis, MN	26.5	979,000	250,000	8,895	305	1,527,000
Syracuse, NY	23.1	876,000	173,000	5,425	109	268,000
Morgantown, WV	35.9	661,000	94,000	2,940	66	311,000
Moorestown, NJ	28.0	583,000	117,000	3,758	118	576,000
Jersey City, NJ	11.5	136,000	21,000	890	41	196,000
Freehold, NJ	34.4	48,000	20,000	545	21	133,000

II. Per-acre values of tree effects

City	*No. of trees*	*Carbon storage (tons)*	*Carbon sequestration (lbs/yr)*	*Pollution removal (lbs/yr)*	*Pollution Value (USD)*
Calgary, Canada	66.7	2.5	0.120	3.6	9.0
Atlanta, GA	111.6	15.9	0.550	39.4	30.0
Toronto, Canada	48.3	6.4	0.258	15.6	39.1
New York, NY	26.4	6.8	0.214	17.0	40.9
Baltimore, MD	50.8	11.5	0.312	16.6	41.2
Philadelphia, PA	25.0	6.3	0.190	13.6	33.5
Washington, DC	49.0	13.3	0.410	21.2	49.7
Boston, MA	33.5	9.0	0.297	16.0	40.4
Woodbridge, NJ	66.5	10.8	0.375	28.4	70.0
Minneapolis, MN	26.2	6.7	0.238	16.4	40.9
Syracuse, NY	54.5	10.8	0.338	13.6	16.7
Morgantown, WV	119.7	17.0	0.532	23.8	56.3
Moorestown, NJ	62.0	12.5	0.400	25.2	61.3
Jersey City, NJ	14.3	2.2	0.094	8.6	20.7
Freehold, NJ	38.5	16.0	0.437	33.6	106.6

Appendix IV. General Recommendations for Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmosphere environment. Four main ways that urban trees affect air quality are[22]:

- Temperature reduction and other microclimate effects
- Removal of air pollutants
- Emission of volatile organic compounds (VOC) and tree maintenance emissions
- Energy effects on buildings

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC emitting species, leads to reduced ozone concentrations in cities[23]. Local urban management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include[24]:

Strategy	***Result***
Increase the number of healthy trees	Increase pollution removal
Sustain existing tree canopy cover	Maintain pollution removal levels
Maximize use of low VOC-emitting tree species	Reduces ozone and carbon monoxide formation
Maintain large, healthy trees	Large trees have greatest per-tree effects
Use long-lived tree species	Reduce long-term pollutant emissions from planting and removal
Use low maintenance tree species	Reduce pollutants emissions from maintenance activities
Reduce fossil fuel use in maintaining vegetation	Reduce pollutant emissions
Plant trees in energy conserving locations	Reduce pollutant emissions from power plants
Plant trees to shade parked cars	Reduce vehicular VOC emissions
Supply ample irrigation to vegetation	Enhance pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive tree species	Improve tree health
Utilize evergreen trees for particulate matter capture	Year-round removal of particles

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