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# A Report on the Status of Street Trees in Worcester, Massachusetts

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## Trees in Peril: Responding to the Asian Longhorned Beetle

October 2008

prepared for:

*The City of Worcester, Massachusetts  
and the Massachusetts Department of Conservation and Recreation*

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***Institute Park, Worcester, MA***



*photo by Troy B. Thompson, 2008*

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### *Institute Park, Worcester, MA*



*photo by Troy B. Thompson, 2008*

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**Elm Park Pond, Worcester, MA**



*(Image by K. Jeff Burdett, 2008)*

## Executive Summary

The City of Worcester, Massachusetts is facing a major challenge since the discovery of the exotic invasive Asian longhorned beetle (*Anoplophora glabripennis*) in August 2008. At the highest risk are 81% of the city's street trees—trees in the genera *Acer*, *Betula*, *Aesculus*, *Salix*, and *Ulmus*, the preferred hosts of Asian longhorned beetle in the United States according to a United States Department of Agriculture, Animal and Plant Health Inspection Service host list (Sawyer 2008). The removal of infested trees during the eradication process will dramatically alter the cityscape. The purpose of this report is to present the current condition of the street tree population and quantify the environmental services that this part of Worcester's urban forest provides.

As eradication efforts continue, the city will undergo a necessary reforestation process. Reforestation in Worcester should not only restore the city's urban forest, but also improve it. The city has an opportunity to diversify its trees and plant species to maximize future benefits and minimize future conflicts. Table 1 shows some of the general characteristics of Worcester's street trees.

Trees in urbanized areas play a role in mitigating the negative environmental effects of urbanization from reducing air pollution and sequestering carbon dioxide to reducing stormwater runoff. Urban trees also contribute economic value to communities and contribute to the health and well-being of those who live, work, and recreate in urban areas. The USDA Forest Service has developed a program to quantify the benefits of urban street trees. The Street Tree Analysis Resource Tool for Urban Forest Managers (STRATUM) uses tree inventory information to provide "structure, function, and value" of the urban forest. Communities can use information from STRATUM reports to better understand the structure of their street tree population, the environmental services the trees provide, and the dollar value for those services. The quantified environmental benefits and dollar values are based on models and represent the best approximation of these figures. The following report is the result of a STRATUM analysis conducted October 2008.

**Table 1. Worcester Street Information at a Glance**

<b>Worcester Street Trees at a Glance</b>	
Total street trees	17,113
Most common genus (% of total trees)	Maple (79.7%)
Three most common species (% of total trees)	Norway maple (60.8%), sugar maple (9.6%), red maple (6.4%)
<b>Percentage of street trees that are preferred hosts of Asian longhorned beetle</b>	<b>81%</b>
Total canopy cover (ft <sup>2</sup> )	19,612,402
Total annual benefits of street trees	\$ 2,395,854
Replacement value of total street tree population	\$ 96,703,673

## Methods

Data for this report came from Worcester’s TreeKeeper website, which the city uses to archive and manage information related to its street trees. The Worcester Department of Public Works and Parks conducted the inventory in 2005-2006. The inventory data were downloaded on June 11, 2008 and formatted to meet requirements for STRATUM analysis, as established in the i-Tree protocols. The protocols can be found at [www.itreetools.org](http://www.itreetools.org).

Analysis of trees by neighborhood was completed using Microsoft Excel, SAS (v. 9.1), and MINITAB (v. 14).

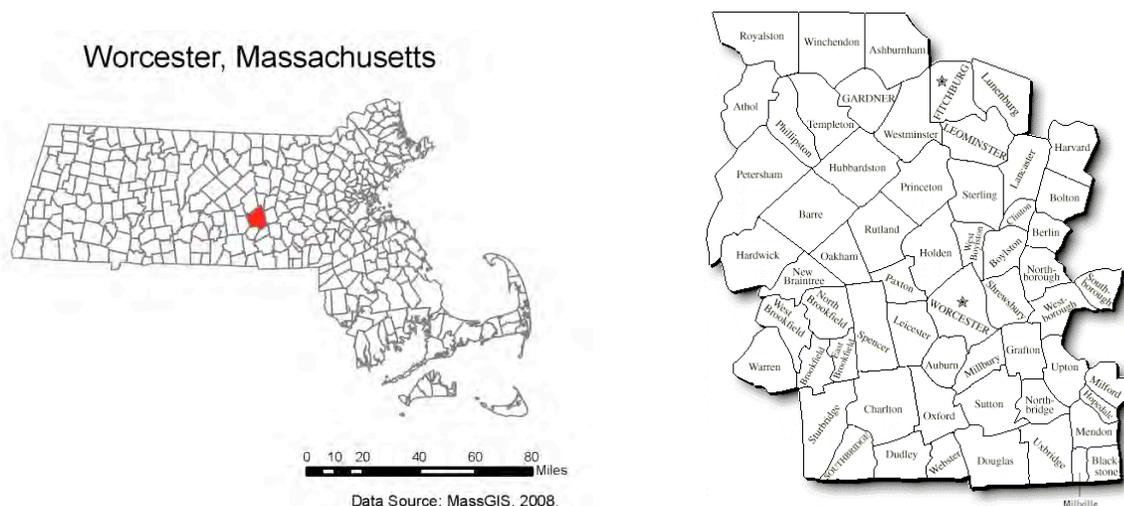
For a listing of input variables for the analyses see Appendix 1.

## Orientation

Worcester is located at 42°16’8”N, 71°48’14”W (42.268843, -71.803774). Figure 1 provides a contextual location of Worcester and its relationship to the surrounding communities of Worcester County. According to the United States Census Bureau, the city has a total area of 38.6 square miles (99.9 km<sup>2</sup>), of which, 37.6 square miles (97.3 km<sup>2</sup>) of it is land and 1.0 square miles (2.6 km<sup>2</sup>) of it (2.59%) is water. Worcester is bordered by the towns of Auburn, Grafton, Holden, Leicester, Millbury, Paxton, Shrewsbury, and West Boylston.

(<http://www.census.gov/geo/www/gazetteer/gazette.html>)

**Figure 1. Context Maps - Worcester, MA and Worcester County Communities**



# Street Tree Structure

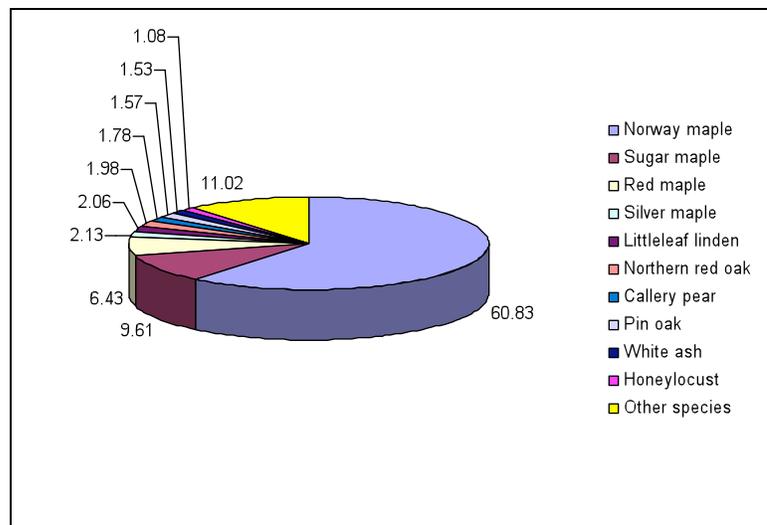
## Species Composition

Species in the maple family (*Aceraceae*) make up 4 out of the top 5 trees planted as street trees in Worcester. Table 2 and Figure 2 show distribution of the 10 most prevalent species in the city. The most prevalent species is Norway maple, a preferred host of Asian longhorned beetle in the United States (Smith 2002).

**Table 2. Distribution of 10 Most Abundant Species in Worcester**

Species	Percent
Norway maple	60.83
Sugar maple	9.61
Red maple	6.43
Silver maple	2.13
Littleleaf linden	2.06
Northern red oak	1.98
Callery pear	1.78
Pin oak	1.57
White ash	1.53
Honeylocust	1.08
Other species	11.02
<b>Total</b>	<b>100.00</b>

**Figure 2. Distribution of 10 Most Abundant Species in Worcester**

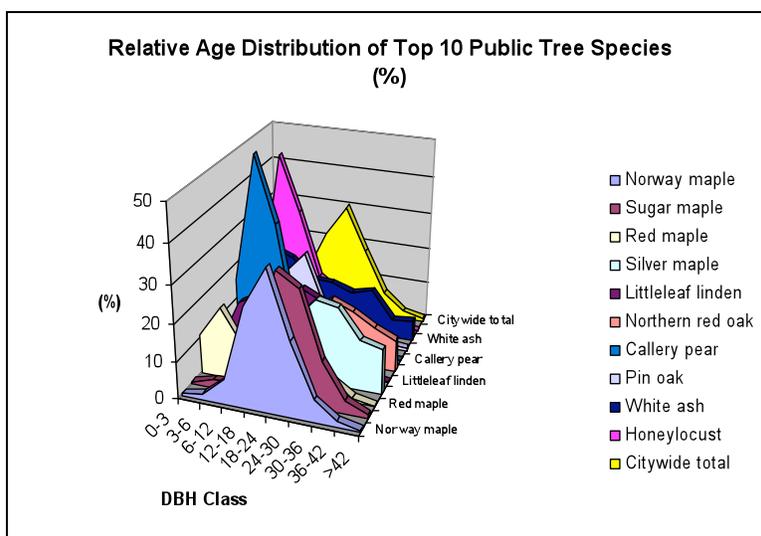


## Relative Age Distribution

Relative age distribution is determined by diameter at breast height<sup>1</sup> (DBH) size classes. DBH, measured 4.5 feet from the ground). Small trees (less than 6-inch caliper) account for 11.6% of the city’s street trees. Most of Worcester’s street trees fall into middle size classes, with few younger trees and even fewer large trees (Figure 3, next page). Most Norway maples fall into middle size classes. Due to the distribution of Norway maples in the city, the Asian longhorned beetle may disproportionately impact trees of the middle size classes. Other preferred hosts of Asian longhorned beetle are distributed differently. Red maples in Worcester are smaller, reflecting recent planting trends, while more silver maples are larger, reflecting the decline in their use as a street tree.

<sup>1</sup> DBH measured 4.5’ above ground

**Figure 3. Relative Age Distribution of Top 10 Public Tree Species by Percent**



The relative age distribution by species, shown in Table 3, indicates that Worcester has small trees that are not preferred hosts of the Asian longhorned beetle. These include littleleaf linden, callery pear, pin oak, and honeylocust. These and other non-preferred hosts of Asian longhorned beetle that are not currently abundant will form the foundation for diversifying Worcester’s urban forest.

**Table 3. Relative Age Distribution of Top 10 Tree Species (%) by DBH Class (in.)**

Relative Age Distribution of Top 10 Tree Species (%) by DBH Class (in.)									
Species	0-3.	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42
Norway maple	0.63	1.57	6.64	26.49	37.14	19.96	5.81	1.42	0.34
Sugar maple	0.61	2.25	2.74	12.83	33.82	30.29	12.83	3.65	0.97
Red maple	10.55	18.82	9.64	17.18	24.27	13.27	5.18	1.00	0.09
Silver maple	1.10	1.10	3.85	9.07	15.93	22.25	21.15	13.46	12.09
Littleleaf linden	2.56	15.06	18.18	14.77	21.59	18.75	8.24	0.85	0.00
Northern red oak	5.62	13.61	7.40	10.06	12.13	16.86	14.50	11.24	8.58
Callery pear	15.46	50.00	32.24	2.30	0.00	0.00	0.00	0.00	0.00
Pin oak	14.50	28.62	16.36	22.68	8.18	4.83	2.97	1.12	0.74
White ash	0.38	20.61	18.32	13.36	12.98	11.07	12.60	4.96	5.73
Honeylocust	5.41	44.32	29.19	11.35	7.57	1.08	0.54	0.54	0.00
<b>Citywide total</b>	<b>3.64</b>	<b>7.94</b>	<b>8.95</b>	<b>21.49</b>	<b>29.90</b>	<b>18.04</b>	<b>6.81</b>	<b>2.18</b>	<b>1.05</b>

## Distribution of Street Trees in Worcester

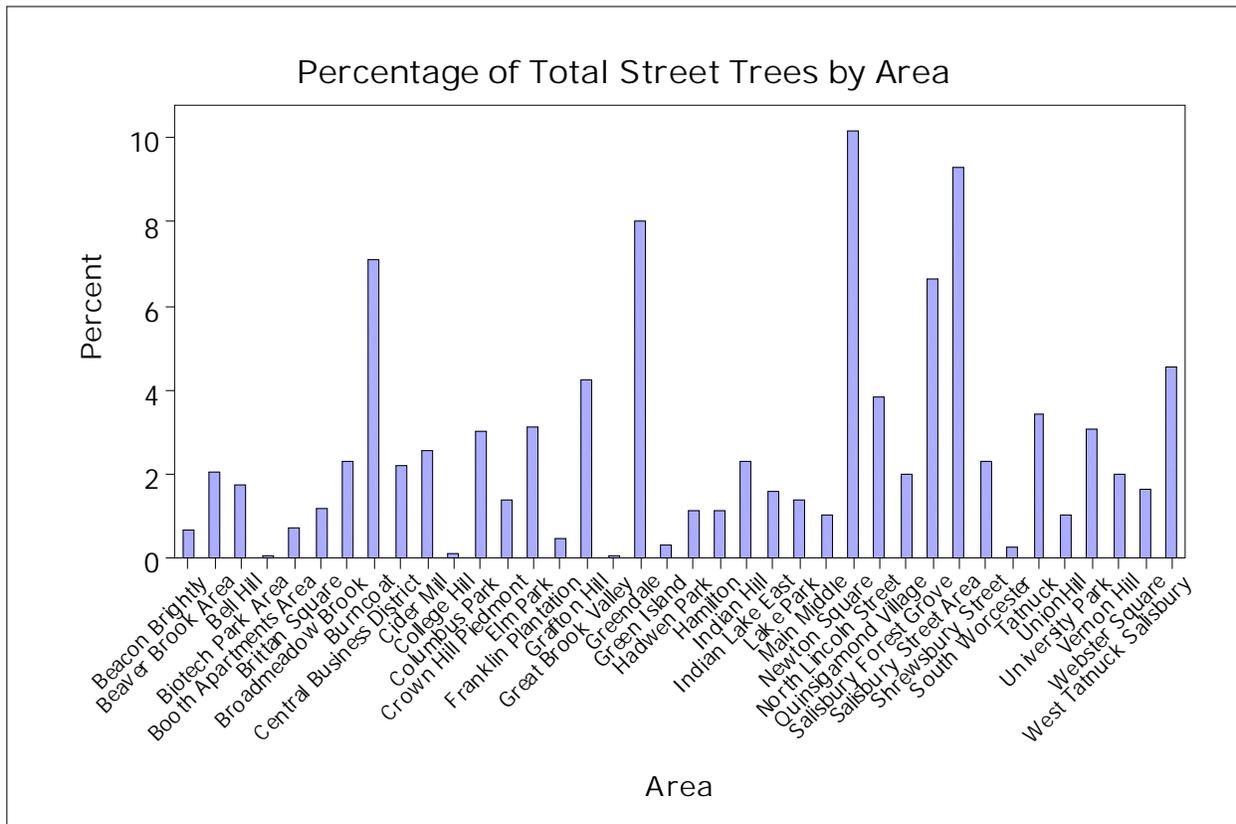
Street trees in Worcester are not evenly distributed throughout the city. Some areas contain nearly 10% of the city's street trees while others, such as South Worcester, contain few trees. Figure 4 (next page) shows street tree distribution throughout Worcester. It does not take into account the size of each area, so an analysis using a Geographic Information System would be able to determine on how equitably Worcester's street trees are distributed throughout the city. Replacement of trees removed due to Asian longhorned beetle may increase equitability as replacement trees selected will be appropriate to site conditions, enabling the trees to maximize their potential.

### Worcester Polytechnic Institute, Worcester, MA



*(Flickr image by Alex, 2008)*

**Figure 4. Percentage of Total Street Trees by Area**

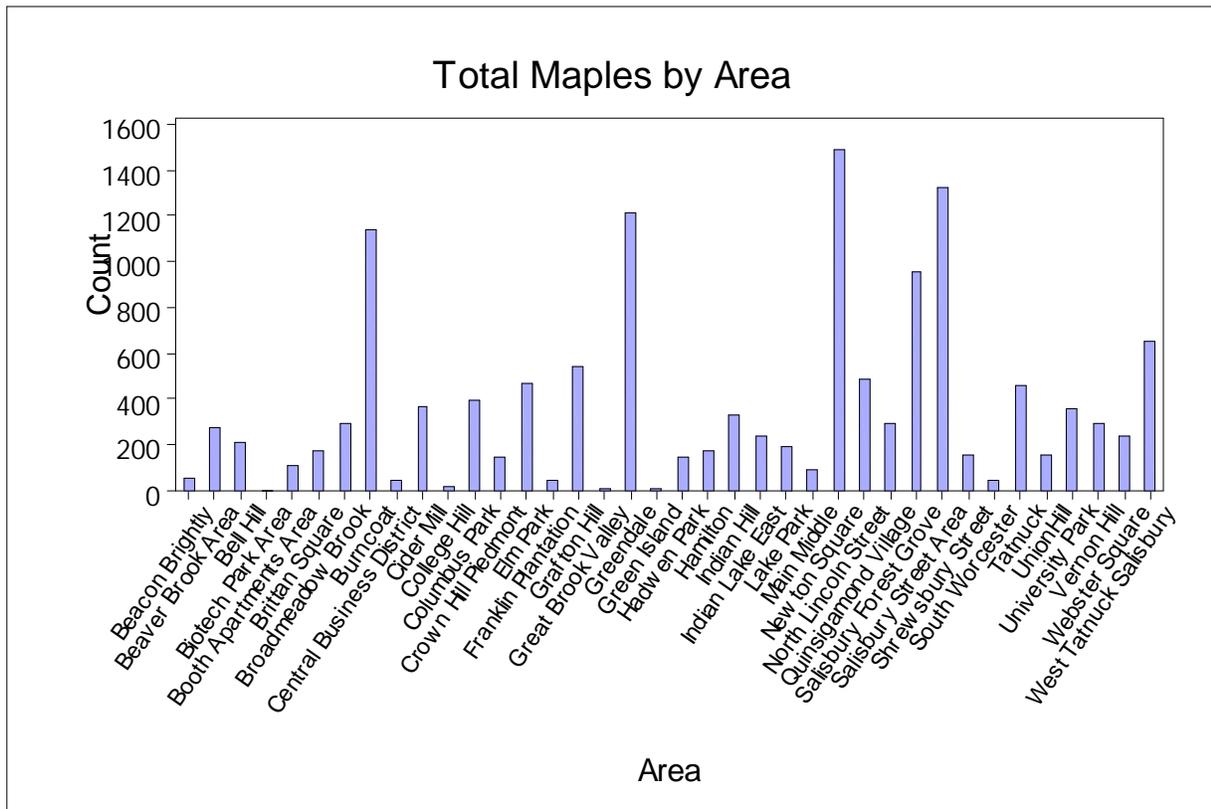


### Distribution of Maples in Worcester

In the United States, Asian longhorned beetles have shown a preference for maple trees. Several neighborhoods have high concentrations of maple trees: Burncoat, Greendale, Newton Square, Salisbury/Forest Grove, and Salisbury Street Area. Figure 5 (next page) shows distribution of maples throughout the city.

Other preferred species for Asian longhorned beetle (*Aesculus*, *Betulus*, *Salix*, *Ulmus* (Sawyer 2008)), make up only 1.2% of the street tree population, making the maple trees of the city a major management concern with respect to the Asian longhorned beetle infestation.

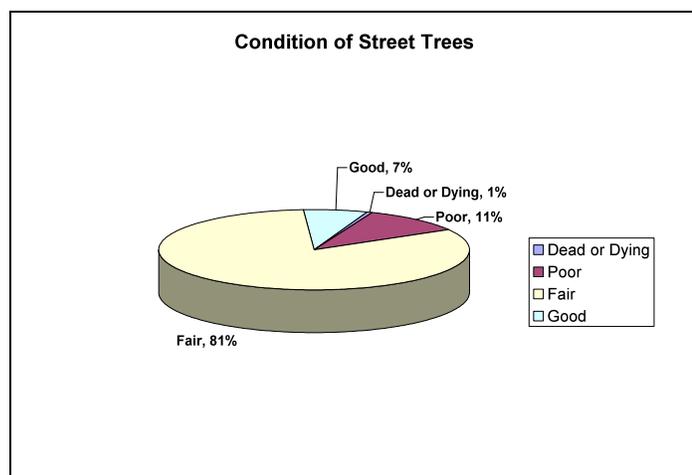
Figure 5. Total Maples by Area



## Condition

Most of Worcester's trees are in fair to good condition (88%), with few poor or dead trees as shown in Figure 6. According to a March 2008 Department of Public Works and Parks report, the city has removed many of the dead and dying trees.

Figure 6. Condition of Street Trees



# Risk Trees

Boring by Asian longhorned beetles can damage and kill limbs creating potentially hazardous situations as limbs break and fall to the ground. According to the 2005-2006 city tree inventory, 91% of the hazardous trees identified were maples. Of the 13,650 maple trees the city inventoried along Worcester streets, 42% were cataloged as hazardous. This totals 5,736 trees. As maples are preferred host trees for Asian longhorned beetles and are likely to be attacked before other species such as oaks, information about present conditions and hazards can help focus risk management since susceptibility to attack adds to the risk.

Figure 7. Percent of Risk Maples by Area

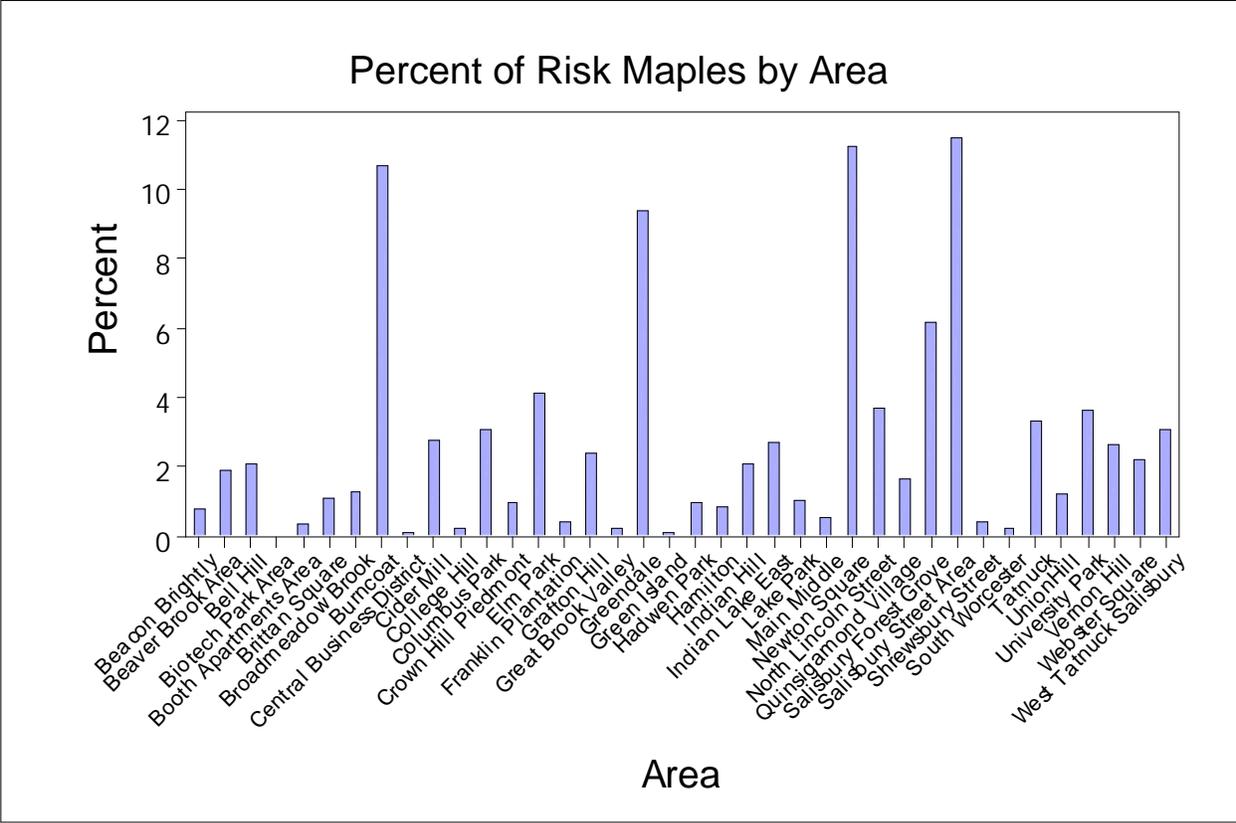


Figure 7 shows that several neighborhoods have more than 5% of the hazard maples: Burncoat, Greendale, Newton Square, Salisbury Forest Grove, and the Salisbury Street Area. These areas also contain the most maples, so this distribution of risk maples is not wholly unexpected, but these are areas where the city may target hazard management to lessen risk associated with these trees that contained defects prior to discovery of the Asian longhorned beetle.

## Importance Values

Importance value is a measure of a community's reliance on a species for environmental services. STRATUM calculates this number (from 0 to 100) by averaging the percentages of total trees, total leaf area, and total canopy cover.

STRATUM calculates importance values for trees that are at least 1% of the total population. The most abundant species have the highest importance values, but some of the city trees provide more functional value than their percentage of the population would indicate (Table 4). The importance value for Norway maple is about equal to its proportion of the urban forest, but looking at the relative age distribution, most Norway maples are not the largest street trees.

Larger trees are able to provide more environmental services (McPherson et al. 2007). In Worcester, there are more large sugar maples and silver maples (over 24 in. DBH), so the importance value for these species is higher than their proportion of the street tree population. For the four most abundant species, all maples, the importance value for the city is 82.2%, marking the functional importance of maples in the current composition of the street tree population.

Leaf area models for STRATUM are based on trees growing in Queens, New York. A computer processed digital images of tree crowns and estimated volume and leaf area. Researchers fit these data to DBH information to create a predictive model for DBH and leaf area. These figures are approximations of crown leaf area. For more information on these methods, see McPherson et al. 2007.

**Table 4. Importance Values for Most Abundant Public Trees**

Importance Values for Most Abundant Public Trees							
Species	Number of Trees	% of Total Trees	Leaf Area (ft <sup>2</sup> )	% of Total Leaf Area	Canopy Cover (ft <sup>2</sup> )	% of Total Canopy Cover	Importance Value
Norway maple	10,409	60.83	31,798,068	56.52	12,610,872	64.30	60.55
Sugar maple	1,644	9.61	9,505,576	16.90	2,165,659	11.04	12.52
Red maple	1,100	6.43	3,201,325	5.69	981,465	5.00	5.71
Silver maple	364	2.13	2,574,250	4.58	685,833	3.50	3.40
Littleleaf linden	352	2.06	683,015	1.21	267,211	1.36	1.54
Northern red oak	338	1.98	1,830,472	3.25	644,525	3.29	2.84
Callery pear	304	1.78	178,079	0.32	68,049	0.35	0.81
Pin oak	269	1.57	564,461	1.00	192,767	0.98	1.19
White ash	262	1.53	1,090,466	1.94	361,239	1.84	1.77
Honeylocust	185	1.08	304,790	0.54	123,741	0.63	0.75
Other trees	1,886	11.02	4,528,201	8.05	1,511,046	7.70	8.92
<b>Total</b>	<b>17,113</b>	<b>100.00</b>	<b>56,258,704</b>	<b>100.00</b>	<b>19,612,402</b>	<b>100.00</b>	<b>100.00</b>

## Benefit-Cost Analysis

Putting a dollar value on benefits of trees can be difficult. Some benefits are more easily quantifiable than others—energy savings, for example, or reduced peak loads of stormwater in well-canopied areas. Other benefits are more difficult to quantify. Some may be impossible to measure: the “sense of place” trees create, improved well being through reduced stress, the value of noise buffering, or the privacy that trees provide. Thus, the dollar value that STRATUM presents is not *the* dollar value of street tree benefits, but an approximation of the value of those benefits.

A benefit-cost analysis compares annual benefits with annual costs to assess the ratio of these two figures. During the 2007 fiscal year, Worcester spent \$ 1,416,069 on street tree management. Subtracting costs from the \$ 2,395,854 in total annual benefits, Worcester’s street trees provide \$979,785 in net benefits for the city. In other words, for every dollar that the city spends on its urban forest, it receives approximately \$1.69 in benefits.

**Table 5. Benefits and Costs**

Total Annual Benefits, Net Benefits, and Costs for All Trees			
Benefits	Total (\$)	\$/tree	\$/capita
Energy	989,814	57.84	5.73
CO2	37,789	2.21	0.22
Air Quality	226,366	13.23	1.31
Stormwater	236,116	13.80	1.37
Aesthetic/Other	905,769	52.93	5.25
<b>Total Benefits</b>	<b>2,395,854</b>	<b>140.00</b>	<b>13.88</b>
<b>Total Costs</b>	<b>1,416,069</b>	<b>82.75</b>	<b>8.20</b>
<b>Net Benefits</b>	<b>979,785</b>	<b>57.25</b>	<b>5.68</b>
<b>Benefit-cost ratio</b>	<b>1.69</b>		

### Total Annual Benefits

Worcester’s street trees provide over \$2 million annually in total benefits to city residents, with each tree, on average, providing \$140 in benefits (Table 5). Trees provide the most benefits in energy savings, from reduced electricity for cooling and reduced natural gas for heating. The second highest benefit category is aesthetic, a category that includes aesthetic and intangible values of trees (i.e. quality of life)—with trees providing value measured by increased property values.

**Table 6. Total Annual Benefits, Quantities and Values**

Total Annual Benefits of Street Trees		
Benefit	Quantity	Value
<b>Energy Saved</b>		
Electricity (MWh)	1,868	\$309,281
Natural gas (Therms)	679,526	\$680,532
<b>Total (\$)</b>		<b>\$989,813</b>
<b>Carbon dioxide</b>		
CO <sub>2</sub> sequestered (lb)	6,888,220	\$23,006
CO <sub>2</sub> released (lb)	-1,201,854	-\$4,014
CO <sub>2</sub> avoided (lb)	5,627,682	\$18,796
<b>Total (lb, \$)</b>	<b>11,314,048</b>	<b>\$37,788</b>
<b>Air Quality</b>		
Avoided pollutants* (lb)	25,790	\$111,720
Deposited pollutants** (lb)	22,642	\$121,798
BVOC emitted (lb)	- 3,096	-\$7,153
<b>Total (lb, \$)</b>	<b>45,336</b>	<b>\$226,365</b>
<b>Stormwater</b>		
Rainfall intercepted (gal)	37,476,204	<b>\$236,116</b>
<b>Aesthetic/Other</b>		
Added property value		<b>\$905,768</b>
<b>TOTAL VALUE</b>		<b>\$2,395,853</b>

\*NO<sub>2</sub>, SO<sub>2</sub>, VOC, PM10    \*\*O<sub>3</sub>, NO<sub>2</sub>, PM10, SO<sub>2</sub>

## Energy Benefits

Worcester street trees provide benefits through energy savings. STRATUM calculates avoided energy for electricity in MegaWatt hours (MWh) and in Therms for natural gas savings. Trees can reduce air conditioning use with direct shading and by reducing air temperature (McPherson and Simpson 2002). In Worcester, the top four maple species (Norway, sugar, red, and silver) account for electricity savings of 1,576 MWh, a value of \$260,881. Natural gas savings by these maples amounts to 576,415 Therms, worth \$577,268.

## Carbon Dioxide

Atmospheric carbon dioxide is a major greenhouse gas, contributing to climate change. Trees reduce atmospheric carbon dioxide by sequestering CO<sub>2</sub> in their biomass while they are alive and also by decreasing electricity and natural gas demand which reduces emissions that generation facilities produce (McPherson 1998). Through sequestration and avoidance, Worcester’s street trees reduce atmospheric CO<sub>2</sub> by over 11.3 million pounds.

## **Air Quality**

Trees can hold atmospheric pollutants on leaf surfaces and also reduce pollutants through reduced demand for generation of electricity and natural gas (McPherson 1998). In Worcester, street trees reduce air pollutants by 45,336 pounds. The STRATUM model accounts for trees' output of biogenic volatile organic compounds (BVOC)

## **Stormwater Benefits**

Trees intercept rainfall on leaves and bark, delaying the water's entry into a community's stormwater management system (Xiao et al. 1998). Worcester has a combined sewer system and has a specific treatment facility to treat the combined sewerage and stormwater. During small rain events, the water is pumped from the Quinsigamond Avenue Combined Sewer Overflow Treatment Facility directly to the sewage treatment plant for full treatment. During larger rain events, however, the overflow facility treats the stormwater and sewerage on site prior to discharging the water into the Blackstone River.

Some treatment is better than no treatment, however, a management goal for the city's combined sewer system is to reduce such discharges from the overflow facility into the Blackstone River. Worcester's street trees presently intercept over 37.4 million gallons of stormwater. According to a June 2008 article, Worcester spends approximately \$2 million on programs for managing stormwater. The value of avoided stormwater (\$236,000) could potentially reduce that amount by approximately 12%.

## **Aesthetic and Other Benefits**

Urban trees have values that can be hard to quantify, such as the health and well being of residents and values associated with the aesthetics at the property and the community level. STRATUM measures these aesthetic and "other" values through increased property values due to trees. Annually, Worcester's street trees add \$905,769 in benefits, as measured by increased property values of single family homes in the city.

## **Replacement Values**

STRATUM calculates replacement values for trees using the Council of Tree and Landscape Appraisers Guide, 9<sup>th</sup> edition. The replacement value is the cost of replacing trees in their "current condition" (i-Tree 2008). This is an approximation for the value of the entire street tree population. For Worcester, replacement value is over \$95.7 million.

Preferred hosts of Asian longhorned beetles in the United States (*Acer*, *Betula*, *Aesculus*, *Salix*, and *Ulmus*) account for over \$80.5 million of the total replacement value, or 84.1%.

## Conclusion

Worcester's street tree population will undergo a major shift due to the current infestation of the Asian longhorned beetle. Increasing the diversity of its street trees has long been a goal of urban forest managers in Worcester. Replanting following removal of infested trees will enable the city to quickly diversify its urban forest and diminish its reliance on one species and family. Through a broader assortment of trees, the city will reduce the vulnerability of its urban forest to future outbreaks, not only of Asian longhorned beetle, but also of other insects and diseases. This will help ensure that benefits can be fully realized and will help ensure the stability of Worcester's urban forest into the future.

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***Institute Park, Worcester, MA***



*photo by Troy B. Thompson, 2008*

## Appendix 1 – STRATUM Inputs

### STRATUM Input Variables

#### Community Data

City Name:	Worcester
Total Municipal Budget FY2007:	\$460,066,279
Population (2000)	172648
Total land area (mi <sup>2</sup> )	38
Average street width (ft)	48
Average sidewalk width (ft)	6
Total linear miles of street	656

#### Benefit Prices

Electricity (\$/KWh)	\$0.1602
Natural gas (\$/Therm)	\$1.6562
CO (\$/lb)	\$0.0033
PM10 (\$/lb)	\$8.31
NO <sub>2</sub> (\$/lb)	\$4.59
SO <sub>2</sub> (\$/lb)	\$3.48
VOC (\$/lb)	\$2.31
Stormwater interception (\$/gallon)	\$0.0063
Median Home Resale Value (\$)	227,000

#### Sources:

**Municipal budget information:** Comprehensive Annual Financial Report for Fiscal Year Ending June 30, 2007, James A. DelSignore, City Auditor.

**Population and land area:** U.S. Census, Massachusetts -- Place and County Subdivision, Census 2000 Summary File 1, <http://factfinder.census.gov>  
Average street and sidewalk width: City of Worcester, Department of Public Works and Parks

**Linear miles of street:** MassGIS, Worcester roads layer, Executive Office of Transportation - Office of Transportation Planning Roads, ArcMap9.2

**Electricity and Natural gas prices:** local utility prices as of September 1, 2008

**CO, PM10, NO<sub>2</sub>, SO<sub>2</sub>, and VOC:** STRATUM default values for the Northeast

**Stormwater interception:** Estimated value to treat a gallon of combined stormwater and sewerage for Boston, Boston Water and Sewer Commission

**Median Home Resale Value:** Study by the Warren Group, [http://www.boston.com/realestate/specials/06\\_07\\_sales\\_single/](http://www.boston.com/realestate/specials/06_07_sales_single/)

## Appendix 2 – STRATUM Charts

### Population Summary of Trees

Worcester, MA  
Population Summary of  
Trees

10/23/2008

Species	DBH Class (in)									Total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	
<b>Broadleaf Deciduous Large (BDL)</b>										
Norway maple	66	163	691	2,757	3,866	2,078	605	148	35	10,409
Sugar maple	10	37	45	211	556	498	211	60	16	1,644
Silver maple	4	4	14	33	58	81	77	49	44	364
Northern red oak	19	46	25	34	41	57	49	38	29	338
Pin oak	39	77	44	61	22	13	8	3	2	269
White ash	1	54	48	35	34	29	33	13	15	262
Honeylocust	10	82	54	21	14	2	1	1	0	185
BDL OTHER	77	190	224	187	155	95	92	44	37	1,101
<b>Total</b>	<b>226</b>	<b>653</b>	<b>1,145</b>	<b>3,339</b>	<b>4,746</b>	<b>2,853</b>	<b>1,076</b>	<b>356</b>	<b>178</b>	<b>14,572</b>
<b>Broadleaf Deciduous Medium (BDM)</b>										
Red maple	116	207	106	189	267	146	57	11	1	1,100
Littleleaf linden	9	53	64	52	76	66	29	3	0	352
BDM OTHER	50	53	18	23	10	7	2	1	0	164
<b>Total</b>	<b>175</b>	<b>313</b>	<b>188</b>	<b>264</b>	<b>353</b>	<b>219</b>	<b>88</b>	<b>15</b>	<b>1</b>	<b>1,616</b>
<b>Broadleaf Deciduous Small (BDS)</b>										
Callery pear	47	152	98	7	0	0	0	0	0	304
BDS OTHER	169	222	81	27	4	3	0	0	0	506
<b>Total</b>	<b>216</b>	<b>374</b>	<b>179</b>	<b>34</b>	<b>4</b>	<b>3</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>810</b>
<b>Broadleaf Evergreen Large (BEL)</b>										
BEL OTHER	0	0	0	0	0	0	0	0	0	0
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Broadleaf Evergreen Medium (BEM)</b>										
BEM OTHER	0	7	0	0	0	0	0	0	0	7
<b>Total</b>	<b>0</b>	<b>7</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>7</b>
<b>Broadleaf Evergreen Small (BES)</b>										
BES OTHER	0	0	0	0	0	0	0	0	0	0
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>

<b>Conifer Evergreen Large (CEL)</b>										
CEL OTHER	5	9	10	37	13	13	1	2	0	90
<b>Total</b>	<b>5</b>	<b>9</b>	<b>10</b>	<b>37</b>	<b>13</b>	<b>13</b>	<b>1</b>	<b>2</b>	<b>0</b>	<b>90</b>
<b>Conifer Evergreen Medium (CEM)</b>										
CEM OTHER	1	2	10	3	1	0	0	0	0	17
<b>Total</b>	<b>1</b>	<b>2</b>	<b>10</b>	<b>3</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>17</b>
<b>Conifer Evergreen Small (CES)</b>										
CES OTHER	0	0	0	1	0	0	0	0	0	1
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>1</b>
<b>Palm Evergreen Large (PEL)</b>										
PEL OTHER	0	0	0	0	0	0	0	0	0	0
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Palm Evergreen Medium (PEM)</b>										
PEM OTHER	0	0	0	0	0	0	0	0	0	0
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Palm Evergreen Small (PES)</b>										
PES OTHER	0	0	0	0	0	0	0	0	0	0
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Citywide Total</b>										
	<b>623</b>	<b>1,358</b>	<b>1,532</b>	<b>3,678</b>	<b>5,117</b>	<b>3,088</b>	<b>1,165</b>	<b>373</b>	<b>179</b>	<b>17,113</b>

# Complete Population of Public Trees

Worcester, MA  
Complete Population of Public  
Trees

10/23/2008

Species	DBH Class (in)									Total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	
<b>Broadleaf Deciduous Large (BDL)</b>										
Acer platanoides	66	163	691	2,757	3,866	2,078	605	148	35	10,409
Acer saccharum	10	37	45	211	556	498	211	60	16	1,644
Acer saccharinum	4	4	14	33	58	81	77	49	44	364
Quercus rubra	19	46	25	34	41	57	49	38	29	338
Quercus palustris	39	77	44	61	22	13	8	3	2	269
Fraxinus americana	1	54	48	35	34	29	33	13	15	262
Gleditsia triacanthos	10	82	54	21	14	2	1	1	0	185
Fraxinus pennsylvanica	0	9	33	13	21	12	7	7	6	108
Platanus hybrida	10	45	35	11	7	0	0	0	0	108
Quercus alba	0	4	0	10	14	21	24	17	16	106
Zelkova serrata	7	56	16	4	0	0	0	0	0	83
Quercus coccinea	0	1	4	8	15	18	10	7	5	68
Ulmus pumila	1	14	21	10	4	4	6	1	5	66
Ailanthus altissima	6	5	15	20	5	3	3	2	0	59
Ginkgo biloba	25	16	9	8	0	0	0	0	0	58
Robinia pseudoacacia	0	3	8	19	12	5	6	1	0	54
Ulmus americana	2	3	12	17	12	3	3	2	0	54
Tilia americana	0	1	0	10	9	6	18	3	1	48
Prunus serotina	0	3	8	9	19	2	4	0	0	45
Carya ovata	0	0	2	14	12	15	0	0	0	43
Elm	9	16	11	1	0	0	0	0	0	37
Carya glabra	1	0	0	15	15	0	2	0	0	33
Betula papyrifera	0	1	11	1	1	0	0	0	0	14
Acer pseudoplatanus	0	2	3	3	2	2	1	0	0	13
Ulmus parvifolia	7	4	0	0	0	0	0	0	0	11
Fagus sylvatica	2	2	2	0	0	1	1	0	2	10
Liriodendron tulipifera	0	1	5	1	0	1	2	0	0	10
Juglans cinerea	0	0	5	3	1	0	0	0	0	9
Liquidambar styraciflua	0	0	7	1	0	0	0	0	0	8
Populus tremuloides	0	2	3	2	0	0	0	0	1	8
Aesculus hippocastanum	1	0	1	1	1	1	1	0	1	7
Betula nigra	3	0	3	0	1	0	0	0	0	7
Populus deltoides	1	0	1	2	0	0	2	1	0	7
Fraxinus nigra	0	0	4	0	0	0	0	0	0	4
Juglans nigra	1	1	0	0	2	0	0	0	0	4
Larix laricina	0	0	0	1	1	0	1	0	0	3
Metasequoia glyptostroboides	0	0	2	1	0	0	0	0	0	3
Quercus prinus	0	0	0	0	0	0	1	2	0	3

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Betula lenta	0	0	0	2	0	0	0	0	0	2
Quercus robur	1	1	0	0	0	0	0	0	0	2
Celtis occidentalis	0	0	1	0	0	0	0	0	0	1
Fagus grandifolia	0	0	1	0	0	0	0	0	0	1
Populus species	0	0	1	0	0	0	0	0	0	1
Populus grandidentata	0	0	0	0	1	0	0	0	0	1
Quercus macrocarpa	0	0	0	0	0	0	0	1	0	1
Tilia tomentosa	0	0	0	0	0	1	0	0	0	1
<b>Total</b>	<b>226</b>	<b>653</b>	<b>1,145</b>	<b>3,339</b>	<b>4,746</b>	<b>2,853</b>	<b>1,076</b>	<b>356</b>	<b>178</b>	<b>14,572</b>

<b>Broadleaf Deciduous Medium (BDM)</b>										
Acer rubrum	116	207	106	189	267	146	57	11	1	1,100
Tilia cordata	9	53	64	52	76	66	29	3	0	352
Acer campestre	45	39	0	1	0	0	0	0	0	85
Catalpa speciosa	1	2	1	8	7	4	1	1	0	25
Betula pendula	0	5	10	1	0	0	0	0	0	16
Acer negundo	1	0	3	7	2	2	0	0	0	15
Carpinus betulus	2	3	1	2	0	0	0	0	0	8
Morus alba	1	2	0	4	1	0	0	0	0	8
Cladrastis kentukea	0	1	2	0	0	0	0	0	0	3
Betula populifolia	0	0	1	0	0	0	0	0	0	1
Salix species	0	1	0	0	0	0	0	0	0	1
Sassafras albidum	0	0	0	0	0	0	1	0	0	1
Ulmus rubra	0	0	0	0	0	1	0	0	0	1
<b>Total</b>	<b>175</b>	<b>313</b>	<b>188</b>	<b>264</b>	<b>353</b>	<b>219</b>	<b>88</b>	<b>15</b>	<b>1</b>	<b>1,616</b>

<b>Broadleaf Deciduous Small (BDS)</b>										
Pyrus calleryana	47	152	98	7	0	0	0	0	0	304
Syringa reticulata	76	94	0	0	0	0	0	0	0	170
Prunus species	51	62	16	14	2	2	0	0	0	147
Malus species	20	39	43	8	0	0	0	0	0	110
Acer palmatum	5	8	7	0	0	0	0	0	0	20
Cornus florida	3	3	5	1	0	0	0	0	0	12
Cornus kousa	8	2	1	0	0	0	0	0	0	11
Sorbus species	2	0	4	3	1	1	0	0	0	11
Amelanchier species	0	5	2	0	0	0	0	0	0	7
Hydrangea species	2	1	0	0	0	0	0	0	0	3
Syringa pekinensis	0	3	0	0	0	0	0	0	0	3
Crataegus species	0	2	0	0	0	0	0	0	0	2
Koelreuteria paniculata	0	0	0	1	1	0	0	0	0	2
Stewartia species	0	2	0	0	0	0	0	0	0	2
Chionanthus virginicus	1	0	0	0	0	0	0	0	0	1
Halesia carolina	0	0	1	0	0	0	0	0	0	1
Magnolia x soulangiana	1	0	0	0	0	0	0	0	0	1
Pyrus communis	0	1	0	0	0	0	0	0	0	1
Rhus species	0	0	1	0	0	0	0	0	0	1
Salix discolor	0	0	1	0	0	0	0	0	0	1

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
<b>Total</b>	<b>216</b>	<b>374</b>	<b>179</b>	<b>34</b>	<b>4</b>	<b>3</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>810</b>
<b>Broadleaf Evergreen Large (BEL)</b>										
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Broadleaf Evergreen Medium (BEM)</b>										
Magnolia species	0	7	0	0	0	0	0	0	0	7
<b>Total</b>	<b>0</b>	<b>7</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>7</b>
<b>Broadleaf Evergreen Small (BES)</b>										
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Conifer Evergreen Large (CEL)</b>										
Pinus strobus	3	0	4	13	8	9	1	2	0	40
Picea abies	1	1	1	10	1	1	0	0	0	15
Picea pungens 'glauca'	0	3	1	8	3	0	0	0	0	15
Ulmus thomasii	1	2	2	0	0	0	0	0	0	5
Abies balsamea	0	1	0	1	0	1	0	0	0	3
Abies concolor	0	1	1	1	0	0	0	0	0	3
Picea species	0	0	1	1	0	0	0	0	0	2
Pinus rigida	0	0	0	0	1	1	0	0	0	2
Pseudotsuga menziesii	0	0	0	1	0	1	0	0	0	2
Pinus nigra	0	0	0	1	0	0	0	0	0	1
Pinus resinosa	0	0	0	1	0	0	0	0	0	1
Sciadopitys verticillata	0	1	0	0	0	0	0	0	0	1
<b>Total</b>	<b>5</b>	<b>9</b>	<b>10</b>	<b>37</b>	<b>13</b>	<b>13</b>	<b>1</b>	<b>2</b>	<b>0</b>	<b>90</b>
<b>Conifer Evergreen Medium (CEM)</b>										
Tsuga canadensis	0	2	3	2	1	0	0	0	0	8
Juniperus virginiana	1	0	6	0	0	0	0	0	0	7
Thuja occidentalis	0	0	1	1	0	0	0	0	0	2
<b>Total</b>	<b>1</b>	<b>2</b>	<b>10</b>	<b>3</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>17</b>
<b>Conifer Evergreen Small (CES)</b>										
Juniperus species	0	0	0	1	0	0	0	0	0	1
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>1</b>
<b>Palm Evergreen Large (PEL)</b>										
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Palm Evergreen Medium (PEM)</b>										
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Palm Evergreen Small (PES)</b>										
<b>Total</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>
<b>Citywide Total</b>	<b>623</b>	<b>1,358</b>	<b>1,532</b>	<b>3,678</b>	<b>5,117</b>	<b>3,088</b>	<b>1,165</b>	<b>373</b>	<b>179</b>	<b>17,113</b>

## Relative Performance Index for Public Trees

Worcester, MA

Relative Performance Index for Public Trees

10/23/2008

Species	Dead or Dying	Poor	Fair	Good	RPI	# of Trees Total	% of Total Population
Norway maple	0.28	9.92	86.13	3.67	0.99	10,409	60.83
Sugar maple	0.18	18.44	76.51	4.87	0.95	1,643	9.60
Red maple	0.45	10.73	78.73	10.09	1.02	1,100	6.43
Silver maple	0.00	6.04	90.93	3.02	1.01	364	2.13
Littleleaf linden	0.57	9.38	73.30	16.76	1.06	352	2.06
Northern red oak	0.30	5.62	81.36	12.72	1.06	338	1.98
Callery pear	1.32	4.93	77.30	16.45	1.07	304	1.78
Pin oak	0.74	5.20	60.59	33.46	1.16	269	1.57
White ash	4.20	32.44	58.40	4.96	0.84	262	1.53
Honeylocust	0.00	2.70	84.32	12.97	1.08	185	1.08
Japanese tree lilac	2.35	2.35	80.59	14.71	1.06	170	0.99
Plum	2.72	8.16	80.27	8.84	1.00	147	0.86
Apple	0.91	3.64	83.64	11.82	1.06	110	0.64
Green ash	1.85	20.37	67.59	10.19	0.95	108	0.63
London planetree	0.00	5.56	50.00	44.44	1.22	108	0.63
White oak	0.00	7.55	82.08	10.38	1.04	106	0.62
Hedge maple	0.00	14.12	78.82	7.06	0.99	85	0.50
Japanese zelkova	2.41	9.64	80.72	7.23	0.99	83	0.49
Scarlet oak	0.00	4.41	88.24	7.35	1.04	68	0.40
Siberian elm	0.00	7.58	72.73	19.70	1.09	66	0.39
Tree of heaven	6.78	11.86	81.36	0.00	0.90	59	0.34
Ginkgo	0.00	6.90	36.21	56.90	1.28	58	0.34
Black locust	0.00	12.96	87.04	0.00	0.96	54	0.32
American elm	11.11	9.26	75.93	3.70	0.88	54	0.32
American basswood	0.00	10.42	83.33	6.25	1.00	48	0.28
Black cherry	2.22	11.11	86.67	0.00	0.95	45	0.26
Shagbark hickory	0.00	4.65	76.74	18.60	1.10	43	0.25
Eastern white pine	0.00	7.50	77.50	15.00	1.06	40	0.23
Elm	5.41	0.00	91.89	2.70	0.98	37	0.22
Pignut hickory	3.03	3.03	81.82	12.12	1.04	33	0.19
Northern catalpa	0.00	40.00	52.00	8.00	0.86	25	0.15
Japanese maple	0.00	15.00	75.00	10.00	1.00	20	0.12
European white birch	0.00	12.50	81.25	6.25	0.99	16	0.09
Boxelder	6.67	20.00	73.33	0.00	0.85	15	0.09
Norway spruce	0.00	0.00	86.67	13.33	1.09	15	0.09
Blue spruce	0.00	0.00	46.67	53.33	1.30	15	0.09
Paper birch	0.00	0.00	85.71	14.29	1.10	14	0.08
Sycamore maple	0.00	30.77	61.54	7.69	0.91	13	0.08

Species	Dead or Dying	Poor	Fair	Good	RPI	# of Trees Total	% of Total Population
Flowering dogwood	0.00	8.33	91.67	0.00	0.98	12	0.07
Kousa dogwood	0.00	9.09	72.73	18.18	1.07	11	0.06
Sorbus species	0.00	18.18	72.73	9.09	0.98	11	0.06
Chinese elm	0.00	0.00	72.73	27.27	1.17	11	0.06
European beech	0.00	10.00	80.00	10.00	1.03	10	0.06
Tulip tree	0.00	10.00	30.00	60.00	1.28	10	0.06
Butternut	11.11	0.00	66.67	22.22	1.03	9	0.05
European hornbeam	0.00	0.00	100.00	0.00	1.03	8	0.05
Sweetgum	0.00	12.50	0.00	87.50	1.41	8	0.05
White mulberry	0.00	0.00	100.00	0.00	1.03	8	0.05
Quaking aspen	12.50	25.00	50.00	12.50	0.83	8	0.05
Eastern hemlock	0.00	25.00	62.50	12.50	0.96	8	0.05
Horsechestnut	0.00	14.29	57.14	28.57	1.10	7	0.04
Serviceberry	0.00	0.00	85.71	14.29	1.10	7	0.04
River birch	0.00	14.29	57.14	28.57	1.10	7	0.04
Eastern red cedar	0.00	0.00	100.00	0.00	1.03	7	0.04
Magnolia	0.00	0.00	57.14	42.86	1.25	7	0.04
Eastern cottonwood	0.00	0.00	71.43	28.57	1.17	7	0.04
Rock elm	20.00	0.00	80.00	0.00	0.82	5	0.03
Black ash	0.00	0.00	50.00	50.00	1.28	4	0.02
Black walnut	0.00	25.00	50.00	25.00	1.03	4	0.02
Balsam fir	0.00	33.33	66.67	0.00	0.85	3	0.02
White fir	0.00	0.00	66.67	33.33	1.20	3	0.02
Yellowwood	0.00	0.00	100.00	0.00	1.03	3	0.02
Hydrangea species	0.00	0.00	100.00	0.00	1.03	3	0.02
Tamarack	0.00	0.00	66.67	33.33	1.20	3	0.02
Dawn redwood	0.00	0.00	0.00	100.00	1.54	3	0.02
Chestnut oak	0.00	0.00	100.00	0.00	1.03	3	0.02
Peking lilac	0.00	0.00	100.00	0.00	1.03	3	0.02
Black birch	0.00	50.00	50.00	0.00	0.77	2	0.01
Hawthorn	0.00	0.00	100.00	0.00	1.03	2	0.01
Goldenrain tree	0.00	0.00	100.00	0.00	1.03	2	0.01
Spruce	0.00	0.00	100.00	0.00	1.03	2	0.01
Pitch pine	0.00	0.00	100.00	0.00	1.03	2	0.01
Douglas fir	0.00	0.00	0.00	100.00	1.54	2	0.01
English oak	0.00	100.00	0.00	0.00	0.51	2	0.01
Stewartia species	0.00	0.00	100.00	0.00	1.03	2	0.01
Northern white cedar	0.00	0.00	100.00	0.00	1.03	2	0.01
Gray birch	0.00	0.00	100.00	0.00	1.03	1	0.01
Northern hackberry	0.00	0.00	100.00	0.00	1.03	1	0.01
Fringetree	0.00	100.00	0.00	0.00	0.51	1	0.01
American beech	0.00	100.00	0.00	0.00	0.51	1	0.01

Species	Dead or Dying	Poor	Fair	Good	RPI	# of Trees Total	% of Total Population
Carolina silverbell	0.00	0.00	100.00	0.00	1.03	1	0.01
Juniper species	0.00	0.00	100.00	0.00	1.03	1	0.01
Chinese magnolia; Saucer magnolia	0.00	0.00	100.00	0.00	1.03	1	0.01
Austrian pine	0.00	0.00	100.00	0.00	1.03	1	0.01
Red pine	0.00	0.00	100.00	0.00	1.03	1	0.01
Cottonwood	0.00	0.00	0.00	100.00	1.54	1	0.01
Bigtooth aspen	0.00	0.00	100.00	0.00	1.03	1	0.01
Common pear	0.00	0.00	100.00	0.00	1.03	1	0.01
Bur oak	0.00	0.00	100.00	0.00	1.03	1	0.01
Rhus species	0.00	0.00	0.00	100.00	1.54	1	0.01
Willow	0.00	0.00	100.00	0.00	1.03	1	0.01
Sassafras	0.00	0.00	100.00	0.00	1.03	1	0.01
Pussy willow	0.00	0.00	100.00	0.00	1.03	1	0.01
Umbrella pine	0.00	0.00	100.00	0.00	1.03	1	0.01
Silver linden	0.00	0.00	100.00	0.00	1.03	1	0.01
Slippery elm	0.00	0.00	100.00	0.00	1.03	1	0.01
Citywide total	0.51	10.59	82.26	6.63	1.00	17,112	100.00

## Available Planting Spaces

### Summary of Available Planting Sites for Public Trees

Zone	No. of Unplanted Sites	No. of Planted Sites	Total No. of Sites	Stocking (%)	No. of Unplanted Sites			
					Small	Medium	Large	Undefined
Citywide total	1,659	17,113	18,772	91	0	0	0	1,659

## Canopy Cover of Public Trees (Acres)

Worcester, MA

### Canopy Cover of Public Trees (Acres)

10/23/2008

Zone	Acres	% of Total Canopy
1	450.24	100.00
Citywide total	450.24	100.00

	Total Land Area	Total Street and Sidewalk Area	Total Canopy Cover	Canopy Cover as % of Total Land Area	Canopy Cover as % of Total Streets and Sidewalks
Citywide total	24,319.90	4,770.89	450.24	1.85	9.44

## Hazard Trees Most Common by Species (%)

Worcester, MA

Hazard Trees Most Common Public Trees by Species  
(%)

10/23/2008

Species Name	Hazard tree	Non-hazard tree
Norway maple	42.31	57.69
Sugar maple	52.37	47.63
Red maple	27.36	72.64
Silver maple	43.68	56.32
Littleleaf linden	11.65	88.35
Northern red oak	52.66	47.34
Callery pear	0.66	99.34
Pin oak	13.75	86.25
White ash	44.27	55.73
Honeylocust	17.30	82.70
Other trees	18.03	81.97
Citywide total	37.81	62.19

## Annual Energy Benefits of Public Trees by Species

Worcester, MA

10/24/2008

### Annual Energy Benefits of Public Trees by Species

Species	Total Electricity (MWh)	Electricity (\$)	Total Natural Gas (Therms)	Natural Gas (\$)	Total (\$)	% of Total Tree Numbers	% of Total \$	Avg. \$/tree
Norway maple	1,214.35	201,011.41	442,030.91	442,685.09	643,696.50	60.83	65.03	61.84
Sugar maple	206.26	34,142.13	77,896.41	78,011.70	112,153.80	9.61	11.33	68.22
Red maple	94.92	15,712.29	35,467.42	35,519.91	51,232.20	6.43	5.18	46.57
Silver maple	60.51	10,016.00	21,021.01	21,052.12	31,068.13	2.13	3.14	85.35
Littleleaf linden	27.14	4,491.73	10,309.83	10,325.09	14,816.82	2.06	1.50	42.09
Northern red oak	54.33	8,993.65	17,861.17	17,887.60	26,881.25	1.98	2.72	79.53
Callery pear	6.84	1,132.23	2,683.75	2,687.72	3,819.96	1.78	0.39	12.57
Pin oak	18.21	3,014.45	6,102.71	6,111.74	9,126.19	1.57	0.92	33.93
White ash	32.21	5,331.75	11,303.68	11,320.41	16,652.16	1.53	1.68	63.56
Honeylocust	12.06	1,996.02	4,580.09	4,586.87	6,582.88	1.08	0.67	35.58
Other street trees	141.60	23,439.65	50,269.90	50,344.30	73,783.95	11.02	7.45	39.12
<b>Citywide total</b>	<b>1,868.43</b>	<b>309,281.31</b>	<b>679,526.63</b>	<b>680,532.50</b>	<b>989,813.81</b>	<b>100.00</b>	<b>100.00</b>	<b>57.84</b>

## Annual Stormwater Benefits of Public Trees by Species

Worcester, MA

10/24/2008

### Annual Stormwater Benefits of Public Trees by Species

Species	Total Rainfall Interception (Gal)	Total (\$)	% of Total Tree Numbers	% of Total \$	Avg. \$/tree
Norway maple	22,775,106.00	143,493.09	60.83	60.77	13.79
Sugar maple	5,205,148.50	32,794.71	9.61	13.89	19.95
Red maple	2,018,240.75	12,715.80	6.43	5.39	11.56
Silver maple	1,531,642.38	9,650.02	2.13	4.09	26.51
Littleleaf linden	465,391.59	2,932.17	2.06	1.24	8.33
Northern red oak	1,228,170.13	7,738.01	1.98	3.28	22.89
Callery pear	130,988.20	825.28	1.78	0.35	2.71
Pin oak	365,359.94	2,301.93	1.57	0.97	8.56
White ash	679,561.50	4,281.54	1.53	1.81	16.34
Honeylocust	193,768.56	1,220.83	1.08	0.52	6.60
Other street trees	2,882,821.00	18,163.03	11.02	7.69	9.63
Citywide total	37,476,204.00	236,116.50	100.00	100.00	13.80

## Stored CO2 Benefits of Public Trees by Species

Worcester, MA

10/24/2008

### Stored CO2 Benefits of Public Trees by Species

Species	Total stored CO2 (lbs)	Total (\$)	% of Total Tree Numbers	% of Total \$	Avg. \$/tree
Norway maple	91,605,296.00	305,961.69	60.83	64.70	29.39
Sugar maple	19,936,066.00	66,586.46	9.61	14.08	40.50
Red maple	4,116,322.00	13,748.52	6.43	2.91	12.50
Silver maple	7,228,325.50	24,142.61	2.13	5.11	66.33
Littleleaf linden	1,240,909.00	4,144.64	2.06	0.88	11.77
Northern red oak	5,564,704.50	18,586.11	1.98	3.93	54.99
Callery pear	137,907.11	460.61	1.78	0.10	1.52
Pin oak	1,091,107.75	3,644.30	1.57	0.77	13.55
White ash	1,904,388.88	6,360.66	1.53	1.35	24.28
Honeylocust	270,901.34	904.81	1.08	0.19	4.89
Other street trees	3,851,018.75	28,356.71	11.02	6.00	15.04
Citywide total	141,585,920.00	472,897.19	100.00	100.00	27.63

## Annual CO2 Benefits of Public Trees by Species

Worcester,  
MA

10/24/2008

### Annual CO2 Benefits of Public Trees by Species

Species	Sequestered (lb)	Sequestered (\$)	Decomposition Release(lb)	Maintenance Release (lb)	Total Release (\$)	Avoided (lb)
Norway maple	5,327,843.00	17,795.00	- 610,194.63	- 162,208.95	2,579.83	3,657,603.75
Sugar maple	586,935.00	1,960.36	- 105,581.27	- 29,619.96	- 451.57	621,250.13
Red maple	141,907.13	473.97	- 52,892.49	- 12,792.17	- 219.39	285,900.94
Silver maple	122,886.58	410.44	- 35,386.44	- 7,982.12	- 144.85	182,251.22
Littleleaf linden	31,096.62	103.86	- 17,200.13	- 4,454.81	- 72.33	81,731.59
Northern red oak	155,098.56	518.03	- 28,169.96	- 5,920.34	- 113.86	163,648.50
Callery pear	27,526.56	91.94	- 628.86	- 347.25	- 3.26	20,602.11
Pin oak	61,564.98	205.63	- 13,078.80	- 2,284.52	- 51.31	54,850.93
White ash	65,848.48	219.93	- 10,380.01	- 3,784.31	- 47.31	97,016.55
Honeylocust	17,771.06	59.36	- 5,194.40	- 1,222.22	- 21.43	36,319.51
Other street trees	349,743.13	1,168.14	- 74,718.97	- 17,812.41	- 309.05	426,507.72
Citywide total	6,888,220.50	23,006.66	- 953,425.88	- 248,429.03	4,014.20	5,627,682.50

(Continued)

Species	Avoided (\$)	Net Total (lb)	Total (\$)	% of Total Tree Numbers	% of Total \$	Avg. \$/tree
Norway maple	12,216.40	8,213,043.00	27,431.56	60.83	72.59	2.64
Sugar maple	2,074.98	1,072,983.88	3,583.77	9.61	9.48	2.18
Red maple	954.91	362,123.41	1,209.49	6.43	3.20	1.10
Silver maple	608.72	261,769.23	874.31	2.13	2.31	2.40
Littleleaf linden	272.98	91,173.27	304.52	2.06	0.81	0.87
Northern red oak	546.59	284,656.78	950.75	1.98	2.52	2.81
Callery pear	68.81	47,152.57	157.49	1.78	0.42	0.52
Pin oak	183.20	101,052.59	337.52	1.57	0.89	1.25
White ash	324.04	148,700.70	496.66	1.53	1.31	1.90
Honeylocust	121.31	47,673.96	159.23	1.08	0.42	0.86
Other street trees	1,424.54	683,719.44	2,283.62	11.02	6.04	1.21
Citywide total	18,796.46	11,314,048.00	37,788.93	100.00	100.00	2.21

## Annual Air Quality Benefits of Public Trees by Species

Worcester, MA  
10/24/2008

### Annual Air Quality Benefits of Public Trees by Species

Species	Total Deposition					Avoided				Total Avoided (\$)	BVOC Emissions		Total (lb)	Total (\$)	% of Total Tree Numbers
	O3 (lb)	NO2 (lb)	PM10 (lb)	SO2 (lb)	Deposition (\$)	NO2 (lb)	PM10 (lb)	VOC (lb)	SO2 (lb)		(lb)	(\$)			
Norway maple	7,020.34	3,034.92	3,446.89	1,151.98	78,806.16	10,367.98	671.14	397.70	5,329.48	72,631.47	-1,165.41	-2,692.09	30,255.01	148,745.55	60.83
Sugar maple	1,205.06	521.18	591.93	197.83	13,533.34	1,789.74	116.09	69.07	905.39	12,489.93	-761.21	-1,758.39	4,635.62	24,264.88	9.61
Red maple	525.06	226.75	261.93	87.64	5,932.45	819.76	53.14	31.58	416.64	5,727.17	-134.63	-310.99	2,287.88	11,348.63	6.43
Silver maple	381.80	165.05	187.46	62.65	4,285.81	506.37	32.69	19.27	265.50	3,564.40	-136.58	-315.51	1,484.21	7,534.70	2.13
Littleleaf linden	143.61	60.37	69.20	22.06	1,588.09	236.09	15.32	9.12	119.12	1,646.54	-73.74	-170.34	601.14	3,064.29	2.06
Northern red oak	344.81	148.91	172.01	57.56	3,895.82	444.35	28.60	16.76	238.34	3,145.36	-332.82	-768.82	1,118.50	6,272.35	1.98
Callery pear	40.89	17.85	19.94	6.97	459.64	60.38	3.92	2.34	30.03	419.67	0.00	0.00	182.34	879.30	1.78
Pin oak	103.13	44.54	51.44	17.21	1,165.18	150.12	9.67	5.68	79.89	1,060.56	-93.49	-215.97	368.19	2,009.77	1.57
White ash	194.14	81.61	93.56	29.82	2,146.92	270.71	17.49	10.32	141.34	1,903.60	0.00	0.00	838.99	4,050.52	1.53
Honeylocust	63.11	25.57	29.97	9.68	689.77	104.90	6.81	4.05	52.93	731.61	-27.81	-64.24	269.21	1,357.14	1.08
Other street trees	825.45	352.76	410.29	137.32	9,295.38	1,196.00	77.31	45.69	621.39	8,400.05	-370.88	-856.74	3,295.33	16,838.70	11.02
Citywide total	10,847.94	4,679.51	5,334.62	1,780.71	121,798.60	15,946.39	1,032.19	611.59	8,200.04	111,720.40	-3,096.58	-7,153.10	45,336.41	226,365.89	100.00

## Annual Aesthetic/Other Benefit of Public Trees by Species

Worcester, MA

10/24/2008

### Annual Aesthetic/Other Benefit of Public Trees by Species

Species	Total (\$)	% of Total Tree Numbers	% of Total \$	Avg. \$/tree
Norway maple	628,255.50	60.83	69.36	60.36
Sugar maple	92,289.41	9.61	10.19	56.14
Red maple	37,178.32	6.43	4.10	33.80
Silver maple	12,987.23	2.13	1.43	35.68
Littleleaf linden	6,643.89	2.06	0.73	18.87
Northern red oak	15,613.35	1.98	1.72	46.19
Callery pear	13,282.51	1.78	1.47	43.69
Pin oak	11,475.46	1.57	1.27	42.66
White ash	11,444.37	1.53	1.26	43.68
Honeylocust	8,218.37	1.08	0.91	44.42
Other street trees	68,380.45	11.02	7.55	36.26
Citywide total	905,768.81	100.00	100.00	52.93

## Average Annual Benefits of Public Trees by Species (\$/tree)

Worcester, MA

10/24/2008

Average Annual Benefits of Public Trees by Species  
(\$/tree)

Species	Energy	CO2	Air Quality	Stormwater	Aesthetic/Other	Total
Norway maple	61.84	2.64	14.29	13.79	60.36	152.91
Sugar maple	68.22	2.18	14.76	19.95	56.14	161.24
Red maple	46.57	1.10	10.32	11.56	33.80	103.35
Silver maple	85.35	2.40	20.70	26.51	35.68	170.64
Littleleaf linden	42.09	0.87	8.71	8.33	18.87	78.87
Northern red oak	79.53	2.81	18.56	22.89	46.19	169.99
Callery pear	12.57	0.52	2.89	2.71	43.69	62.38
Pin oak	33.93	1.25	7.47	8.56	42.66	93.87
White ash	63.56	1.90	15.46	16.34	43.68	140.94
Honeylocust	35.58	0.86	7.34	6.60	44.42	94.80
Other street trees	39.12	1.21	8.93	9.63	36.26	95.15

## Average Annual Benefits of Public Trees by Species

Average Annual Benefits of Public Trees by Species

Species	Energy	CO2	Air Quality	Stormwater	Aesthetic/ Other	Total (\$)	% of Total \$
Norway maple	643,696.50	27,431.56	148,745.55	143,493.14	628,255.50	1,591,622.25	66.43
Sugar maple	112,153.83	3,583.77	24,264.88	32,794.71	92,289.41	265,086.59	11.06
Red maple	51,232.20	1,209.49	11,348.63	12,715.80	37,178.32	113,684.45	4.75
Silver maple	31,068.13	874.31	7,534.70	9,650.02	12,987.23	62,114.38	2.59
Littleleaf linden	14,816.82	304.52	3,064.29	2,932.17	6,643.89	27,761.70	1.16
Northern red oak	26,881.25	950.75	6,272.35	7,738.01	15,613.35	57,455.72	2.40
Callery pear	3,819.96	157.49	879.30	825.28	13,282.51	18,964.54	0.79
Pin oak	9,126.19	337.52	2,009.77	2,301.93	11,475.46	25,250.86	1.05
White ash	16,652.16	496.66	4,050.52	4,281.54	11,444.37	36,925.25	1.54
Honeylocust	6,582.88	159.23	1,357.14	1,220.83	8,218.37	17,538.45	0.73
Other street trees	73,783.95	2,283.62	16,838.70	18,163.03	68,380.45	179,449.73	7.49
Citywide total	989,813.81	37,788.92	226,365.84	236,116.45	905,768.88	2,395,854.00	100.00

## Total Annual Benefits, Net Benefits, and Costs for Public Trees

Worcester, MA

10/24/2008

### Total Annual Benefits, Net Benefits, and Costs for Public Trees

Benefits	Total (\$)	\$/tree	\$/capita
Energy	989,814	57.84	5.73
CO2	37,789	2.21	0.22
Air Quality	226,366	13.23	1.31
Stormwater	236,116	13.80	1.37
Aesthetic/Other	905,769	52.93	5.25
<b>Total Benefits</b>	<b>2,395,854</b>	<b>140.00</b>	<b>13.88</b>
<b>Cost</b>			
Planting	65,786	3.84	0.38
Contract Pruning	0	0.00	0.00
Pest Management	0	0.00	0.00
Irrigation	0	0.00	0.00
Removal	0	0.00	0.00
Administration	151,080	8.83	0.88
Inspection/Service	0	0.00	0.00
Infrastructure Repairs	0	0.00	0.00
Litter Clean-up	0	0.00	0.00
Liability/Claims	0	0.00	0.00
<b>Other Costs</b>	<b>1,199,203</b>	<b>70.08</b>	<b>6.95</b>
<b>Total Costs</b>	<b>1,416,069</b>	<b>82.75</b>	<b>8.20</b>
<b>Net Benefits</b>	<b>979,785</b>	<b>57.25</b>	<b>5.68</b>
<b>Benefit-cost ratio</b>	<b>1.691905</b>		

# Replacement Value of Public Trees by Species

Worcester, MA

10/24/2008

## Replacement Value of Public Trees by Species

Species	DBH Class (in)									Total	% of Total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42		
Norway maple	9,018.53	64,887.06	801,944.56	8,106,177.50	22,128,786.00	19,404,362.00	8,265,516.00	2,603,040.00	691,926.69	62,075,660.00	64.19
Sugar maple	1,575.67	10,919.08	37,383.07	404,661.69	2,104,817.25	3,106,536.50	1,888,309.50	697,410.00	211,097.36	8,462,710.00	8.75
Red maple	10,768.96	97,819.33	177,007.69	824,285.88	2,239,629.25	1,997,850.50	1,150,148.88	282,879.50	30,901.34	6,811,291.50	7.04
Silver maple	723.66	1,282.08	12,597.86	69,528.64	232,925.33	518,405.53	703,035.00	608,475.63	583,173.94	2,730,147.75	2.82
Littleleaf linden	1,077.22	24,220.80	95,717.82	214,139.94	583,300.75	858,723.94	558,757.06	73,788.73	0.00	2,409,726.25	2.49
Northern red oak	1,477.78	24,484.08	47,089.32	171,477.63	403,203.84	913,406.69	1,149,309.25	1,169,275.38	954,392.75	4,834,117.00	5.00
Callery pear	8,457.26	50,193.54	85,382.37	14,718.77	0.00	0.00	0.00	0.00	0.00	158,751.92	0.16
Pin oak	6,684.98	28,985.77	42,436.38	142,421.55	94,391.48	89,771.95	75,448.81	37,228.27	27,715.20	545,084.31	0.56
White ash	232.12	12,986.44	38,246.51	60,276.84	121,407.91	165,591.34	263,578.72	147,051.64	197,239.78	1,006,611.25	1.04
Honeylocust	1,106.00	34,136.75	76,784.03	73,767.59	95,240.37	22,379.48	16,289.50	21,549.54	0.00	341,253.22	0.35
Japanese tree lilac	10,681.49	35,513.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	46,194.77	0.05
Plum	8,020.34	20,048.58	12,668.63	29,577.72	7,965.53	12,979.08	0.00	0.00	0.00	91,259.88	0.09
Apple	2,595.30	16,198.39	55,762.99	28,101.94	0.00	0.00	0.00	0.00	0.00	102,658.62	0.11
Green ash	0.00	3,941.13	39,452.27	37,324.06	111,491.76	101,041.57	87,762.55	108,241.56	83,044.97	572,299.88	0.59
London planetree	1,057.96	20,629.18	64,574.48	52,107.80	73,557.78	0.00	0.00	0.00	0.00	211,927.19	0.22
White oak	0.00	2,079.94	0.00	49,228.04	127,665.23	334,218.44	551,948.31	560,086.13	577,553.25	2,202,779.50	2.28
Hedge maple	4,662.71	15,705.51	0.00	3,982.76	0.00	0.00	0.00	0.00	0.00	24,350.98	0.03
Japanese zelkova	670.52	24,139.24	24,245.01	17,811.13	0.00	0.00	0.00	0.00	0.00	66,865.91	0.07
Scarlet oak	0.00	418.44	7,133.94	31,862.10	119,370.08	230,041.73	186,467.20	162,745.13	137,462.98	875,501.63	0.91
Siberian elm	193.22	3,924.05	13,488.00	11,626.41	7,604.70	13,536.14	27,143.48	3,894.87	35,200.50	116,611.38	0.12
Tree of heaven	1,085.27	1,357.80	7,592.58	20,423.72	7,149.12	8,781.71	12,594.39	12,632.02	0.00	71,616.62	0.07
Ginkgo	2,975.89	7,839.72	16,163.34	43,191.99	0.00	0.00	0.00	0.00	0.00	70,170.95	0.07
Black locust	0.00	825.18	9,301.13	51,979.84	70,354.13	48,115.04	84,294.35	18,502.83	0.00	283,372.50	0.29
American elm	327.69	838.70	8,804.35	31,505.18	39,628.48	19,468.61	28,430.38	24,818.84	0.00	153,822.23	0.16
American basswood	0.00	418.44	0.00	38,300.90	76,138.76	76,964.07	313,153.41	73,788.73	27,492.60	606,256.94	0.63
Black cherry	0.00	961.56	6,143.22	17,171.90	72,619.03	10,491.42	38,053.39	0.00	0.00	145,440.53	0.15
Shagbark hickory	0.00	0.00	2,325.28	48,937.12	75,239.83	140,977.05	0.00	0.00	0.00	267,479.28	0.28
Eastern white pine	363.34	0.00	5,321.23	50,056.58	54,423.07	101,080.66	16,289.50	43,099.07	0.00	270,633.44	0.28
Elm	1,210.24	5,449.85	12,789.05	3,042.72	0.00	0.00	0.00	0.00	0.00	22,491.86	0.02
Pignut hickory	134.47	0.00	0.00	43,206.66	95,271.21	0.00	28,317.44	0.00	0.00	166,929.78	0.17
Northern catalpa	163.85	518.18	523.73	14,543.55	23,299.16	25,958.15	9,403.69	12,409.42	0.00	86,819.72	0.09
Japanese maple	485.19	3,535.83	9,766.12	0.00	0.00	0.00	0.00	0.00	0.00	13,787.14	0.01
European white birch	0.00	1,357.80	5,171.89	1,162.64	0.00	0.00	0.00	0.00	0.00	7,692.33	0.01
Boxelder	101.04	0.00	2,222.32	12,966.54	6,438.80	12,979.08	0.00	0.00	0.00	34,707.77	0.04
Norway spruce	105.09	592.79	1,475.99	41,487.11	7,742.93	12,756.48	0.00	0.00	0.00	64,160.38	0.07
Blue spruce	0.00	1,416.35	1,162.64	28,145.18	24,917.09	0.00	0.00	0.00	0.00	55,641.25	0.06
Paper birch	0.00	320.52	9,696.10	2,978.80	3,982.76	0.00	0.00	0.00	0.00	16,978.19	0.02
Sycamore maple	0.00	892.91	2,596.56	7,961.79	11,725.69	15,557.19	13,994.23	0.00	0.00	52,728.38	0.05
Flowering dogwood	491.54	838.70	4,246.47	2,102.68	0.00	0.00	0.00	0.00	0.00	7,679.39	0.01
Kousa dogwood	726.27	885.84	2,312.94	0.00	0.00	0.00	0.00	0.00	0.00	3,925.05	0.00
Sorbus species	395.96	0.00	3,397.18	6,308.04	2,456.04	4,001.88	0.00	0.00	0.00	16,559.10	0.02
Chinese elm	997.33	1,785.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2,783.15	0.00
European beech	180.81	1,070.39	3,265.32	0.00	0.00	14,323.21	12,876.03	0.00	61,802.69	93,518.45	0.10
Tulip tree	0.00	558.11	9,345.14	3,512.74	0.00	6,900.34	32,962.81	0.00	0.00	53,279.15	0.06
Butternut	0.00	0.00	6,782.07	9,128.17	977.14	0.00	0.00	0.00	0.00	16,887.38	0.02
European hornbeam	210.19	1,255.33	1,475.99	7,965.53	0.00	0.00	0.00	0.00	0.00	10,907.03	0.01
Sweetgum	0.00	0.00	14,884.43	6,308.11	0.00	0.00	0.00	0.00	0.00	21,192.54	0.02
White mulberry	193.22	543.12	0.00	4,650.56	2,102.68	0.00	0.00	0.00	0.00	7,489.59	0.01
Quaking aspen	0.00	212.72	1,625.71	2,325.28	0.00	0.00	0.00	0.00	7,040.10	11,203.81	0.01
Eastern hemlock	0.00	738.96	3,081.00	6,085.44	5,862.84	0.00	0.00	0.00	0.00	15,768.25	0.02
Horsechestnut	163.85	0.00	1,203.17	2,978.80	3,982.76	4,001.88	9,403.69	0.00	13,857.60	35,917.44	0.04
Serviceberry	0.00	2,266.56	2,951.98	0.00	0.00	0.00	0.00	0.00	0.00	5,218.54	0.01
River birch	459.44	0.00	3,042.24	0.00	8,305.70	0.00	0.00	0.00	0.00	11,807.38	0.01
Eastern red cedar	134.47	0.00	6,975.84	0.00	0.00	0.00	0.00	0.00	0.00	7,110.31	0.01
Magnolia	0.00	3,250.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3,250.18	0.00
Eastern cottonwood	193.22	0.00	535.95	3,294.15	0.00	0.00	9,626.29	6,316.01	0.00	19,965.62	0.02
Rock elm	22.41	738.96	2,325.28	0.00	0.00	0.00	0.00	0.00	0.00	3,086.66	0.00
Black ash	0.00	0.00	5,619.43	0.00	0.00	0.00	0.00	0.00	0.00	5,619.43	0.01
Black walnut	134.47	369.48	0.00	0.00	11,921.12	0.00	0.00	0.00	0.00	12,425.07	0.01
Balsam fir	0.00	167.46	0.00	1,162.64	0.00	3,356.07	0.00	0.00	0.00	4,686.17	0.00
White fir	0.00	662.15	1,789.33	4,922.80	0.00	0.00	0.00	0.00	0.00	7,374.29	0.01
Yellowwood	0.00	369.48	2,325.28	0.00	0.00	0.00	0.00	0.00	0.00	2,694.76	0.00
Hydrangea species	327.69	320.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	648.22	0.00
Tamarack	0.00	0.00	0.00	4,452.78	12,300.87	0.00	20,880.04	0.00	0.00	37,633.70	0.04
Dawn redwood	0.00	0.00	4,625.87	6,308.11	0.00	0.00	0.00	0.00	0.00	10,933.98	0.01
Chestnut oak	0.00	0.00	0.00	0.00	0.00	0.00	18,584.77	49,192.48	0.00	67,777.26	0.07
Peking lilac	0.00	961.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	961.56	0.00
Black birch	0.00	0.00	0.00	4,919.07	0.00	0.00	0.00	0.00	0.00	4,919.07	0.01
Hawthorn	0.00	738.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	738.96	0.00