i-Tree Ecosystem Analysis

Falls Church

Urban Forest Effects and Values
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Acknowledgements

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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 Falls Church, Virginia was conducted during 2011 using i-Tree Eco sampling protocols and analysis tools. Data from 38 field plots located throughout Falls Church were analyzed using the Urban Forest Effects (UFORE) model developed by the U.S. Forest Service, Northern Research Station.

Key findings

- Number of trees: 59,677 (SE: 8,298)
- Tree canopy cover: 35% (SE: 0.82)
- Most common tree species: flowering dogwood, eastern redcedar, and eastern white pine
- Percentage of trees less than 6" trunk diameter: 48%
- Carbon storage: 21,100 tons (valued at $388 million)
- Annual gross carbon sequestration: 970 tons (valued at $17,900)
- Annual avoided carbon emissions: 307 tons (valued at $5,654)
- Annual pollution removal: 19 tons (valued at $138 thousand)
- Annual building energy savings: $219 thousand
- Structural value of trees: $147 million (SE: 27 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

Table of Contents

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 Falls Church, 38 one-tenth-acre plots were sampled using a randomized grid sampling method. 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, Falls Church's human population was set at 12,332 as estimated by the U.S. Census Bureau in 2010 (http://quickfacts.census.gov/qfd/states/51/51610.html).

Structure of Falls Church's Urban Forest

Tree Characteristics of the Urban Forest

The urban forest of Falls Church comprises about 59,700 trees with a tree canopy cover of about 35 percent (see Appendix III for comparable values from other cities). The three most common tree species are flowering dogwood (~7 percent), eastern red cedar (~6 percent), and eastern white pine (~6 percent) as shown in Figure 1. There were 56 unique taxa of woody plants catalogued in the field survey. With the exception of the top three species mentioned above (and Norway maple and northern white-cedar), 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 tree density in Falls Church averages about 47 trees per acre, which is comparable to other localities along the East Coast (Appendix III). Trees that have diameters less than 6-inches constitute about 48 percent of the tree population (Fig. 3), which suggests that there are plentiful young trees to help sustain forest cover into the future.

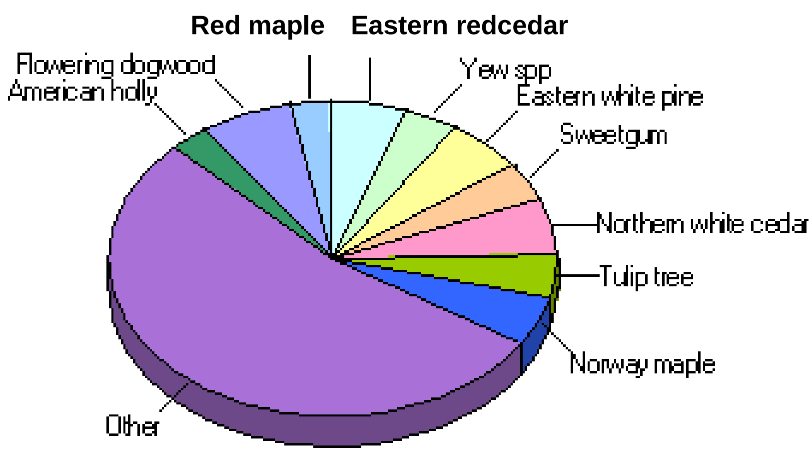

Figure 1. Tree species composition (percent of total) in City of Falls Church

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 Falls Church, about 63 percent of the trees are species native to North America, while 56 percent are native to the state (Fig. 4). Species exotic to Virginia make up 38 percent of the population. Most of Falls Church's exotic tree species are indigenous to Asia (~15 percent of the species).

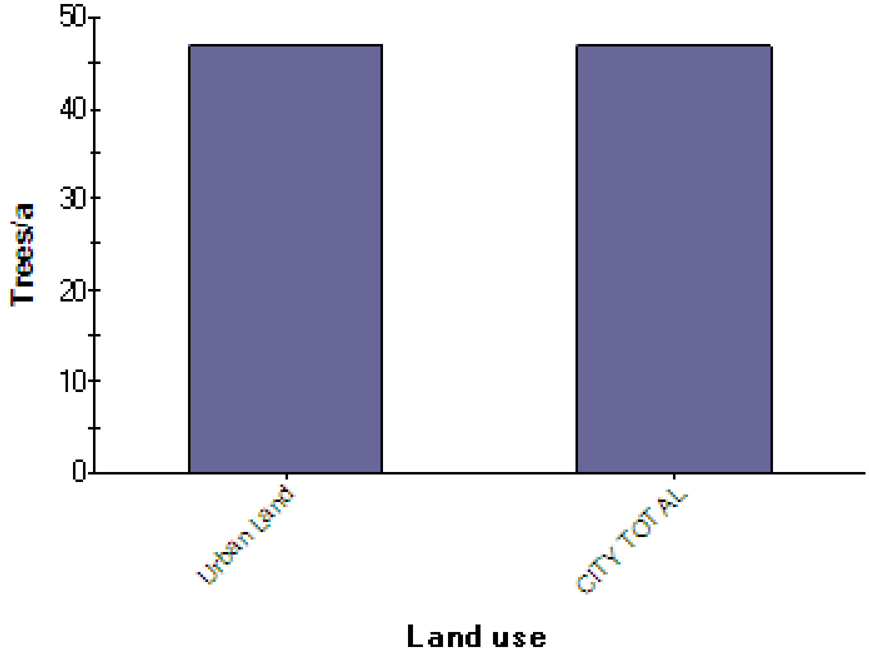

Figure 2. Trees per acre (a) in City of Falls Church by land use

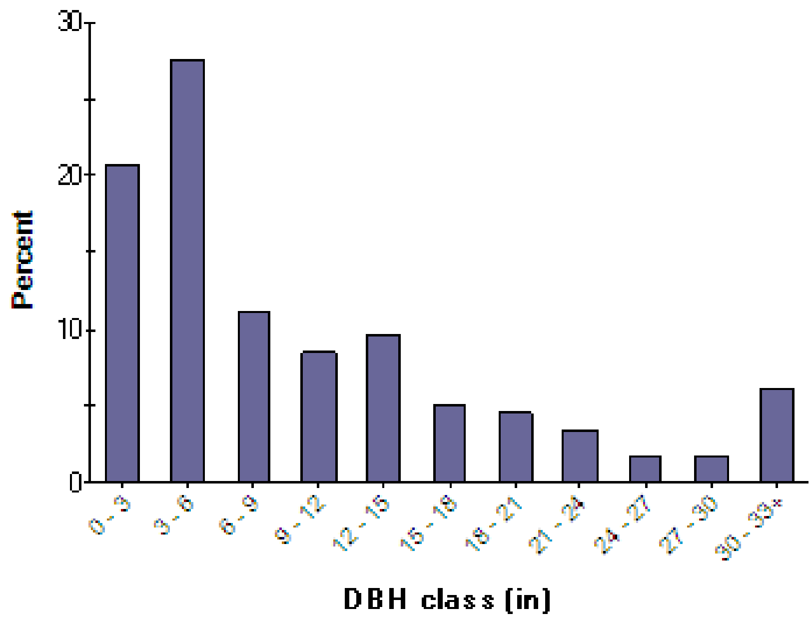

Figure 3. Trunk diameter distribution (DBH=stem diameter at 4.5 feet above ground line) of trees in City of Falls Church.

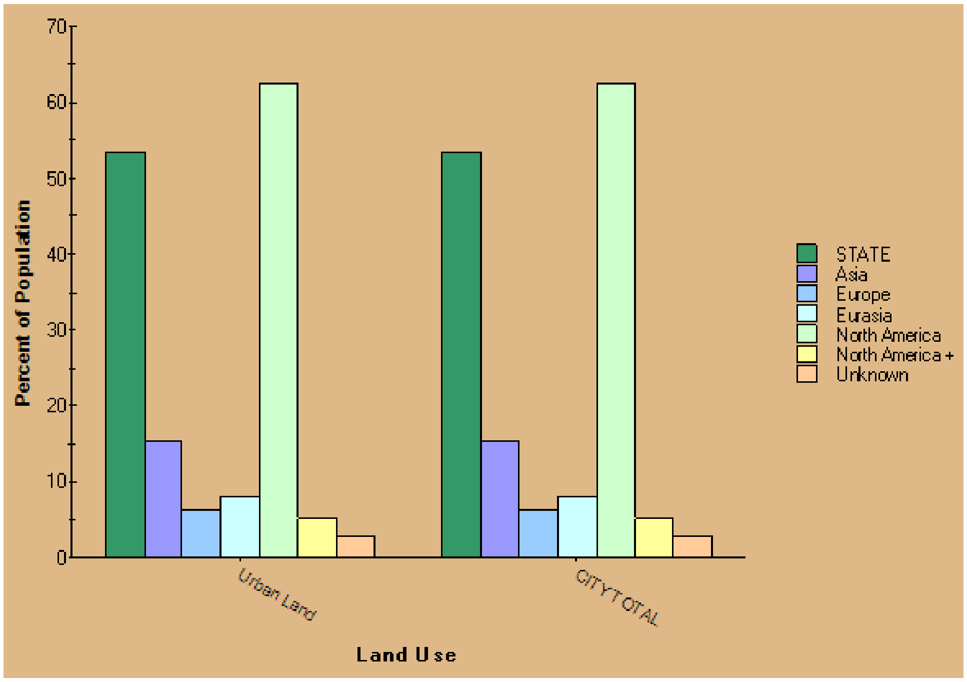

Figure 4. Species composition of live trees in City of Falls Church by geographic origin

"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 35 percent of Falls Church's land area. Many tree benefits are directly proportional to the amount of healthy leaf surface area. In Falls Church, the three most dominant tree species in terms of leaf area are tulip-poplar, black walnut, and sweetgum (Table 1). These three species are the only species accounting 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. Falls Church's ten most important species are listed in Table 1 below. Tulip-poplar, sweetgum, black walnut, and red maple are the four most important species, each having an IV exceeding 10.

The two most dominant ground cover types in Falls Church are tar (28 percent) and grass (26 percent) as shown in Figure 5. The three impervious ground cover classes (Building, Cement, and Tar) make up 55 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 19 percent of the land area (data not shown), which suggests moderate potential for increasing Falls Church's tree canopy cover.

Table 1. Ten most important tree species in City of Falls Church. 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)*
Tulip-poplar	4.5	26.1	30.6
Sweetgum	3.9	10.7	14.7
Black walnut	2.2	11.1	13.4
Red maple	2.8	7.6	10.4
Norway maple	5.1	4.3	9.3
Eastern white pine	5.6	2.9	8.5
Flowering dogwood	6.7	1.3	8.1
Eastern redcedar	5.6	2.3	7.9
Northern white-cedar	5.6	0.3	6.0
Eastern hemlock	2.2	3.5	5.7

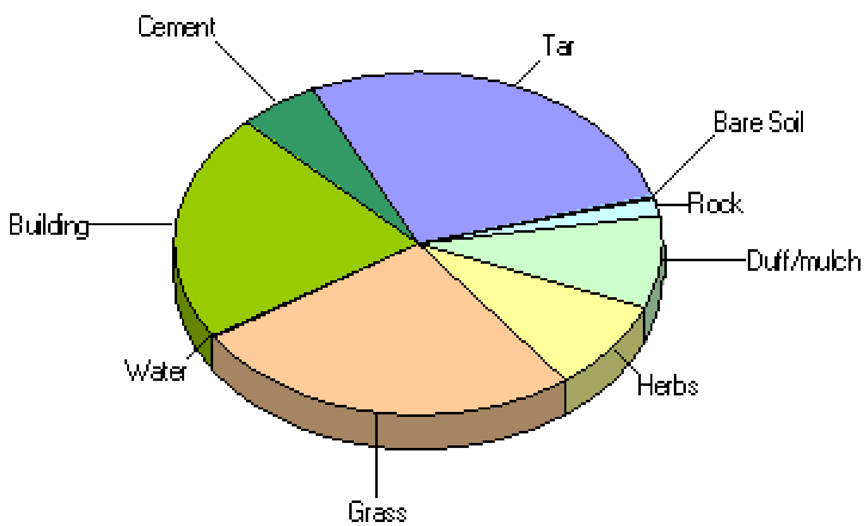

Figure 5. Ground cover composition (percent of total) in City of Falls Church

Structural and Functional Values of Falls Church'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 Falls Church's urban forest exceeds $146 million. The most valuable species in Falls Church's urban forest is tulip-poplar at nearly $34 million (Fig. 6). The ten most valuable species alone have a combined value of over $113 million. A summary of annual functional values are shown below and summarized in the subsequent sections of this report.

Structural values of trees in Falls Church's urban forest:

- Structural value: $147 million
- Carbon storage: $388 thousand

Functional values of trees in Falls Church's urban forest (annual basis):

- Carbon sequestration (removal): $17.9 thousand
- Pollution removal: $138 thousand
- Energy savings and carbon emission reductions: $225 thousand

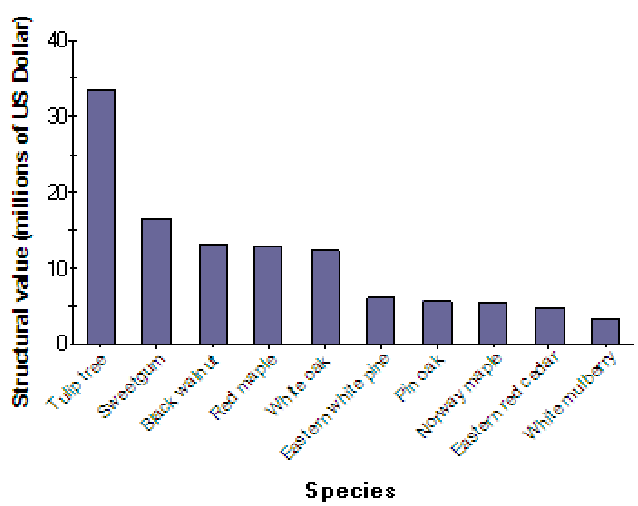

Figure 6. Structural value of the ten most valuable tree species in City of Falls Church

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 Falls Church's trees is about 970 tons of carbon per year with an associated value of $17,900. Net carbon sequestration (accounting for losses from carbon dioxide release through tree respiration) in Falls Church's urban forest is about 813 tons annually. Tulip-poplar sequesters the most carbon annually (~148 tons), which accounts for about 18% of all sequestered carbon in the urban forest (Fig. 7).

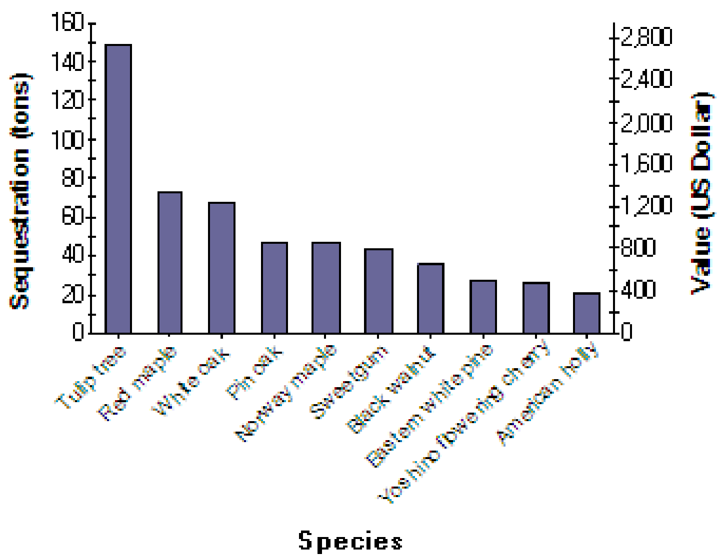

Figure 7. Annual carbon sequestration quantity and value for top ten tree species in Falls Church

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 Falls Church are estimated to store 21,100 tons of carbon, which is valued at $388 thousand. Of all the species sampled, tulip-poplar stores the most carbon (~24% 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 Falls Church was estimated using field data and recent pollution and weather data available. Pollution removal is greatest for ozone (O_3) as shown in Figure 8. It is estimated that Falls Church'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]).

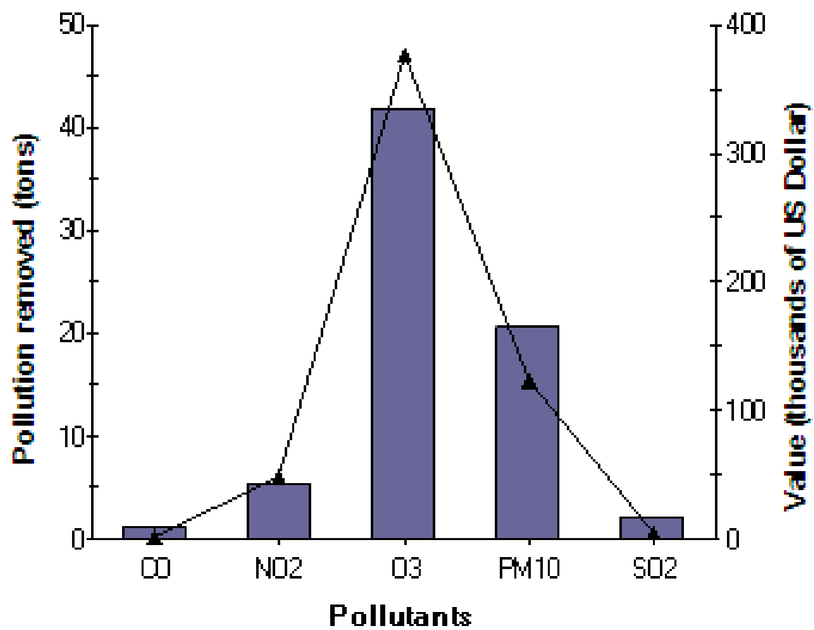

Figure 8. Pollution removal (bars) and associated monetary value (line) for trees in City of Falls Church

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 Falls Church 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]	1,972	n/a	1,972
MWH[2]	33	1,807	1,840
Carbon avoided (tons)	39	268	307

[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]	24,177	n/a	24,177
MWH[3]	3,501	191,723	195,224
Carbon avoidance	718	4,935	5,654

[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. 9): Asian longhorned beetle (ALB), gypsy moth (GM), emerald ash borer (EAB), and Dutch elm disease (DED).

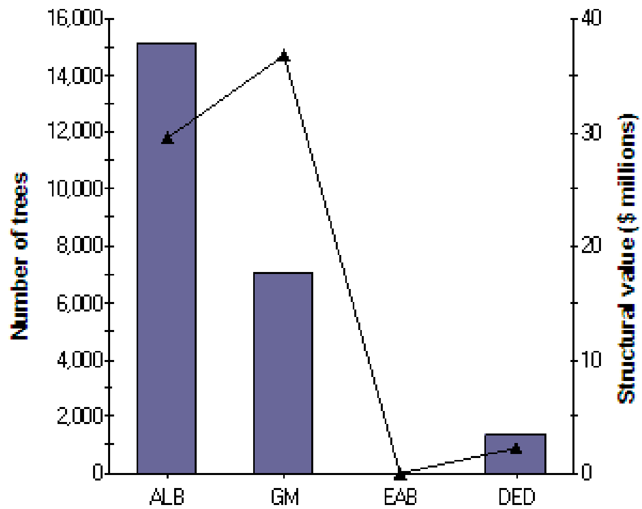

Figure 9. Susceptible trees (bars) and potential structural value loss (line) by pest for City of Falls Church's urban forest

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 25 percent of Falls Church's urban forest, which represents a potential loss of $29.4 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 12 percent of the tree population, representing a potential loss of $36.7 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. Although native ash are known to inhabit Falls Church, there was no measurable vulnerability to DED in terms of potential loss of trees or their structural value in this assessment.

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 some elm species have shown varying degrees of resistance, Falls Church could possibly lose 2.2 percent of its trees to this pest ($2.18 million in structural value).

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

Species	Number of Trees		Carbon Stored (ton)		Structural Values ($)	
	Value	SE	Value	SE	Value	SE
Flowering dogwood	4,023	2,151	118.8	80.2	1,340,340	787,810
Eastern redcedar	3,353	1,775	304.9	233.9	4,782,440	3,586,460
Eastern white pine	3,353	3,348	389.2	388.6	5,932,667	5,923,812
Northern white-cedar	3,353	2,743	26.6	20.2	483,871	365,538
Norway maple	3,017	1,308	962.2	579.8	5,425,327	2,996,209
Tulip-poplar	2,682	1,370	4,961.7	2,719.8	33,526,753	17,961,032
Sweetgum	2,347	1,057	1,551.2	904.8	16,544,529	9,482,398
Yew spp	2,347	2,343	65.7	65.6	1,873,635	1,870,838
Red maple	1,676	1,091	2,113.8	1,343.9	13,003,581	7,705,010
American holly	1,676	707	312.7	199.4	2,735,156	1,596,667
White mulberry	1,676	707	606.9	382.0	3,257,420	1,840,056
Black walnut	1,341	934	2,722.5	2,278.5	13,031,863	10,121,047
Red mulberry	1,341	1,050	37.7	33.9	373,832	321,640
Norway spruce	1,341	801	307.1	272.9	3,117,991	2,577,197
White spruce	1,341	801	17.7	12.8	299,804	225,214
London planetree	1,341	934	136.1	118.0	1,613,224	1,345,338
Yoshino flowering cherry	1,341	1,050	274.0	198.6	1,850,036	1,288,499
Eastern hemlock	1,341	934	193.4	163.7	2,277,620	1,879,674
Japanese maple	1,006	564	79.5	66.0	864,148	654,314
English holly	1,006	564	20.1	12.3	259,706	153,419
Chinese holly	1,006	740	12.0	8.9	168,093	124,255
Cucumber tree	1,006	740	129.2	97.2	1,309,145	948,012
Black cherry	1,006	740	265.8	263.9	1,156,184	1,129,454
Pin oak	1,006	564	1,309.1	1,105.5	5,548,365	4,164,449
Littleleaf linden	1,006	1,004	22.4	22.3	625,844	624,910
American elm	1,006	740	408.4	285.1	2,150,612	1,684,914
Siberian elm	1,006	740	6.5	5.6	62,716	53,435
Lagerstroemia spp	671	467	48.7	44.4	554,878	495,437
Southern magnolia	671	467	191.8	138.0	1,759,695	1,262,068
Blue spruce	671	467	45.8	44.5	569,031	549,217
White oak	671	670	2,191.3	2,188.0	12,211,852	12,193,626
Smooth sumac	671	670	18.3	18.3	297,826	297,382
Black haw	671	670	11.6	11.6	137,671	137,466
Mimosa	335	335	1.0	1.0	17,509	17,483
Serviceberry spp	335	335	1.6	1.6	4,306	4,299
Pignut hickory	335	335	250.4	250.0	1,775,358	1,772,708
Northern catalpa	335	335	556.1	555.3	1,826,637	1,823,911
Eastern redbud	335	335	4.6	4.6	64,481	64,385
Northern hackberry	335	335	1.0	1.0	15,301	15,278

Hinoki cypress	335	335	10.3	10.2	260,700	260,311
Creeping strawberry bush	335	335	3.2	3.1	47,693	47,622
Rose-of-sharon	335	335	0.4	0.4	15,872	15,848
Ligustro	335	335	4.8	4.8	63,591	63,496
Waxyleaf privet	335	335	1.4	1.4	24,504	24,467
Common privet	335	335	5.9	5.9	58,437	58,350
Apple spp	335	335	104.3	104.2	756,163	755,035
Apple	335	335	30.1	30.0	359,380	358,844
Japanese black pine	335	335	6.8	6.8	312,026	311,560
Common chokecherry	335	335	1.2	1.2	13,329	13,309
Callery pear	335	335	174.0	173.8	1,123,581	1,121,904
English oak	335	335	2.9	2.9	54,856	54,774
Weeping willow	335	335	41.5	41.5	342,348	341,837
Lilac spp	335	335	1.8	1.8	24,334	24,298
Slippery elm	335	335	1.3	1.3	28,241	28,199
Leather leaf viburnum	335	335	2.1	2.1	32,983	32,933
Viburnum spp	335	335	24.3	24.3	274,127	273,718
Total	**59,677**	**8,298**	**21,093.7**	**4,687.7**	**146,641,610**	**27,081,701**

Appendix II. Relative Tree Effects

The urban forest in City of Falls Church 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 Falls Church in 103 days
- Annual carbon (C) emissions from 12,700 automobiles
- Annual C emissions from 6,360 single-family houses

Carbon monoxide removal is equivalent to:
- Annual carbon monoxide emissions from 2 automobiles
- Annual carbon monoxide emissions from 7 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 120 automobiles
- Annual nitrogen dioxide emissions from 80 single-family houses

Sulfur dioxide removal is equivalent to:
- Annual sulfur dioxide emissions from 2,400 automobiles
- Annual sulfur dioxide emissions from 40 single-family houses

Particulate matter less than 10 micron (PM10) removal is equivalent to:
- Annual PM10 emissions from 17,800 automobiles
- Annual PM10 emissions from 1,710 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in Falls Church in 4.7 days
- Annual C emissions from 600 automobiles
- Annual C emissions from 300 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

References

1. Nowak D.J. and Dwyer J.F. *Understanding the benefits and costs of urban forest ecosystems*. Handbook of Urban and Community Forestry in the Northeast. Ed. John E. Kuser. Kluwer Academics/Plenum Pub., New York. 2000. 11-22.

2. Murray, F.J.; Marsh L.; Bradford, P.A. 1994. *New York State Energy Plan, Vol. II: Issue Reports*. Albany, NY: New York State Energy Office.

3. Abdollahi, K.K.; Z.H. Ning; and A. Appeaning (eds). 2000. *Global climate change and the urban forest*. Baton Rouge, LA: GCRCC and Franklin Press. 77p.

4. McPherson, E.G. and J. R. Simpson 1999. *Carbon dioxide reduction through urban forestry: guidelines for professional and volunteer tree planters*. Gen. Tech. Rep. PSW-171. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research station 237 p. http://wcufre.ucdavis.edu/products/cufr_43.pdf

5. Nowak, D.J., and D.E. Crane. 2000. *The Urban Forest Effects (UFORE) Model: quantifying urban forest structure and functions*. In: Hansen, M. and T. Burk (Eds.) Integrated Tools for Natural Resources Inventories in the 21st Century. Proc. Of the IUFRO Conference. USDA Forest Service General Technical Report NC-212. North Central Research Station, St. Paul, MN. pp. 714-720. See also http://www.ufore.org.

6. Nowak, D.J.; Crane, D.E.; Dwyer, J.F. 2002. *Compensatory value of urban trees in the United States.* Journal of Arboriculture. 28(4): 194 - 199.

7. Northeastern Area State and Private Forestry. 2005. *Asian Longhorned Beetle*. NewCity Square, PA: U.S. Department of Agriculture, Northeastern Area State and Private Forestry. http://www.na.fs.fed.us/spfo/alb

8. Northeastern Area State and Private Forestry. 2005. *Gypsy moth digest*. NewCity Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. http://na.fs.fed.us/fhp/gm

9. Northeastern Area State and Private Forestry. 2005. *Forest health protection emerald ash borer home*. NewCity Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. http://www.na.fs.fed.us/spfo/eab/index.html

10. Northeastern Area State and Private Forestry. 1998. *How to identify and manage Dutch Elm Disease*. NA-PR-07-98. NewCity Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. http://www.na.fs.fed.us/spfo/pubs/howtos/ht_ded/ht_ded.htm

11. Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Hoehn, R.E. 2005. *The urban forest effects (UFORE) model: field data collection manual*. V1b. NewCity Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station, 34 p. http://www.fs.fed.us/ne/syracuse/Tools/downloads/UFORE_Manual.pdf

12. Nowak, D.J. 1994. *Atmospheric carbon dioxide reduction by Chicago's urban forest*. In: McPherson, E.G.; Nowak, D.J.; Rowntree, R.A., eds. Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep. NE-186. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 83-94.

13. Baldocchi, D. 1988. *A multi-layer model for estimating sulfur dioxide deposition to a deciduous oak forest canopy*. Atmospheric Environment. 22: 869-884.

14. Baldocchi, D.D.; Hicks, B.B.; Camara, P. 1987. *A canopy stomatal resistance model for gaseous deposition to vegetated surfaces*. Atmospheric Environment. 21: 91-101.

15. Bidwell, R.G.S.; Fraser, D.E. 1972. *Carbon monoxide uptake and metabolism by leaves*. Canadian Journal of Botany. 50: 1435-1439.

16. Lovett, G.M. 1994. *Atmospheric deposition of nutrients and pollutants in North America: an ecological perspective*. Ecological Applications. 4: 629-650.

17. Zinke, P.J. 1967. *Forest interception studies in the United States*. In: Sopper, W.E.; Lull, H.W., eds. Forest Hydrology. Oxford, UK: Pergamon Press: 137-161.

18. Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Ibarra, M. 2002. *Brooklyn's Urban Forest*. Gen. Tech. Rep. NE-290. NewCity Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 107 p. Council of Tree and Landscape Appraisers guidelines.

For more information, see Nowak, D.J., D.E. Crane, and J.F. Dwyer. 2002. *Compensatory value of urban trees in the United States*. Journal of Arboriculture. 28(4): 194-199.

19. Total city carbon emissions were based on 2003 U.S. per capita carbon emissions - calculated as total U.S. carbon emissions (Energy Information Administration, 2003, Emissions of Greenhouse Gases in the United States 2003. http://www.eia.doe.gov/oiaf/1605/ggrpt) divided by 2003 U.S. total population (www.census.gov). Per capita emissions were multiplied by city population to estimate total city carbon emissions.

20. Average passenger automobile emissions per mile were based on dividing total 2002 pollutant emissions from light-duty gas vehicles (National Emission Trends http://www.epa.gov/ttn/chief/trends/index.html) divided by total miles driven in 2002 by passenger cars (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004).

Average annual passenger automobile emissions per vehicle were based on dividing total 2002 pollutant emissions from light-duty gas vehicles by total number of passenger cars in 2002 (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004).

Carbon dioxide emissions from automobile assumed six pounds of carbon per gallon of gasoline if energy costs of refinement and transportation are included (Graham, R.L., Wright, L.L., and Turhollow, A.F. 1992. The potential for short-rotation woody crops to reduce U.S. CO2 Emissions. Climatic Change 22:223-238.

21. Average household emissions based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household from: Energy Information Administration. Total Energy Consumption in U.S. Households by Type of Housing Unit, 2001 http://www.eia.doe.gov/emeu/recs/contents.html.

CO2, SO2, and NOx power plant emission per KWh from: U.S. Environmental Protection Agency. U.S. Power Plant Emissions Total by Year http://www.epa.gov/cleanenergy/egrid/samples.htm.

CO emission per kWh assumes 1/3 of one percent of C emissions is CO based on: Energy Information Administration. 1994 Energy Use and Carbon Emissions: Non-OECD Countries DOE/EIA-0579.

PM10 emission per kWh from: Layton, M. 2004. 2005 Electricity Environmental Performance Report: Electricity Generation and Air Emissions. California Energy Commission.

http://www.energy.ca.gov/2005_energypolicy/documents/2004-11-15_workshop/2004-11-15_03-A_LAYTON.PDF

CO2, NOx, SO2, PM10, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from: Abraxas energy consulting, http://www.abraxasenergy.com/emissions

CO2 and fine particle emissions per Btu of wood from: Houck, J.E. Tiegs, P.E, McCrillis, R.C. Keithley, C. and Crouch, J. 1998. Air emissions from residential heating: the wood heating option put into environmental perspective. In: Proceedings of U.S. EPA and Air Waste Management Association Conference: Living in a Global Environment, V.1: 373-384.

CO, NOx and SOx emission per Btu based on total emissions and wood burning (tonnes) from: Residential Wood Burning Emissions in British Columbia, 2005. http://www.env.bc.ca/air/airquality/pdfs/wood_emissions.pdf.

Emissions per dry tonne of wood converted to emissions per Btu based on average dry weight per cord of wood and average Btu per cord from: Heating with Wood I. Species characteristics and volumes. http://ianrpubs.unl.edu/forestry/g881.htm

22. Nowak, D.J. 1995. *Trees pollute? A "TREE" explains it all*. In: Proceedings of the 7th National Urban Forestry Conference. Washington, DC: American Forests. Pp. 28-30

23. Nowak, D.J. and J.F. Dwyer. 2007. *Understanding the benefits and costs of urban forest ecosystems*. In: Kuser, J. (ed.) Urban and Community Forestry in the Northeast. New York: Springer. Pp. 25-46.

24. Nowak, D.J. 2000. *The interactions between urban forests and global climate change*. In: Abdollahi, K.K., Z.H. Ning, and A. Appeaning (Eds). Global Climate Change and the Urban Forest. Baton Rouge: GCRCC and Franklin Press. Pp. 31-44.

25. Nowak, D.J., D.E. Crane and J.C. Stevens. 2006. *Air pollution removal by urban trees and shrubs in the United States*. Urban Forestry and Urban Greening. 4:115-123

26. Nowak, D.J., R.E. Hoehn, D.E. Crane, J.C. Stevens, J.T. Walton, and J. Bond. 2008. *A ground-based method of assessing urban forest structure and ecosystem services*. Arboriculture and Urban Forestry. 34(6): 347-358

27. Hirabayashi, S., C. Kroll, and D. Nowak. (2011). *Component-based development and sensitivity analyses of an air pollutant dry deposition model*. Environmental Modeling and Software 26(6): 804-816.

28. Hirabayashi, S., C. Kroll, and D. Nowak. (2011). Urban Forest Effects-Dry Deposition (UFORE-D) Model Descriptions, http://www.itreetools.org/eco/resources/UFORE-D%20Model%20Descriptions_V1_1.pdf

29. Hirabayashi, S. (2011). Urban Forest Effects-Dry Deposition (UFORE-D) Model Enhancements, http://www.itreetools.org/eco/resources/UFORE-D_enhancements.pdf