i-Tree
Ecosystem Analysis

Winchester

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 Winchester, Virginia was conducted during 2011 using i-Tree Eco sampling protocols and analysis tools. Data from 88 field plots located throughout Winchester in four land-use classes (Commercial, Industrial, Residential, and Underdeveloped) were analyzed using the Urban Forest Effects (UFORE) model developed by the U.S. Forest Service, Northern Research Station.

Key findings

- Number of trees: 233,639 (SE: 37,480)
- Tree canopy cover: 21% (SE: 0.52)
- Most common tree species: tree-of-heaven, Siberian elm, and eastern white pine
- Percentage of trees less than 6" trunk diameter: 53%
- Carbon storage: 44,600 tons (valued at $822 thousand)
- Annual gross carbon sequestration: 1,620 tons (valued at $29,900)
- Annual avoided carbon emissions: 471 tons (valued at $8,673)
- Annual pollution removal: 38 tons (valued at $288 thousand)
- Annual building energy savings: $460 thousand
- Structural value of trees: $261 million (SE: 43 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 Winchester, 88 one-tenth-acre plots were sampled using a stratified random sampling method across four land use types: commercial (20 plots), industrial (8 plots), residential (57 plots), and underdeveloped (3 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, Winchester's human population was set at 26,203 as estimated by the U.S. Census Bureau in 2010 (http://quickfacts.census.gov/qfd/states/51/51840.html).

Structure of Winchester's Urban Forest

Tree Characteristics of the Urban Forest

The urban forest of Winchester comprises about 234,000 trees with a tree canopy cover of about 21 percent (see Appendix III for comparable values from other cities). The three most common tree species are tree-of-heaven (~11 percent), Siberian elm (~9 percent), and eastern white pine (~8 percent) as shown in Figure 1. There were 71 unique taxa of woody plants catalogued in the field survey. With the exception of the top three species mentioned above (along with northern hackberry), 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 Winchester averages about 40 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 Underdeveloped lands followed by Residential lands and Industrial lands (Fig. 2). Trees that have diameters less than 6-inches constitute about 53 percent of the tree population (Fig. 3), which suggests that there are plentiful young trees to help sustain forest cover into the future.

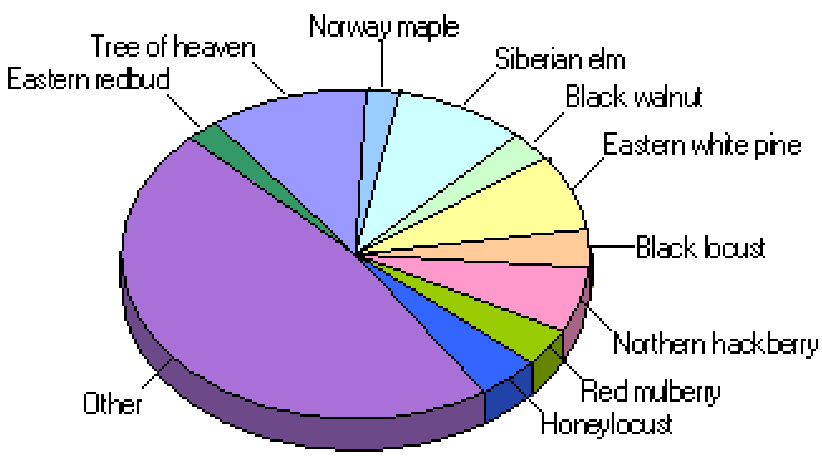

Figure 1. Tree species composition (percent of total) in City of Winchester

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 Winchester, about 56 percent of the trees are species native to North America, while 49 percent are native to the state (Fig. 4). Species exotic to Virginia make up 43 percent of the population. Most of Winchester's exotic tree species are indigenous to Asia (~30 percent of the species).

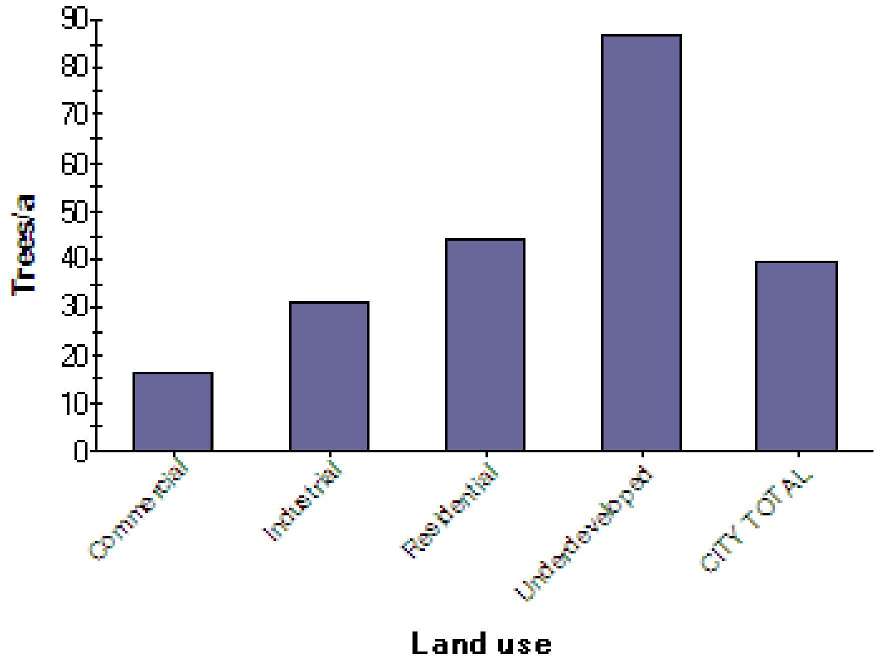

Figure 2. Trees per acre (a) in City of Winchester by land use

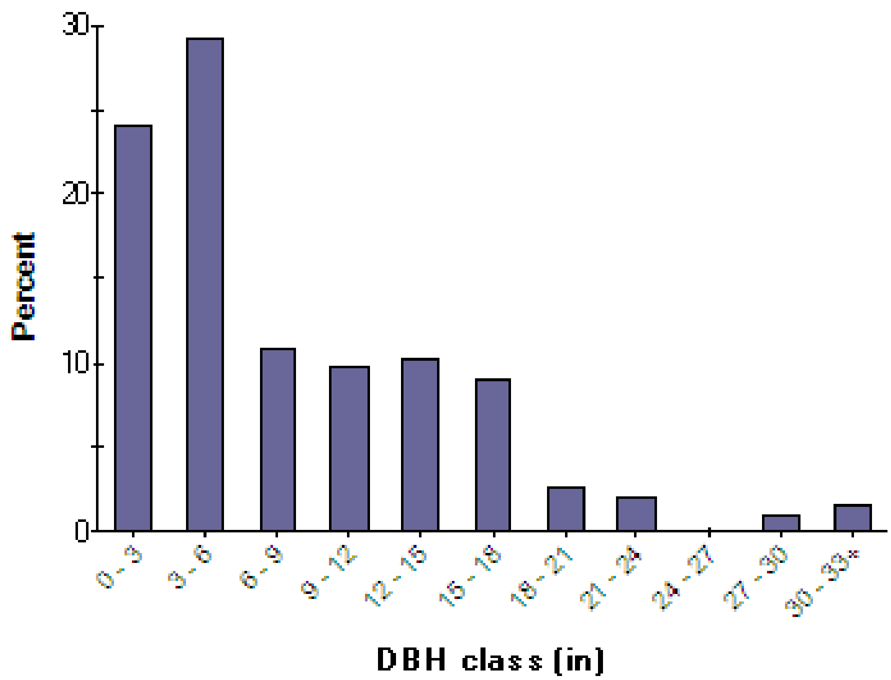

Figure 3. Trunk diameter distribution (DBH=stem diameter at 4.5 feet above ground line) of trees in City of Winchester.

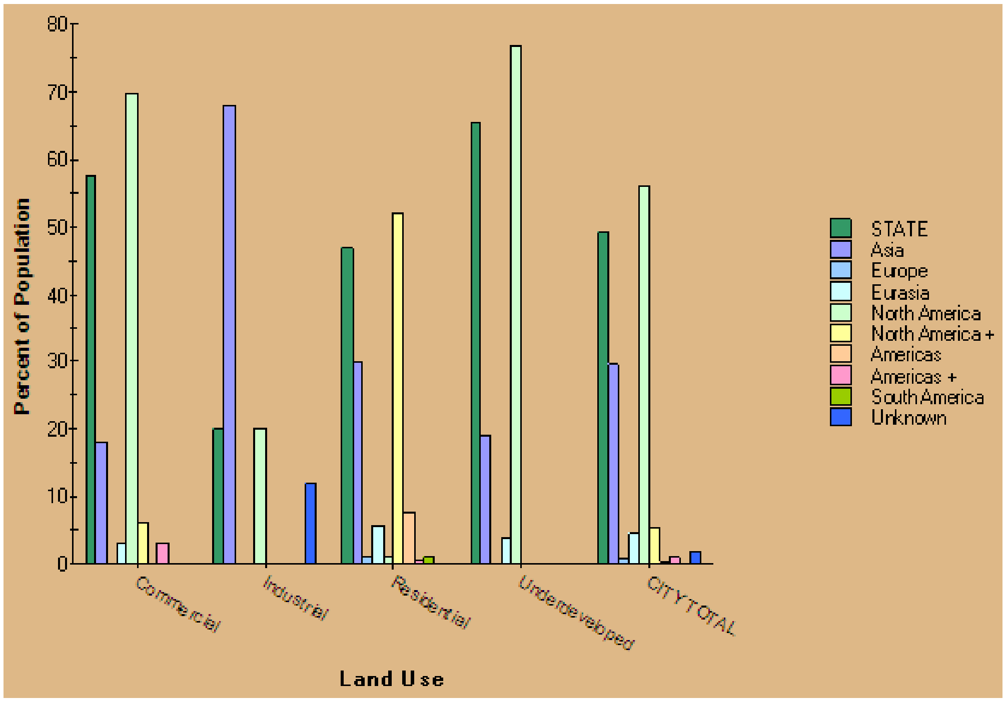

Figure 4. Species composition of live trees in City of Winchester by geographic origin

"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 21 percent of Winchester's land area. Many tree benefits are directly proportional to the amount of healthy leaf surface area. In Winchester, the three most dominant tree species in terms of leaf area are Siberian elm, black walnut, and eastern white pine (Table 1). Siberian elm 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. Winchester's ten most important species are listed in Table 1 below. Five species have an IV exceeding 10, with Siberian elm being the most important species at a value of 23.4.

The two most dominant ground cover types in Winchester are grass (41 percent) and tar (19 percent) as shown in Figure 5. The three impervious ground cover classes (Building, Cement, and Tar) make up 40 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 26 percent of the land area (data not shown), which suggests moderate potential for increasing Winchester's tree canopy cover.

Table 1. Ten most important tree species in City of Winchester. 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)*
Siberian elm	9.1	14.3	23.4
Tree of heaven	11.1	5.7	16.8
Eastern white pine	7.5	8.2	15.7
Northern hackberry	6.3	8.0	14.3
Black walnut	3.0	9.5	12.5
American sycamore	0.6	6.7	7.3
Black locust	3.7	3.3	7.0
Red mulberry	3.7	2.2	5.9
Honeylocust	4.3	1.4	5.7
Norway maple	2.3	2.8	5.1

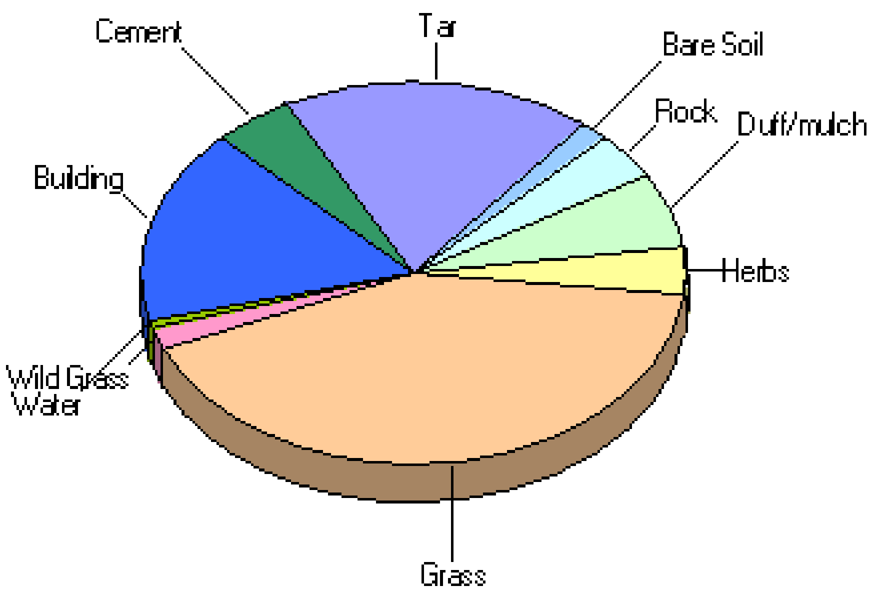

Figure 5. Ground cover composition (percent of total) in City of Winchester

Structural and Functional Values of Winchester'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 Winchester's urban forest exceeds $260 million. The most valuable species in Winchester's urban forest is eastern white pine at nearly $35 million (Fig. 6). The ten most valuable species alone have a combined value of over $160 million. A summary of annual functional values are shown below and summarized in the subsequent sections of this report.

<u>Structural values of trees in Winchester's urban forest:</u>

- Structural value: $261 million
- Carbon storage: $822 thousand

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

- Carbon sequestration (removal): $29.9 thousand
- Pollution removal: $288 thousand
- Energy savings and carbon emission reductions: $469 thousand

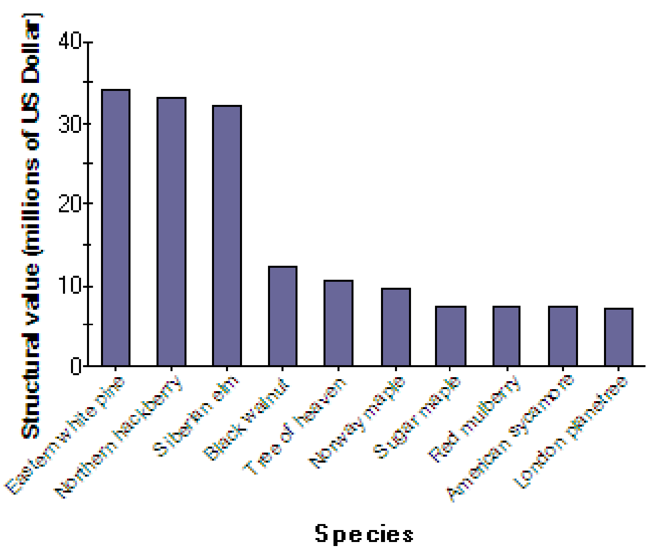

Figure 6. Structural value of the ten most valuable tree species in City of Charlottesville

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 Winchester's trees is about 1,620 tons of carbon per year with an associated value of $29,900. Net carbon sequestration (accounting for losses from carbon dioxide release through tree respiration) in Winchester's urban forest is about 474 tons annually. Northern hackberry sequesters the most carbon annually (~134 tons), which accounts for about 28% of all sequestered carbon in the urban forest (Fig. 7).

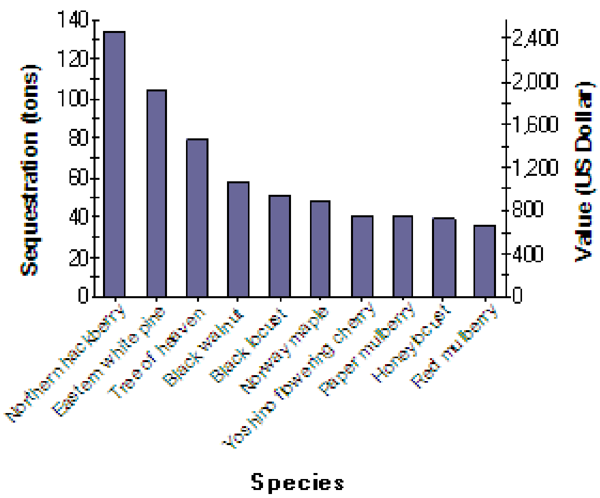

Figure 7. Annual carbon sequestration quantity and value for top ten tree species in Charlottesville

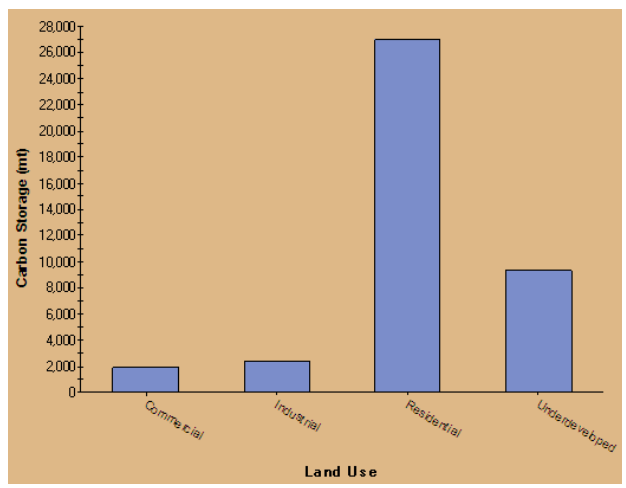

Figure 8. Carbon storage in Charlottesville's urban forest by land use

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 Winchester are estimated to store 44,600 tons of carbon, which is valued at $822 thousand (Fig. 8). Of all the species sampled, Siberian elm stores the most carbon (~26% 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 Winchester 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 Winchester's trees remove 38 tons of air pollution (CO, NO_2, O_3, PM_{10}, and SO_2) per year with an associated value of $288 thousand (based on estimated national median externality costs associated with pollutants[2]).

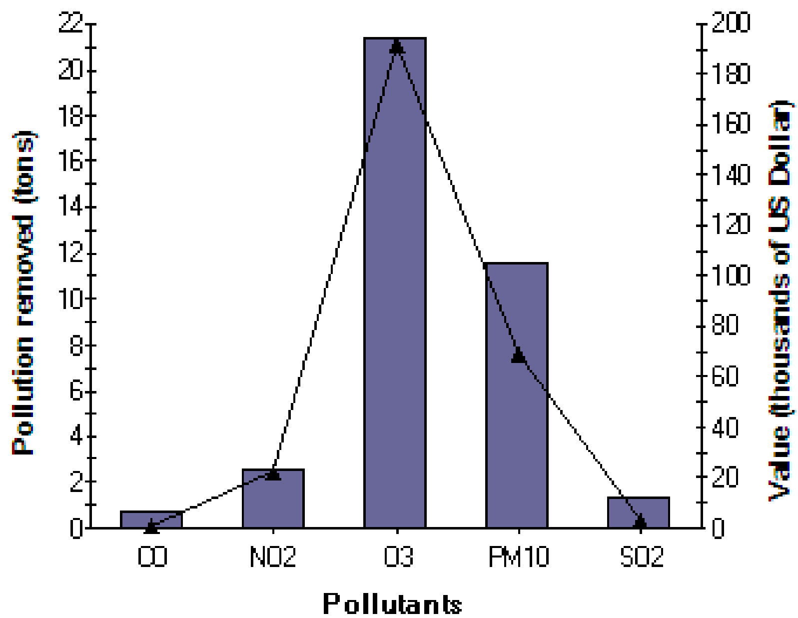

Figure 9. Pollution removal (bars) and associated monetary value (line) for trees in City of Winchester

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 Winchester are estimated to reduce energy-related costs from residential buildings by $460 thousand annually (Tables 2 and 3). Trees also provide an additional $8,674 in value[5] by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 471 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]	24,059	n/a	24,059
MWH[2]	369	1,189	1,558
Carbon avoided (tons)	471	0	427

[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]	294,963	n/a	294,963
MWH[3]	39,151	126,153	165,304
Carbon avoidance	8,674	0	8674

[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).

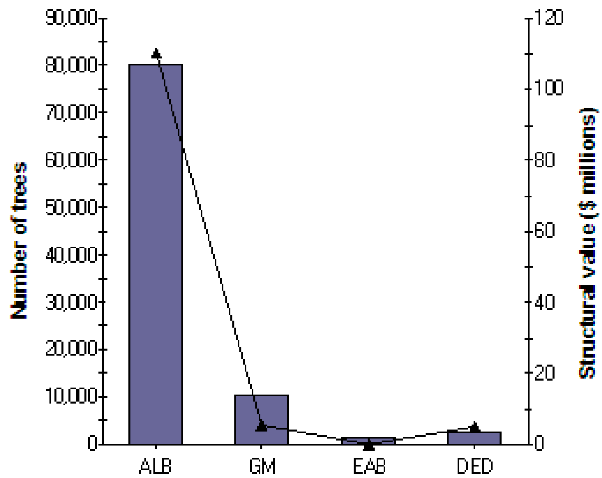

Figure 10. Susceptible trees (bars) and potential structural value loss (line) by pest for City of Winchester's urban forest

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 34 percent of Winchester's urban forest, which represents a potential loss of $110 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 $5.31 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 0.5 percent of Winchester's tree population ($201 thousand 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 some elm species have shown varying degrees of resistance, Winchester could possibly lose 1 percent of its trees to this pest ($4.82 million in structural value).

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**
Commercial	Black locust	5,771	5,767	996,073	995,382
Commercial	Catalpa spp	2,164	2,163	1,116,281	1,115,507
Commercial	Eastern white pine	2,164	2,163	229,933	229,773
Commercial	Northern white cedar	2,164	2,163	109,600	109,524
Commercial	American sycamore	1,443	1,442	7,287,478	7,282,425
Commercial	Viburnum spp	1,443	1,442	85,400	85,341
Commercial	Baldcypress	721	721	1,835,958	1,834,685
Commercial	Black walnut	721	721	133,775	133,682
Commercial	Callery pear	721	721	606,442	606,021
Commercial	Crabapple	721	721	55,203	55,164
Commercial	Goldenrain tree	721	721	1,496,173	1,495,136
Commercial	Hedge maple	721	721	1,282,291	1,281,402
Commercial	Kousa dogwood	721	721	154,316	154,209
Commercial	Leyland cypress	721	721	367,983	367,728
Commercial	Northern hackberry	721	721	11,362	11,354
Commercial	Plum spp	721	721	1,034,089	1,033,372
Commercial	Siberian elm	721	721	35,677	35,652
Commercial	Weeping willow	721	721	194,469	194,334
Commercial	**Total**	**23,806**	**8,579**	**17,032,502**	**7,653,183**
Industrial	Tree of heaven	7,095	7,090	760,770	760,234
Industrial	Paper mulberry	4,967	4,963	3,743,302	3,740,663
Industrial	London planetree	2,129	2,127	6,931,697	6,926,810
Industrial	Black haw	1,419	1,418	53,647	53,609
Industrial	Flowering dogwood	710	709	641,318	640,866
Industrial	Northern hackberry	710	709	11,175	11,167
Industrial	Washington hawthorn	710	709	164,115	164,000
Industrial	**Total**	**17,738**	**14,637**	**12,306,024**	**8,015,167**
Residential	Siberian elm	17,320	7,027	25,447,483	12,607,201
Residential	Tree of heaven	15,528	8,432	6,536,021	4,952,726
Residential	Northern hackberry	10,153	4,661	31,088,300	21,833,751
Residential	Honeylocust	8,361	6,097	5,387,210	2,908,675
Residential	Eastern redbud	5,375	2,664	3,435,835	1,910,535
Residential	Norway maple	5,375	2,218	9,671,366	5,312,970
Residential	Black walnut	4,778	1,986	12,081,515	7,616,404
Residential	Boxelder	4,778	3,003	3,512,923	2,959,399
Residential	Common chokecherry	4,778	3,235	410,385	314,750
Residential	Eastern white pine	4,181	3,194	7,009,127	4,946,721
Residential	Red maple	4,181	1,718	3,136,665	1,559,663
Residential	Black cherry	3,583	2,509	5,014,029	3,515,810

Residential	Holly spp	3,583	2,201	1,418,127	1,023,330
Residential	Pin oak	3,583	1,843	2,909,842	1,759,732
Residential	Yoshino flowering cherry	3,583	2,201	5,522,437	4,258,867
Residential	American holly	2,986	2,984	1,789,926	1,788,427
Residential	Hackberry spp	2,986	2,450	1,044,970	1,004,333
Residential	White mulberry	2,986	1,542	3,872,334	2,450,452
Residential	American elm	2,389	1,877	4,732,814	4,621,997
Residential	Black haw	2,389	1,877	54,246	40,367
Residential	Flowering dogwood	2,389	1,161	1,443,093	1,097,692
Residential	Leyland cypress	2,389	1,877	1,587,602	1,144,890
Residential	Lilac spp	1,792	1,015	6,464,179	6,368,034
Residential	Rose-of-sharon	1,792	1,790	336,122	335,840
Residential	Silver maple	1,792	1,325	1,609,230	1,482,051
Residential	Southern magnolia	1,792	1,325	992,373	914,058
Residential	Spruce spp	1,792	1,790	1,016,878	1,016,027
Residential	Apple spp	1,194	836	50,492	35,375
Residential	Black locust	1,194	1,193	1,524,178	1,522,902
Residential	Callery pear	1,194	836	2,231,360	1,803,002
Residential	Common lilac	1,194	836	437,946	387,456
Residential	Northern white cedar	1,194	1,193	72,030	71,969
Residential	Osage orange	1,194	1,193	94,323	94,244
Residential	Plum spp	1,194	1,193	5,217,184	5,212,815
Residential	Sugar maple	1,194	836	7,519,843	5,423,592
Residential	Sweet cherry	1,194	1,193	1,896,982	1,895,393
Residential	White ash	1,194	836	201,093	149,832
Residential	Amur privet	597	597	28,280	28,257
Residential	Common box	597	597	28,280	28,257
Residential	Common cherry laurel	597	597	20,157	20,140
Residential	European crabapple	597	597	395,291	394,960
Residential	Fraser fir	597	597	427,416	427,058
Residential	Freeman maple	597	597	78,203	78,137
Residential	Japanese black pine	597	597	1,037,553	1,036,684
Residential	Japanese maple	597	597	270,684	270,457
Residential	Japanese zelkova	597	597	1,802,669	1,801,159
Residential	Kwanzan cherry	597	597	405,190	404,851
Residential	Leather leaf viburnum	597	597	160,973	160,838
Residential	Northern catalpa	597	597	1,859,428	1,857,871
Residential	Norway spruce	597	597	2,456,397	2,454,339
Residential	Paper birch	597	597	742,586	741,964
Residential	Red mulberry	597	597	96,089	96,009
Residential	Silver linden	597	597	106,992	106,903
Residential	Walnut spp	597	597	2,613,629	2,611,440
Residential	White cedar	597	597	80,147	80,080
Residential	Winged burningbush	597	597	32,633	32,605

Residential	Winged elm	597	597	92,043	91,966
Residential	**Total**	**150,504**	**31,490**	**179,505,104**	**35,429,582**
Underdeveloped	Eastern white pine	11,198	11,194	26,861,336	26,852,939
Underdeveloped	Red mulberry	7,998	7,996	7,316,952	7,314,665
Underdeveloped	Freeman maple	3,199	3,198	1,046,783	1,046,456
Underdeveloped	Northern hackberry	3,199	1,599	1,960,250	1,815,083
Underdeveloped	Siberian elm	3,199	3,198	6,706,746	6,704,649
Underdeveloped	Tree of heaven	3,199	3,198	3,219,176	3,218,169
Underdeveloped	Black locust	1,600	1,599	3,695,514	3,694,359
Underdeveloped	Black walnut	1,600	1,599	81,583	81,557
Underdeveloped	Honeylocust	1,600	1,599	282,006	281,917
Underdeveloped	Locust spp	1,600	1,599	70,501	70,479
Underdeveloped	Smoke tree	1,600	1,599	687,556	687,341
Underdeveloped	White mulberry	1,600	1,599	411,986	411,857
Underdeveloped	**Total**	**41,591**	**11,194**	**52,340,389**	**20,724,836**
CITY TOTAL	**Total**	**233,639**	**37,480**	**261,184,019**	**42,515,740**

Appendix II. Relative Tree Effects

The urban forest in City of Winchester 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 Winchester in 103 days
- Annual carbon (C) emissions from 26,800 automobiles
- Annual C emissions from 13,400 single-family houses

Carbon monoxide removal is equivalent to:
- Annual carbon monoxide emissions from 3 automobiles
- Annual carbon monoxide emissions from 12 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 160 automobiles
- Annual nitrogen dioxide emissions from 106 single-family houses

Sulfur dioxide removal is equivalent to:
- Annual sulfur dioxide emissions from 2,050 automobiles
- Annual sulfur dioxide emissions from 34 single-family houses

Particulate matter less than 10 micron (PM10) removal is equivalent to:
- Annual PM10 emissions from 30,800 automobiles
- Annual PM10 emissions from 2,970 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in Winchester in 3.7 days
- Annual C emissions from 1,000 automobiles
- Annual C emissions from 500 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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