

i-Tree Ecosystem Analysis

Burlington



Urban Forest Effects and Values
July 2015



Summary

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 vegetation structure, function, and value of the Burlington urban forest was conducted during 2014. Data collected from 176 field plots (out of total 183 plots) located throughout Burlington were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station.

- Number of trees: 702,000
- Tree cover: 34.4%
- Most common species: Red maple, Norway maple, Buckthorn spp
- Percentage of trees less than 6" (15.2 cm) diameter: 61.6%
- Pollution removal: 77 metric tons/year (\$1.69 million/year)
- Carbon storage: 132,000 metric tons (\$10.3 million)
- Carbon sequestration: 3,450 metric tons/year (\$271 thousand/year)
- Oxygen production: 6,360 metric tons/year (\$0 /year)
- Avoided runoff: 192,000 cubic meters/year (\$451 thousand/year)
- Building energy savings: \$57.4 thousand/year
- Avoided carbon emissions: \$3.45 thousand/year
- Structural values: \$553 million

Metric Ton: 1000 kilograms

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

Carbon storage and carbon sequestration values are calculated based on \$78 per metric ton

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

Pollution removal value is calculated based on the prices of \$1253 per metric ton (carbon monoxide), \$4767 per metric ton (ozone), \$459 per metric ton (nitrogen dioxide), \$166 per metric ton (sulfur dioxide), \$32078 per metric ton (particulate matter less than 10 microns and greater than 2.5 microns), \$200283 per metric ton (particulate matter less than 2.5 microns)

Energy saving value is calculated based on the prices of \$160 per MWH and \$16.44 per MBTU

Monetary values (\$) are reported in US Dollars throughout the report except where noted

For an overview of i-Tree Eco methodology, see Appendix I. Data collection quality is determined by the local data collectors, over which i-Tree has no control. Additionally, some of the plot and tree information may not have been collected, so not all of the analyses may have been conducted for this report.

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I. Tree Characteristics of the Urban Forest

The urban forest of Burlington has an estimated 702,000 trees with a tree cover of 34.4 percent. Trees that have diameters less than 6-inches (15.2 cm) constitute 61.6 percent of the population. The three most common species are Red maple (7.3 percent), Norway maple (7.3 percent), and Buckthorn spp (6.0 percent).

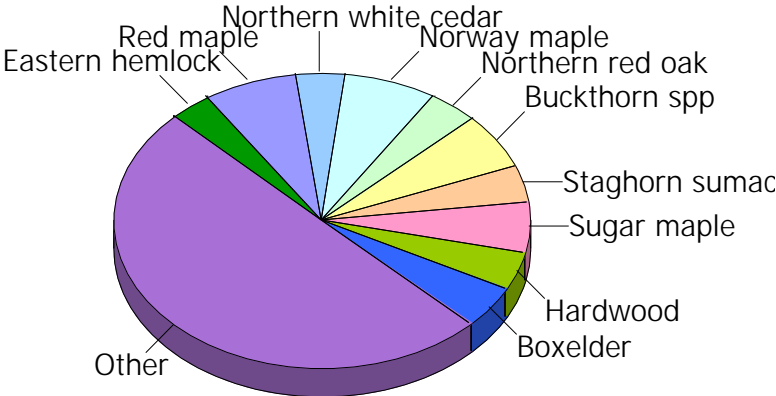


Figure 1. Tree species composition in Burlington

The overall tree density in Burlington is 256 trees/hectare (see Appendix III for comparable values from other cities).

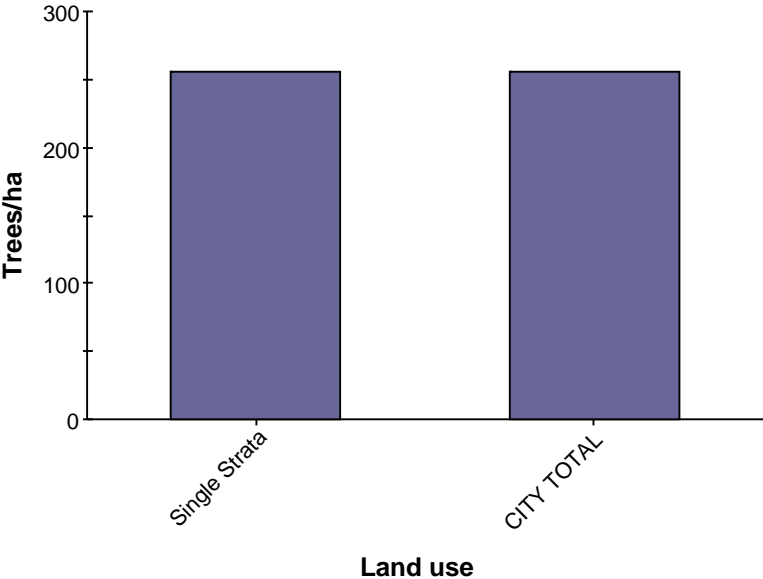


Figure 2. Number of trees/ha in Burlington by land use

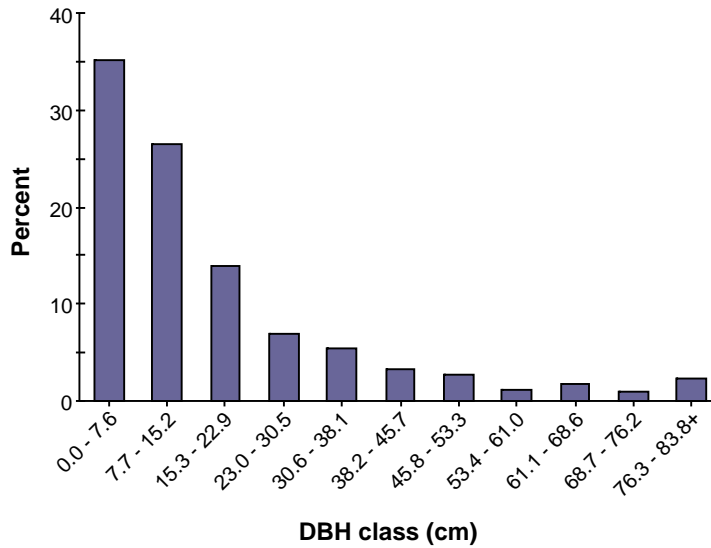


Figure 3. Percent of tree population by diameter class (DBH=stem diameter at 1.37 meter)

Urban forests are composed of a mix of native and exotic tree species. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. Increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but it can also pose a risk to native plants if some of the exotic species are invasive plants that can potentially out-compete and displace native species. In Burlington, about 67 percent of the trees are species native to North America, while 55 percent are native to the state or district. Species exotic to North America make up 33 percent of the population. Most exotic tree species have an origin from North America + (15.9 percent of the species).

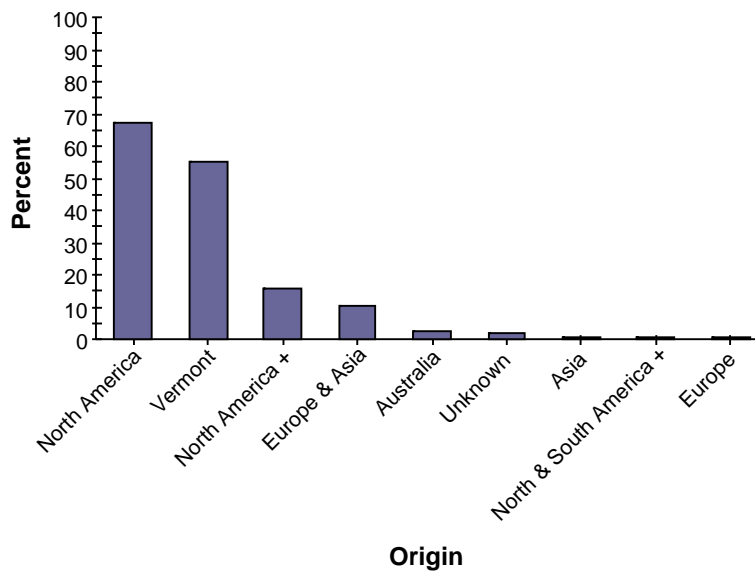


Figure 4. Percent of live trees by species origin

The plus sign (+) indicates the plant is native to another continent other than the ones listed in the grouping.

Invasive plant species are often characterized by their vigor, ability to adapt, reproductive capacity, and general lack of natural enemies. These abilities enable them to displace native plants and make them a threat to natural areas [1]. Two of the 102 tree species sampled in Burlington are identified as invasive on the state invasive species list [2]. These invasive species comprise 10.4 percent of the tree population though they may only cause a minimal level of impact. These two invasive species are Norway maple (7.3 percent of population), and Black locust (3.1 percent) (see Appendix V for a complete list of invasive species).

II. Urban Forest Cover and Leaf Area

Many tree benefits equate directly to the amount of healthy leaf surface area of the plant. In Burlington, the most dominant species in terms of leaf area are Red maple, Sugar maple, and Eastern white pine. Trees cover about 34.4 percent of Burlington.

The 10 most important species are listed in Table 1. Importance values (IV) are calculated as the sum of relative leaf area and relative composition.

Table 1. Most important species in Burlington

Species Name	Percent Population	Percent Leaf Area	IV
Red maple	7.3	8.1	15.4
Sugar maple	5.6	7.8	13.3
Norway maple	7.3	4.9	12.2
Northern red oak	3.9	6.7	10.6
Boxelder	4.6	5.8	10.4
Eastern white pine	2.8	6.9	9.6
Silver maple	1.2	6.8	8.0
Buckthorn spp	6.0	1.3	7.4
Black locust	3.1	3.5	6.6
Eastern hemlock	3.3	3.3	6.6

The most dominant ground cover types are Grass (25.6 percent) and Herbs (16 percent).

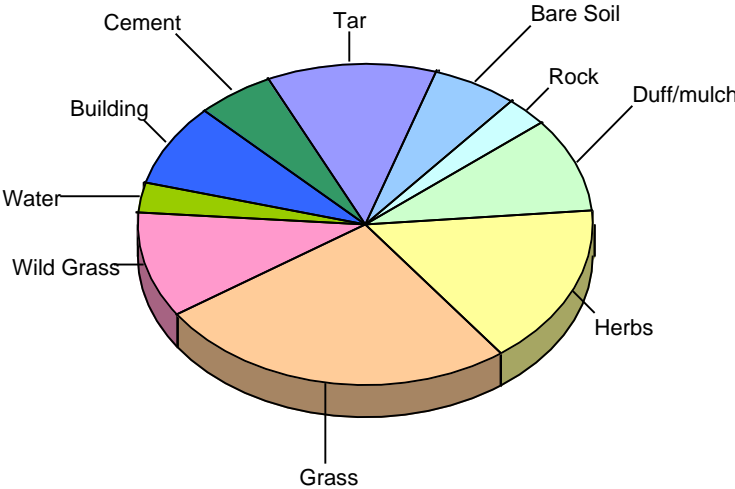


Figure 5. Percent ground cover in Burlington

III. Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation [3].

Pollution removal by trees and shrubs in Burlington was estimated using field data and recent available pollution and weather data. Pollution removal was greatest for ozone. It is estimated that trees and shrubs remove 77 metric tons of air pollution (ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 10 microns and greater than 2.5 microns (PM10), particulate matter less than 2.5 microns (PM2.5), and sulfur dioxide (SO2)) per year with an associated value of \$1.69 million (see Appendix I for more details).

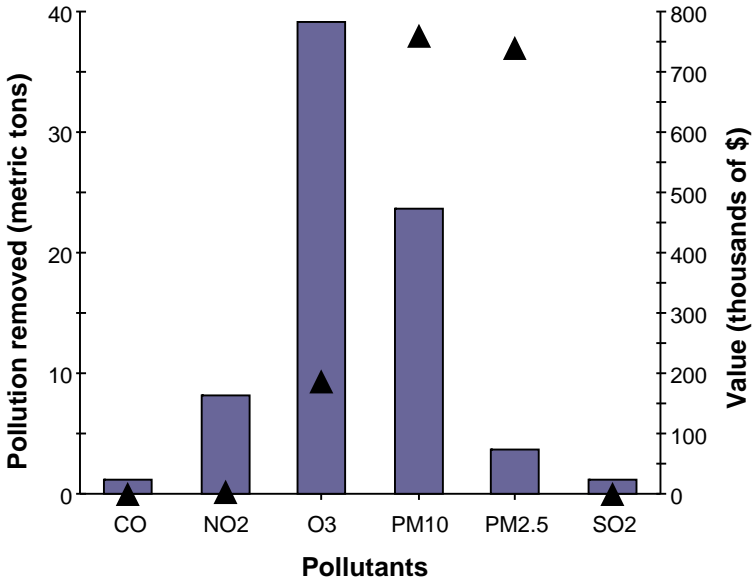


Figure 6. Pollution removal (bars) and associated value (points) for trees in Burlington

PM10 consists of particulate matter less than 10 microns and greater than 2.5 microns. As PM2.5 is also estimated, the sum of PM10 and PM2.5 provides the total pollution removal and value for particulate matter less than 10 microns.

Pollution Removal value is calculated based on the prices of \$1253 per metric ton (carbon monoxide), \$4767 per metric ton (ozone), \$459 per metric ton (nitrogen dioxide), \$166 per metric ton (sulfur dioxide), \$32078 per metric ton (particulate matter less than 10 microns and greater than 2.5 microns), \$200283 per metric ton (particulate matter less than 2.5 microns)

Trees remove PM2.5 when particulate matter is deposited on leaf surfaces. This deposited PM2.5 can be resuspended to the atmosphere or removed during rain events and dissolved or transferred to the soil. This combination of events can lead to interesting results depending on various atmospheric factors. Generally, pollution removal is positive with positive benefits. However, there are some cases when net removal is negative or resuspended particles lead to increased pollution concentrations and negative values. During some months (e.g., with no rain), trees resuspend more particles than they

remove. Resuspension can also lead to increased overall PM2.5 concentrations if the boundary layer conditions are lower during net resuspension periods than during net removal periods. Since the pollution removal value is based on the change in pollution concentration, it is possible to have situations when trees remove PM2.5 but increase concentrations and thus have negative values during periods of positive overall removal. These events are not common, but can happen.

IV. Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power plants [4].

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of Burlington trees is about 3,450 metric tons of carbon per year with an associated value of \$271 thousand. Net carbon sequestration in the urban forest is about 2,390 metric tons. Carbon storage and carbon sequestration values are calculated based on \$78 per metric ton (see Appendix I for more details).

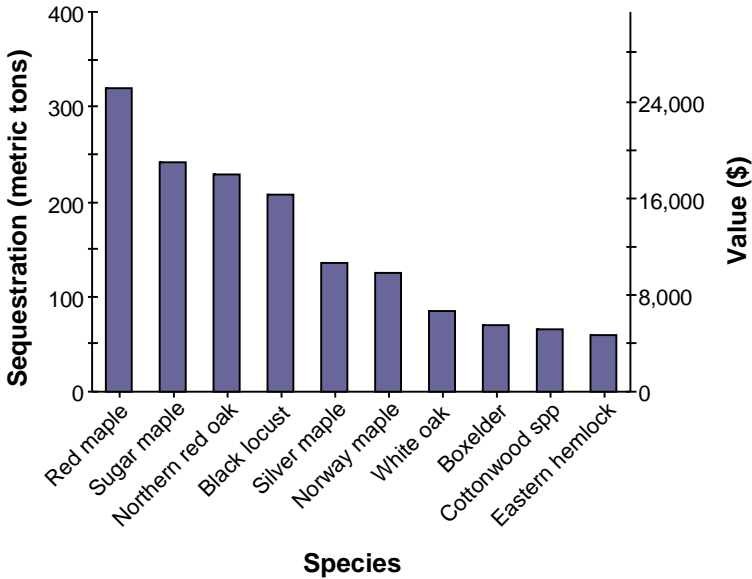


Figure 7. Carbon sequestration and value for species with greatest overall carbon sequestration in Burlington

As trees grow they store more 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 Burlington are estimated to store 132,000 metric tons of carbon (\$10.3 million). Of all the species sampled, Northern red oak stores the most carbon (approximately 13.7% of the total carbon stored. Red maple sequesters the most carbon (13.4% of all sequestered carbon.)

V. Oxygen Production

Oxygen production is one of the most commonly cited benefits of urban trees. The net annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass.

Trees in Burlington are estimated to produce 6,360 metric tons of oxygen per year. However, this tree benefit is relatively insignificant because of the large and relatively stable amount of oxygen in the atmosphere and extensive production by aquatic systems. Our atmosphere has an enormous reserve of oxygen. If all fossil fuel reserves, all trees, and all organic matter in soils were burned, atmospheric oxygen would only drop a few percent [5].

Table 2. The top 20 oxygen production species.

Species	Oxygen (metric tons)	Net Carbon Sequestration (metric tons/yr)	Number of trees	Leaf Area (square kilometers)
Red maple	852.83	319.81	50,996.00	5.45
Sugar maple	644.08	241.53	38,973.00	5.24
Northern red oak	607.63	227.86	27,364.00	4.52
Black locust	554.61	207.98	21,974.00	2.36
Silver maple	359.76	134.91	8,707.00	4.55
Norway maple	334.64	125.49	50,996.00	3.33
White oak	225.17	84.44	4,975.00	1.35
Boxelder	185.95	69.73	31,925.00	3.91
Cottonwood spp	174.72	65.52	5,390.00	0.85
Eastern hemlock	157.33	59.00	23,218.00	2.19
Green ash	155.44	58.29	19,901.00	1.85
Black willow	152.59	57.22	2,073.00	1.46
Birch spp	128.83	48.31	7,463.00	0.60
White ash	127.41	47.78	10,780.00	0.89
Oak spp	121.44	45.54	1,244.00	0.40
Staghorn sumac	106.67	40.00	28,193.00	0.55
Buckthorn spp	101.47	38.05	42,290.00	0.90
Red pine	99.73	37.40	7,877.00	0.59
Ash spp	89.52	33.57	14,097.00	0.85
Northern white cedar	89.09	33.41	26,535.00	1.06

VI. Avoided Runoff

Surface runoff can be a cause for concern in many urban areas as it can contribute pollution to streams, wetlands, rivers, lakes, and oceans. During precipitation events, some portion of the precipitation is intercepted by vegetation (trees and shrubs) while the other portion reaches the ground. The portion of the precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff [6]. In urban areas, the large extent of impervious surfaces increases the amount of surface runoff.

Urban trees, however, are beneficial in reducing surface runoff. Trees intercept precipitation, while their root systems promote infiltration and storage in the soil. The trees of Burlington help to reduce runoff by an estimated 192,000 cubic meters a year with an associated value of \$451 thousand (see Appendix I for more details).

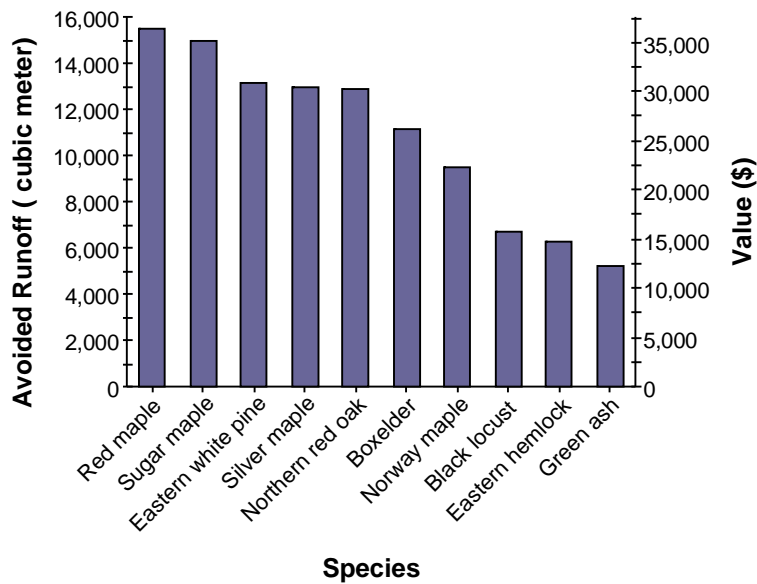


Figure 8. Avoided runoff and value for species with greatest overall impact on runoff in Burlington

VII. 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 [7].

Trees in Burlington are estimated to reduce energy-related costs from residential buildings by \$57.4 thousand annually. Trees also provide an additional \$3,454 in value by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 44 metric tons of carbon emissions).

Table 3. Annual energy savings due to trees near residential buildings. Note: negative numbers indicate an increased energy use or carbon emission.

	Heating	Cooling	Total
MBTU ¹	-879	n/a	-879
MWH ²	-7	456	449
Carbon avoided (mt ³)	-14	58	44

¹One million British Thermal Units

²Megawatt-hour

³Metric ton

Table 4. Annual savings¹ (\$) 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	-14,451	n/a	-14,451
MWH ³	-1,120	72,960	71,840
Carbon avoided	-1,099	4,553	3,454

¹Based on the prices of \$160 per MWH and \$16.44 per MBTU (see Appendix I for more details)

²One million British Thermal Units

³Megawatt-hour

VIII. Structural and Functional Values

Urban forests have a structural value based on the trees themselves (e.g., the cost of having to replace a tree with a similar tree); they also have functional values (either positive or negative) based on the functions the trees perform.

The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees [8]. Annual functional values also tend to increase with increased number and size of healthy trees, and are usually on the order of several million dollars per year. Through proper management, urban forest values can be increased; however, the values and benefits also can decrease as the amount of healthy tree cover declines.

Structural values:

- Structural value: \$553 million
- Carbon storage: \$10.3 million

Annual functional values:

- Carbon sequestration: \$271 thousand
- Pollution removal: \$1.69 million
- Lower energy costs and carbon emission reductions: \$60.8 thousand (Note: negative value indicates increased energy cost and carbon emission value)

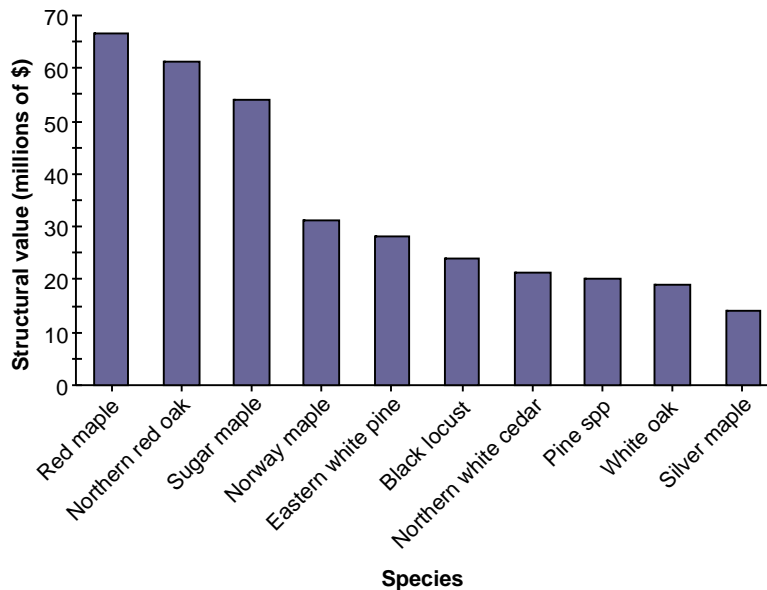


Figure 9. Structural value of the 10 most valuable tree species in Burlington

IX. Potential Pest Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. As pests tend to have differing tree hosts, the potential damage or risk of each pest will differ among cities. Thirty-one pests were analyzed for their potential impact and compared with pest range maps [9] for the conterminous United States. In the following graph, the pests are color coded according to the county's proximity to the pest occurrence in the United States. Red indicates that the pest is within the county; orange indicates that the pest is within 250 miles of the county; yellow indicates that the pest is within 750 miles of the county; and green indicates that the pest is outside of these ranges.

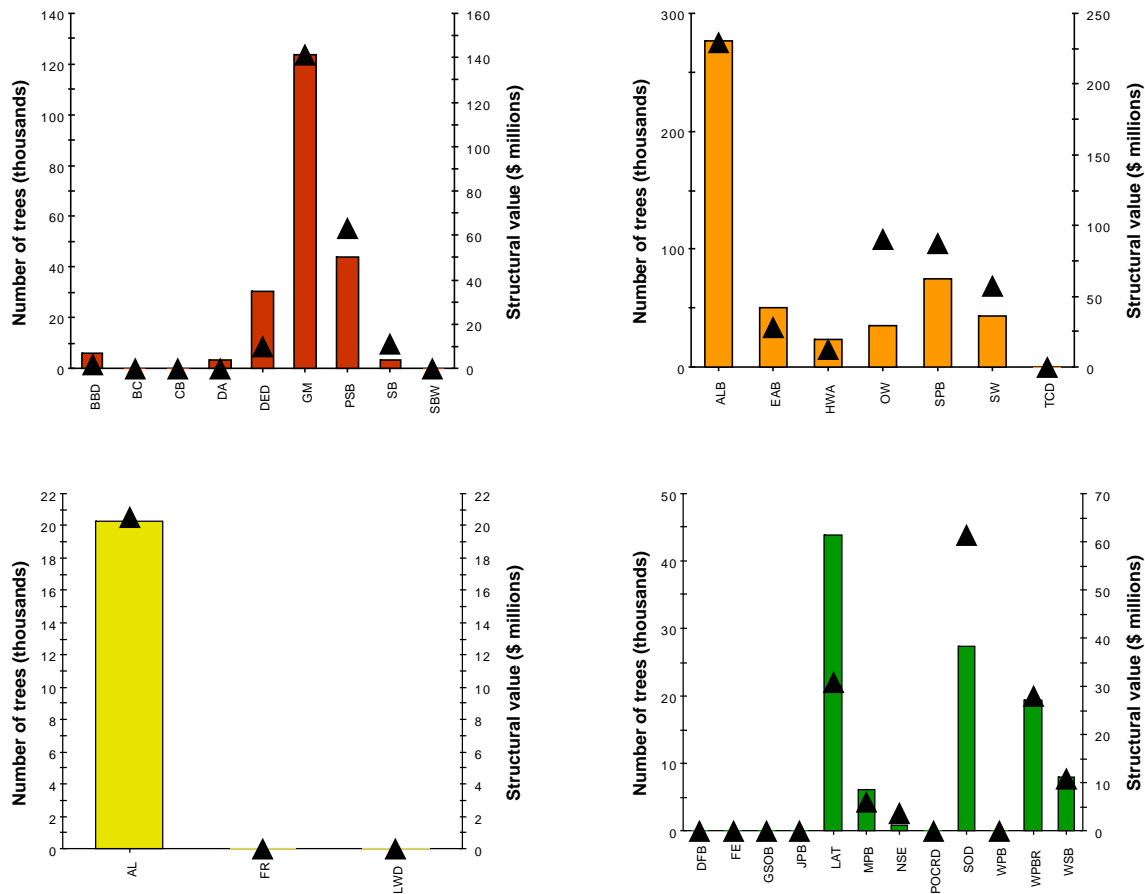


Figure 10. Number of susceptible Burlington trees and structural value by pest (points)

Aspen Leafminer (AL) [10] is an insect that causes damage primarily to trembling or small tooth aspen by larval feeding of leaf tissue. AL has the potential to affect 2.9 percent of the population (\$20.5 million in structural value).

Asian Longhorned Beetle (ALB) [11] is an insect that bores into and kills a wide range of hardwood species. ALB poses a threat to 39.4 percent of the Burlington urban forest, which represents a potential loss of \$230 million in structural value.

Beech Bark Disease (BBD) [12] is an insect-disease complex that primarily impacts American beech. This disease threatens 0.9 percent of the population, which represents a potential loss of \$2.14 million in structural value.

Butternut Canker (BC) [13] is caused by a fungus that infects butternut trees. The disease has since caused significant declines in butternut populations in the United States. Potential loss of trees from BC is 0.0 percent (\$0 in structural value).

The most common hosts of the fungus that cause Chestnut Blight (CB) [14] are American and European chestnut. CB has the potential to affect 0.0 percent of the population (\$0 in structural value).

Dogwood Anthracnose (DA) [15] is a disease that affects dogwood species, specifically flowering and Pacific dogwood. This disease threatens 0.5 percent of the population, which represents a potential loss of \$153 thousand in structural value.

American elm, one of the most important street trees in the twentieth century, has been devastated by the Dutch Elm Disease (DED) [16]. Since first reported in the 1930s, it has killed over 50 percent of the native elm population in the United States. Although some elm species have shown varying degrees of resistance, Burlington could possibly lose 4.3 percent of its trees to this pest (\$9.88 million in structural value).

Douglas-Fir Beetle (DFB) [17] is a bark beetle that infests Douglas-fir trees throughout the western United States, British Columbia, and Mexico. Potential loss of trees from DFB is \$0 (\$0 in structural value).

Emerald Ash Borer (EAB) [18] has killed thousands of ash trees in parts of the United States. EAB has the potential to affect 7.1 percent of the population (\$28.2 million in structural value).

One common pest of white fir, grand fir, and red fir trees is the Fir Engraver (FE) [19]. FE poses a threat to 0.0 percent of the Burlington urban forest, which represents a potential loss of \$0 in structural value.

Fusiform Rust (FR) [20] is a fungal disease that is distributed in the southern United States. It is particularly damaging to slash pine and loblolly pine. FR has the potential to affect 0.0 percent of the population (\$0 in structural value).

The Gypsy Moth (GM) [22] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest threatens 17.7 percent of the population, which represents a potential loss of \$142 million in structural value.

Infestations of the Goldspotted Oak Borer (GSOB) [21] have been a growing problem in southern California. Potential loss of trees from GSOB is \$0 (\$0 in structural value).

As one of the most damaging pests to eastern hemlock and Carolina hemlock,

Hemlock Woolly Adelgid (HWA) [23] has played a large role in hemlock mortality in the United States. HWA has the potential to affect 3.3 percent of the population (\$12.9 million in structural value).

The Jeffrey Pine Beetle (JPB) [24] is native to North America and is distributed across California, Nevada, and Oregon where its only host, Jeffrey pine, also occurs. This pest threatens 0.0 percent of the population, which represents a potential loss of \$0 in structural value.

Quaking aspen is a principal host for the defoliator, Large Aspen Tortrix (LAT) [25]. LAT poses a threat to 43.9 thousand percent of the Burlington urban forest, which represents a potential loss of \$30.8 million in structural value.

Laurel Wilt (LWD) [26] is a fungal disease that is introduced to host trees by the redbay ambrosia beetle. This pest threatens 0.0 percent of the population, which represents a potential loss of \$0 in structural value.

Mountain Pine Beetle (MPB) [27] is a bark beetle that primarily attacks pine species in the western United States. MPB has the potential to affect 0.9 percent of the population (\$5.96 million in structural value).

The Northern Spruce Engraver (NSE) [28] has had a significant impact on the boreal and sub-boreal forests of North America where the pest's distribution overlaps with the range of its major hosts. Potential loss of trees from NSE is 829 (\$3.61 million in structural value).

Oak Wilt (OW) [29], which is caused by a fungus, is a prominent disease among oak trees. OW poses a threat to 5.0 percent of the Burlington urban forest, which represents a potential loss of \$90.2 million in structural value.

Port-Orford-Cedar Root Disease (POCRD) [30] is a root disease that is caused by a fungus. POCRD threatens 0.0 percent of the population, which represents a potential loss of \$0 in structural value.

The Pine Shoot Beetle (PSB) [31] is a wood borer that attacks various pine species, though Scotch pine is the preferred host in North America. PSB has the potential to affect 6.3 percent of the population (\$63.1 million in structural value).

Spruce Beetle (SB) [32] is a bark beetle that causes significant mortality to spruce species within its range. Potential loss of trees from SB is 3.32 thousand (\$11.0 million in structural value).

Spruce Budworm (SBW) [33] is an insect that causes severe damage to balsam fir. SBW poses a threat to 0.0 percent of the Burlington urban forest, which represents a potential loss of \$0 in structural value.

Sudden Oak Death (SOD) [34] is a disease that is caused by a fungus. Potential loss of trees from SOD is 27.4 thousand (\$61.4 million in structural value).

Although the Southern Pine Beetle (SPB) [35] will attack most pine species, its preferred hosts are loblolly, Virginia, pond, spruce, shortleaf, and sand pines. This pest threatens 10.7 percent of the population, which represents a potential loss of \$87.6 million in structural value.

The Sirex Wood Wasp (SW) [36] is a wood borer that primarily attacks pine species. SW poses a threat to 6.1 percent of the Burlington urban forest, which represents a potential loss of \$57.6 million in structural value.

Thousand Canker Disease (TCD) [37] is an insect-disease complex that kills several species of walnuts, including black walnut. Potential loss of trees from TCD is \$0 (\$0 in structural value).

The Western Pine Beetle (WPB) [38] is a bark beetle and aggressive attacker of ponderosa and Coulter pines. This pest threatens 0.0 percent of the population, which represents a potential loss of \$0 in structural value.

Western spruce budworm (WSB) [40] is an insect that causes defoliation in western conifers. This pest threatens 1.1 percent of the population, which represents a potential loss of \$10.8 million in structural value.

Appendix I. i-Tree Eco Model and Field Measurements

i-Tree Eco is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects [41], including:

- Urban forest structure (e.g., species composition, tree health, leaf area, etc.).
- 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, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<2.5 microns and <10 microns).
- 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 pests, such as Asian longhorned beetle, emerald ash borer, gypsy moth, and Dutch elm disease.

In the field 0.040 hectare plots were randomly distributed. Typically, all field data are collected during the leaf-on season to properly assess tree canopies. Within each plot, typical data collection (actual data collection may vary depending upon the user) includes land use, 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 [42, 43].

Invasive species are identified using an invasive species list [2] for the state in which the urban forest is located. These lists are not exhaustive and they cover invasive species of varying degrees of invasiveness and distribution. In instances where a state did not have an invasive species list, a list was created based on the lists of the adjacent states. Tree species that are identified as invasive by the state invasive species list are cross-referenced with native range data. This helps eliminate species that are on the state invasive species list, but are native to the study area.

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 [44]. 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. Carbon storage and carbon sequestration values are based on estimated or customized local carbon values. For international reports that do not have local values, estimates are based on the carbon value for the United States [45] and converted to local currency with user-defined exchange rates.

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O₂ release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate

the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition [46].

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models [47, 48]. 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 [49, 50] that were adjusted depending on leaf phenology and leaf area. Removal estimates of particulate matter less than 10 microns incorporated a 50 percent resuspension rate of particles back to the atmosphere [51]. 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 [52, 53, and 54].

Air pollution removal value was calculated based on local incidence of adverse health effects and national median externality costs. The number of adverse health effects and associated economic value is calculated for ozone, sulfur dioxide, nitrogen dioxide, and particulate matter <2.5 microns using the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP). The model uses a damage-function approach that is based on the local change in pollution concentration and population [55].

National median externality costs were used to calculate the value of carbon monoxide removal and particulate matter less than 10 microns and greater than 2.5 microns [56]. PM10 denotes particulate matter less than 10 microns and greater than 2.5 microns throughout the report. As PM2.5 is also estimated, the sum of PM10 and PM2.5 provides the total pollution removal and value for particulate matter less than 10 microns.

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis.

The value of avoided runoff is based on estimated or user-defined local values. For international reports that do not have local values, the national average value for the United States is utilized and converted to local currency with user-defined exchange rates. The U.S. value of avoided runoff is based on the U.S. Forest Service's Community Tree Guide Series [57].

If appropriate field data were collected, seasonal effects of trees on residential building energy use were calculated based on procedures described in the literature [7] using distance and direction of trees from residential structures, tree height and tree condition data. To calculate the monetary value of energy savings, local or custom prices per MWH or MBTU are utilized.

Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information [58]. Structural value may not be included for international projects if there is insufficient local data to complete the valuation procedures.

Potential pest risk is based on pest range maps and the known pest host species that are likely to experience mortality. Pest range maps from the Forest Health Technology Enterprise Team (FHTET) [9] were used to determine the proximity of each pest to the

county in which the urban forest is located. For the county, it was established whether the insect/disease occurs within the county, is within 250 miles of the county edge, is between 250 and 750 miles away, or is greater than 750 miles away. FHTET did not have pest range maps for Dutch elm disease and chestnut blight. The range of these pests was based on known occurrence and the host range, respectively [9].

Appendix II. Relative Tree Effects

The urban forest in Burlington provides benefits that include carbon storage and sequestration, and air pollutant removal. To estimate the relative value of these benefits, tree benefits were compared to estimates of average municipal carbon emissions [59], average passenger automobile emissions [60], and average household emissions [61].

Carbon storage is equivalent to:

- Amount of carbon emitted in Burlington in 208 days
- Annual carbon (C) emissions from 87,000 automobiles
- Annual C emissions from 43,700 single-family houses

Carbon monoxide removal is equivalent to:

- Annual carbon monoxide emissions from 5 automobiles
- Annual carbon monoxide emissions from 21 single-family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 567 automobiles
- Annual nitrogen dioxide emissions from 378 single-family houses

Sulfur dioxide removal is equivalent to:

- Annual sulfur dioxide emissions from 1,860 automobiles
- Annual sulfur dioxide emissions from 31 single-family houses

Particulate matter less than 10 micron (PM10) removal is equivalent to:

- Annual PM10 emissions from 80,500 automobiles
- Annual PM10 emissions from 7,770 single-family houses

Annual carbon sequestration is equivalent to:

- Amount of carbon emitted in Burlington in 5.5 days
- Annual C emissions from 2,300 automobiles
- Annual C emissions from 1,100 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 i-Tree Eco model.

I. City totals for trees

City	% Tree Cover	Number of trees	Carbon storage (metric tons)	Carbon Sequestration (metric tons/yr)	Pollution removal (metric tons/yr)
Calgary, Canada	7.2	11,889,000	404,000	19,400	296
Atlanta, GA	36.8	9,415,000	1,220,000	42,100	1,508
Toronto, Canada	20.5	7,542,000	900,000	36,600	1,100
New York, NY	21	5,212,000	1,226,000	38,400	1,521
Baltimore, MD	21	2,627,000	541,000	14,600	390
Philadelphia, PA	15.7	2,113,000	481,000	14,600	523
Washington, DC	28.6	1,928,000	474,000	14,600	379
Boston, MA	22.3	1,183,000	289,000	9,500	258
Woodbridge, NJ	29.5	986,000	145,000	5,000	191
Minneapolis, MN	26.5	979,000	227,000	8,100	277
Syracuse, NY	23.1	876,000	157,000	4,900	99
Morgantown, WV	35.9	661,000	85,000	2,700	60
Moorestown, NJ	28	583,000	106,000	3,400	107
Jersey City, NJ	11.5	136,000	19,000	800	37
Freehold, NJ	34.4	48,000	18,000	500	19

II. Per hectare values of tree effects

City	No. of trees	Carbon Storage (metric tons)	Carbon sequestration (metric tons/yr)	Pollution removal (metric tons/yr)
Calgary, Canada	164.8	5.60	0.13	4.0
Atlanta, GA	275.8	35.64	0.62	44.2
Toronto, Canada	119.4	14.35	0.29	17.5
New York, NY	65.2	15.24	0.24	19.1
Baltimore, MD	125.5	25.78	0.35	18.6
Philadelphia, PA	61.8	14.12	0.21	15.2
Washington, DC	121.1	29.81	0.46	23.8
Boston, MA	82.8	20.18	0.33	17.9
Woodbridge, NJ	164.3	24.21	0.42	31.8
Minneapolis, MN	64.7	15.02	0.27	18.4
Syracuse, NY	134.7	24.21	0.38	15.2
Morgantown, WV	295.8	38.11	0.60	26.7
Moorestown, NJ	153.2	28.02	0.45	28.2
Jersey City, NJ	35.3	4.93	0.11	9.6
Freehold, NJ	95.1	35.87	0.49	37.7

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 [62]:

- 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 [63]. Local urban management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include [63]:

Strategy	Result
Increase the number of healthy trees	Increase pollution removal
Sustain existing tree cover	Maintain pollution removal levels
Maximize use of low VOC-emitting trees	Reduces ozone and carbon monoxide formation
Sustain large, healthy trees	Large trees have greatest per-tree effects
Use long-lived trees	Reduce long-term pollutant emissions from planting and removal
Use low maintenance trees	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 water to vegetation	Enhance pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive species	Improve tree health
Utilize evergreen trees for particulate matter	Year-round removal of particles

Appendix V. Invasive Species of the Urban Forest

The following inventoried species were listed as invasive on the Vermont invasive species list [2]:

Species Name ¹	Number of trees	% Tree Number	Leaf Area (km ²)	% Leaf Area
Norway maple	50,996	7.27	3.33	4.94
Black locust	21,974	3.13	2.36	3.49
TOTAL	72,970	10.40	5.68	8.43

¹Species are determined to be invasive if they are listed on the state's invasive species list.

References

1. U.S. Department of Agriculture. National Invasive Species Information Center. 2011. <http://www.invasivespeciesinfo.gov/plants/main.shtml>
2. State invasive species lists were compiled for the following:
 - AL: Alabama Invasive Plant Council. 2007. Center for Invasive Species and Ecosystem Health at the University of Georgia. <<http://www.se-eppc.org/alabama/2007plantlist.pdf>>
 - AK: Alaska National Heritage Program. University of Alaska Anchorage. <<http://aknhp.uaa.alaska.edu/botany/akepic/non-native-plant-species-biographies/>>
 - AZ: Arizona Wildlands Invasive Plant Working Group. 2005. Invasive Non-Native Plants That Threaten Wildlands in Arizona. <<http://sbsc.wr.usgs.gov/research/projects/swepic/SWVMA/InvasiveNon-NativePlantsThatThreatenWildlandsInArizona.pdf>>
 - AR: Jardine, Jude; Witsell, Theo. Arkansas Native Plant Society. Working List of Non-native Invasive Plant Species of Concern to Natural Areas in Arkansas. <<http://www.deltic.com/hunting/ANPS%20INVASIVES%20LIST.pdf>>
 - CA: California Invasive Species Advisory Committee. 2010. The California Invasive Species List. <<http://www.iscc.ca.gov/docs/CaliforniaInvasiveSpeciesList.pdf>>
 - CO: Colorado Weed Management Association. Colorado Noxious Weed List. <<http://www.cwma.org/noxweeds.html#list>>
 - CT: Connecticut Invasive Plants Council. 2009. Connecticut Invasive Plant List. <<ftp://ftp-fc.sc.gov.usda.gov/CT/invasives/WordInvasivesListCommonNameW-Authors4PDF.pdf>>
 - DE: McAvoy, William A. 2001. Invasive Plant Species in Delaware. <<http://www.dnrec.state.de.us/fw/invasive.htm>>
 - FL: Florida Exotic Pest Plant Council Plant List Committee. 2007. FLEPPC 2007 List of Invasive Plant Species. <http://www.fleppc.org/list/07list_ctrfld.pdf>
 - GA: Georgia Exotic Pest Plant Council. List of Non-native Invasive Plants in Georgia. <<http://www.gaeppc.org/list.cfm>>
 - HI: Hawaii State Alien Species Coordinator. Hawaii's Most Invasive Horticultural Plants. <<http://www.state.hi.us/dlnr/dofaw/hortweeds/specieslist.htm>>
Hawaii Invasive Species Partnership. Hawaii's High-Profile Invasive Species. <<http://www.hawaiiinvasivespecies.org/pests/>>
 - IL: Invasive.org: Center for Invasive Species and Ecosystem Health. Illinois Invasive Plant List. <<http://www.invasive.org/species/list.cfm?id=152>>

IN: Indiana Cooperative Agricultural Pest Survey. 2007. Indiana's "Most Unwanted" Invasive Plant Pest List - FY 2007.
<<http://www.extension.entm.purdue.edu/CAPS/downloads/IndianaInvasivePlantPestList.pdf>>

IA: Iowa. Forest Invasive Plants Resource Center. Current and Future Invasive Plants.
<<http://na.fs.fed.us/spfo/invasiveplants/states/ia.asp>>
Iowa Department of Natural Resources. Invasive Plant Species.
<<http://www.iowadnr.gov/forestry/invasive.html>>

KS: Kansas Native Plant Society. 2006. Invasive Plant Fact Sheet. R.L. McGregor Herbarium. University of Kansas.
<http://www.kansasnativeplantsociety.org/invasive_plants.htm>

KY: Kentucky Exotic Pest Plant Council. Center for Invasive Species and Ecosystem Health at the University of Georgia. <<http://www.se-eppc.org/ky/list.htm>>

ME: Public Laws of Maine. An Act to Prevent the Spread of Invasive Aquatic Plants.
<<http://www.mainelegislature.org/ros/LOM/LOM119th/5Pub701-750/5Pub701-750-21.htm>>

Department of Conservation. Maine Natural Areas Program. Invasive Plant Fact Sheets. <<http://www.maine.gov/doc/nrimc/mnap/features/inv sheets.htm>>

MD: Maryland Invasive Species Council. Invasive Species of Concern in Maryland: Terrestrial Plants. <http://www.mdinvasivesp.org/list_terrestrial_plants.html>
Maryland Invasive Species Council. Invasive Species of Concern in Maryland: Aquatic Plants. <http://www.mdinvasivesp.org/list_aquatic_plants.html>

MA: Massachusetts Invasive Plant Advisory Group. 2005. The Evaluation of Non-native Plant Species for Invasiveness in Massachusetts.
<<http://www.newfs.org/docs/docs/MIPAG040105.pdf>>

MI: Michigan Natural Features Inventory. Michigan State University Extension. Michigan Invasive Plant Species Account.
<<http://web4.msue.msu.edu/mnfi/education/factsheets.cfm>>

MN: Minnesota Department of Natural Resources. Invasive Terrestrial Plants.
<<http://www.dnr.state.mn.us/invasives/terrestrialplants/index.html>>
Minnesota Department of Natural Resources. Invasive Aquatic Plants.
<<http://www.dnr.state.mn.us/invasives/aquaticplants/index.html>>

MS: Winters, Faye; Byrd, John D.; Bryson, Charles T. Mississippi's Ten Worst Invasive Weeds: Threatening Fish and Wildlife Habitat.
<http://www.wildlifemiss.org/news/news/2004/mississippi_weeds.htm>
Mississippi Exotic Pest Plant Council. Noteworthy Exotic Plant Species of Mississippi.
<<http://www.se-eppc.org/mississippi/>>

MO: Missouri Botanical Gardens. Missouri Exotic Pest Plants.
<<http://www.mobot.org/mobot/research/mepp/alphalist.shtml>>

NE: Nebraska Invasive Species Advisory Council. Invasive Plants of Nebraska.
<<http://snr.unl.edu/invasives/pdfs/Invasive%20Plant%20Lists/NE%20Invasive%20Plants%20List%20Full%20Document%204-14-11.pdf>>

NV: University of Nevada Cooperative Extension. Invasive Plants in Nevada: An Identification Handbook.
<<http://www.unce.unr.edu/publications/files/ag/other/sp9603.pdf>>

NH: New Hampshire Department of Agriculture, Markets, and Food. NH Prohibited Invasive Species List.
<http://www.nh.gov/agric/divisions/plant_industry/documents/list.pdf>
New Hampshire Department of Agriculture, Markets, and Food. NH Restricted Invasive Species List. <http://www.nh.gov/agric/divisions/plant_industry/documents/watch.pdf>
Cygan, Douglas. New Hampshire Department of Agriculture, Markets, and Food. New Hampshire Invasive Species Committee. 2011. Guide to Invasive Upland Plant Species in New Hampshire. <<http://extension.unh.edu/Forestry/Docs/invasive.pdf>>

NJ: The Native Plant Society of New Jersey. 2004. Appendix to Policy Directive 2004-02 Invasive Nonindigenous Plant Species.
<http://www.npsnj.org/references/invasive_plant_list.pdf>
Ling, Hubert. 2003. Invasive Plant Species. The Native Plant Society of New Jersey.
<http://www.npsnj.org/invasive_species_0103.htm>

NY: New York State Department of Environmental Conservation. Interim Invasive Species Plant List. <<http://www.dec.ny.gov/animals/65408.html>>

NC: Smith, Cherri. 2008. Invasive Exotic Plants of North Carolina. North Carolina Department of Transportation. <http://www.se-eppc.org/northcarolina/NCDOT_Invasive_Exotic_Plants.pdf>
North Carolina Native Plant Society. 2010. Invasive Exotic Species List.
<<http://www.ncwildflower.org/invasives/list.htm>>

ND: North Dakota Department of Agriculture. Catalogue of Species.
<<http://www.agdepartment.com/noxiousweeds/searchweeds.asp>>

OH: Ohio Department of Natural Resources. The Nature Conservancy. 2000. Ohio's Invasive Plant Species.
<<http://www.ohiodnr.com/Portals/3/invasive/pdf/OHIO%20INVASIVE%20PLANTS.pdf>>

OK: Oklahoma Native Plant Society. Oklahoma Biological Survey. OSU Natural Resource Ecology and Management. Oklahoma Non-native Invasive Plant Species. <<http://www.ok-invasive-plant-council.org/images/OKinvasivespp.pdf>>

OR: Oregon Invasive Species Council. 100 Most Dangerous Invaders to Keep Out.

<http://oregon.gov/OISC/most_dangerous.shtml>

PA: Pennsylvania Department of Conservation and Natural Resources. Invasive Exotic Plants in Pennsylvania List.

<<http://www.dcnr.state.pa.us/forestry/invasivetutorial/List.htm>>

RI: Rhode Island Invasive Species Council. Rhode Island Natural History Survey. 2001. Invasives: List. <<http://www.rinhs.org/resources/ri-invasive-species-resources/invasive-list/>>

SC: South Carolina Exotic Pest Plant Council. Center for Invasive Species and Ecosystem Health at the University of Georgia. <<http://www.invasive.org/species/list.cfm?id=27>>

South Carolina Exotic Pest Plant Council Invasive Species List 2008. <<http://www.se-eppc.org/southcarolina/invasivePlants.cfm>>

TN: Tennessee Exotic Pest Plant Council. 2009. Invasive Plants of Tennessee.

<http://www.tneppc.org/invasive_plants>

TX: Watershed Protection Development Review. City of Austin. Central Texas Invasive Plants. Volunteer Field Guide.

<<http://www.ci.austin.tx.us/growgreen/downloads/invasiveplants.pdf>>

VT: Vermont Invasive Exotic Plant Committee. 2005. Invasive Species Watch List for Vermont.

<<http://www.vtinvasiveplants.org/pdfs/VIEPC%20Invasive%20Watch%20List.pdf>>

List of invasive terrestrial plants known to be in Vermont or on our borders.

Developed by Vermont Invasive Exotic Plant Committee. In: Developing Invasive Plant Outreach and Management Projects. The Nature Conservancy

<<http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/vermont/chapter-1-23-for-web.pdf>>

VA: Virginia Native Plant Society. Department of Conservation and Recreation. 2009. Invasive Alien Plant Species of Virginia.

<http://www.dcr.virginia.gov/natural_heritage/documents/invlist.pdf>

WV: West Virginia Division of Natural Resources. Dirty Dozen.

<<http://www.wvdnr.gov/Wildlife/DirtyDozen.shtml>>

WI: Wisconsin Department of Natural Resources. Invasive Species. Terrestrial Invasives - Plants.

<<http://dnr.wi.gov/invasives/species.asp?filterBy=Terrestrial&filterVal=Y&catVal=Plants>>

Wisconsin Department of Natural Resources. Invasive Species. Aquatic Invasives - Plants.

<<http://dnr.wi.gov/invasives/species.asp?filterBy=Aquatic&filterVal=Y&catVal=Plants>>

3. 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.

4. 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.

5. Broecker, W.S. 1970. Man's oxygen reserve. *Science* 168: 1537-1538.

6. Hirabayashi, S. 2012. i-Tree Eco Precipitation Interception Model Descriptions, http://www.itreetools.org/eco/resources/iTree_Eco_Precipitation_Interception_Model_Descriptions_V1_2.pdf

7. 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://wcufrre.ucdavis.edu/products/cufr_43.pdf

8. 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.

9. Insect/disease proximity to study area was completed using the U.S. Forest Service's Forest Health Technology Enterprise Team (FHTET) database. Data includes distribution of pest by county FIPs code for 2004-2009. FHTET range maps are available at www.foresthealth.info for 2006-2010.

10. Kruse, James; Ambourn, Angie; Zogas, Ken 2007. Aspen Leaf Miner. Forest Health Protection leaflet. R10-PR-14. United States Department of Agriculture, Forest Service, Alaska Region. Can be accessed through: http://www.fs.fed.us/r10/spf/fhp/leaflets/aspen_leaf_miner.pdf

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

12. Houston, David R.; O'Brien, James T. 1983. Beech Bark Disease. Forest Insect & Disease Leaflet 75. United States Department of Agriculture, Forest Service. 8 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-75.pdf>

13. Ostry, M.E.; Mielke, M.E.; Anderson, R.L. 1996. How to Identify Butternut Canker and Manage Butternut Trees. United States Department of Agriculture, Forest Service, North Central Forest Experiment Station. Can be accessed through: http://www.na.fs.fed.us/spfo/pubs/howtos/ht_but/ht_but.htm

14. Diller, Jesse D. 1965. Chestnut Blight. Forest Pest Leaflet 94. United States Department of Agriculture, Forest Service. 7 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-94.pdf>

15. Mielke, Manfred E.; Daughtrey, Margery L. How to Identify and Control Dogwood

Anthracnose. NA-GR-18. United States Department of Agriculture, Forest Service, Northeastern Area. Can be accessed through:
http://na.fs.fed.us/spfo/pubs/howtos/ht_dogwd/ht_dog.htm

16. Northeastern Area State and Private Forestry. 1998. HOW to identify and manage Dutch Elm Disease. NA-PR-07-98. Newtown 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

17. Schmitz, Richard F.; Gibson, Kenneth E. 1996. Douglas-fir Beetle. Forest Insect & Disease Leaflet 5. R1-96-87. United States Department of Agriculture, Forest Service. 8 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-5.pdf>

18. Northeastern Area State and Private Forestry. 2005. Forest health protection emerald ash borer home. Newtown 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>

19. Ferrell, George T. 1986. Fir Engraver. Forest Insect & Disease Leaflet 13. United States Department of Agriculture, Forest Service. 8 p. Can be accessed through:
<http://www.fs.fed.us/r6/nr/fid/fidls/fidl-13.pdf>

20. Phelps, W.R.; Czabator, F.L. 1978. Fusiform Rust of Southern Pines. Forest Insect & Disease Leaflet 26. United States Department of Agriculture, Forest Service. 7 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-26.pdf>

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

22. Society of American Foresters. Gold Spotted Oak Borer Hitches Ride in Firewood, Kills California Oaks. Forestry Source. October 2011 Vol. 16, No.10.

23. USDA Forest Service. 2005. Hemlock Woolly Adelgid. Pest Alert. NA-PR-09-05. United States Department of Agriculture, Forest Service, Northern Area State and Private Forestry. Can be accessed through: http://na.fs.fed.us/spfo/pubs/pest_al/hemlock/hwa05.htm

24. Smith, Sheri L.; Borys, Robert R.; Shea, Patrick J. 2009. Jeffrey Pine Beetle. Forest Insect & Disease Leaflet 11. United States Department of Agriculture, Forest Service. 8 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-11.pdf>

25. Ciesla, William M.; Kruse, James J. 2009. Large Aspen Tortrix. Forest Insect & Disease Leaflet 139. United States Department of Agriculture, Forest Service. 8 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-139.pdf>

26. Laurel Wilt. United States Department of Agriculture, Forest Service, Forest Health Protection, Southern Region. Can be accessed through:
<http://www.fs.fed.us/r8/foresthealth/laurelwilt/>

27. Gibson, Ken; Kegley, Sandy; Bentz, Barbara. 2009. Mountain Pine Beetle. Forest Insect & Disease Leaflet 2. United States Department of Agriculture, Forest Service. 12 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-2.pdf>
28. Burnside, R.E. et al. 2011. Northern Spruce Engraver. Forest Insect & Disease Leaflet 180. United States Department of Agriculture, Forest Service. 12 p.
29. Rexrode, Charles O.; Brown, H. Daniel 1983. Oak Wilt. Forest Insect & Disease Leaflet 29. United States Department of Agriculture, Forest Service. 6 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-29.pdf>
30. Liebhold, A. 2010 draft. Geographical Distribution of Forest Pest Species in US. In: *Frontiers in Ecology and the Environment*.
31. Ciesla, William M. 2001. *Tomicus piniperda*. North American Forest Commission. Exotic Forest Pest Information System for North America (EXFOR). Can be accessed through: <http://spfnic.fs.fed.us/exfor/data/pestreports.cfm?pestidval=86&langdisplay=english>
32. Holsten, E.H.; Thier, R.W.; Munson, A.S.; Gibson, K.E. 1999. The Spruce Beetle. Forest Insect & Disease Leaflet 127. United States Department of Agriculture, Forest Service. 12 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-127.pdf>
33. Kucera, Daniel R.; Orr, Peter W. 1981. Spruce Budworm in the Eastern United States. Forest Pest Leaflet 160. United States Department of Agriculture, Forest Service. 8 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-160.pdf>
34. Kliejunas, John. 2005. *Phytophthora ramorum*. North American Forest Commission. Exotic Forest Pest Information System for North America (EXFOR). Can be accessed through: <http://spfnic.fs.fed.us/exfor/data/pestreports.cfm?pestidval=62&langdisplay=english>
35. Clarke, Stephen R.; Nowak, J.T. 2009. Southern Pine Beetle. Forest Insect & Disease Leaflet 49. United States Department of Agriculture, Forest Service. 8 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-49.pdf>
36. Haugen, Dennis A.; Hoebeke, Richard E. 2005. *Sirex* woodwasp - *Sirex noctilio* F. (Hymenoptera: Siricidae). Pest Alert. NA-PR-07-05. United States Department of Agriculture, Forest Service, Northern Area State and Private Forestry. Can be accessed through: http://na.fs.fed.us/spfo/pubs/pest_al/sirex_woodwasp/sirex_woodwasp.htm
37. Seybold, Steven ; Haugen, Dennis; Graves, Andrew. 2010. Thousand Cankers Disease- Pest Alert. NA-PR-02-10. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry.
Cranshaw, W. and N. Tisserat. c. 2009. Walnut twig beetle and the thousand cankers disease of black walnut. Pest Alert. Colorado State University.
http://www.ext.colostate.edu/pubs/insect/0812_alert.pdf
38. DeMars Jr., Clarence J.; Roettgering, Bruce H. 1982. Western Pine Beetle. Forest Insect &

Disease Leaflet 1. United States Department of Agriculture, Forest Service. 8 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-1.pdf>

39. Nicholls, Thomas H.; Anderson, Robert L. 1977. How to Identify White Pine Blister Rust and Remove Cankers. United States Department of Agriculture, Forest Service, North Central Research Station. Can be accessed through: http://na.fs.fed.us/spfo/pubs/howtos/ht_wpblister/toc.htm

40. Fellin, David G.; Dewey, Jerald E. 1986. Western Spruce Budworm. Forest Insect & Disease Leaflet 53. United States Department of Agriculture, Forest Service. 10 p. Can be accessed through: <http://www.fs.fed.us/r6/nr/fid/fidls/fidl-53.pdf>

41. 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>.

42. Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Hoehn, R.E. 2005. The urban forest effects (UFORE) model: field data collection manual. V1b. Newtown 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

43. 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. *Arboric. Urb. For.* 34(6): 347-358.

44. 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.

45. Interagency Working Group on Social Cost of Carbon, United States Government. 2010 Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866. <http://www.epa.gov/oms/climate/regulations/scc-tds.pdf>

46. Nowak, David J., Hoehn, R., and Crane, D. 2007. Oxygen production by urban trees in the United States. *Arboriculture & Urban Forestry* 33(3):220-226.

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

48. 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.

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

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

51. 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.

52. 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.

53. Hirabayashi, S., C. Kroll, and D. Nowak. 2012. i-Tree Eco Dry Deposition Model Descriptions V 1.0

54. Hirabayashi, S. 2011. Urban Forest Effects-Dry Deposition (UFORE-D) Model Enhancements, [http://www.itreetools.org/eco/resources/UFORE-D enhancements.pdf](http://www.itreetools.org/eco/resources/UFORE-D%20enhancements.pdf)

55. Davidson, K., A. Hallberg, D. McCubbin, and B. Hubbell. (2007). Analysis of PM_{2.5} Using the Environmental Benefits Mapping and Analysis Program (BenMAP). *Journal of Toxicology and Environmental Health, Part A* 70(3): 332-346.

56. 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.

57. U.S. Forest Service. *Tree Guides*.
http://www.fs.fed.us/psw/programs/uesd/uep/tree_guides.php

McPherson, E.G., Simpson, J.R., Peper, P.J., Xiao, Q. 1999. *Tree Guidelines for San Joaquin Valley Communities*. Local Government Commission, Sacramento, CA.

McPherson, E.G., Simpson, J.R., Peper, P.J., Scott, K.I., Xiao, Q. 2000. *Tree Guidelines for Coastal Southern California Communities*. Local Government Commission, Sacramento, CA.

McPherson, E.G., Simpson, J.R., Peper, P.J., Xiao, Q., Pittenger, D.R., Hodel, D.R.. 2001. *Tree Guidelines for Inland Empire Communities*. Local Government Commission, Sacramento, CA.

McPherson, E.G., Maco, S.E., Simpson, J.R., Peper, P.J., Xiao, Q., VanDerZanden, A.M., Bell, N. 2002. *Western Washington and Oregon Community Tree Guide: Benefits, Costs, and Strategic Planting*. International Society of Arboriculture, Pacific Northwest, Silverton, OR.

McPherson, E.G., Simpson, J.R., Peper, P.J., Xiao, Q., Maco, S.E., Hoefler, P.J. 2003. *Northern Mountain and Prairie Community Tree Guide: Benefits, Costs and Strategic Planting*. Center for Urban Forest Research, USDA Forest Service, Pacific Southwest Research Station, Albany, CA.

McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., Xiao Q., Mulrean, E. 2004. *Desert*

Southwest Community Tree Guide: Benefits, Costs and Strategic Planting. Phoenix, AZ: Arizona Community Tree Council, Inc. 81 :81.

McPherson, E.G., Simpson, J.R., Peper, P.J., Gardner, S.L., Vargas, K.E., Maco, S.E., Xiao, Q. 2006a. Coastal Plain Community Tree Guide: Benefits, Costs, and Strategic Planting PSW-GTR-201. USDA Forest Service, Pacific Southwest Research Station, Albany, CA.

McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., Gardner, S.L., Vargas, K.E., Xiao, Q. 2006b. Piedmont Community Tree Guide: Benefits, Costs, and Strategic Planting PSW-GTR 200. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., Gardner, S.L., Cozad, S.K., Xiao, Q. 2006c. Midwest Community Tree Guide: Benefits, Costs and Strategic Planting PSW-GTR-199. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

McPherson, E.G., Simpson, J.R., Peper, P.J., Gardner, S.L., Vargas, K.E., Xiao, Q. 2007. Northeast community tree guide: benefits, costs, and strategic planting.

McPherson, E.G., Simpson, J.R., Peper, P.J., Crowell, A.M.N., Xiao, Q. 2010. Northern California coast community tree guide: benefits, costs, and strategic planting. PSW-GTR-228. Gen. Tech. Rep. PSW-GTR-228. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Peper, P.J., McPherson, E.G., Simpson, J.R., Vargas, K.E., Xiao Q. 2009. Lower Midwest community tree guide: benefits, costs, and strategic planting. PSW-GTR-219. Gen. Tech. Rep. PSW-GTR-219. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Peper, P.J., McPherson, E.G., Simpson, J.R., Albers, S.N., Xiao, Q. 2010. Central Florida community tree guide: benefits, costs, and strategic planting. Gen. Tech. Rep. PSW-GTR-230. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Vargas K.E., McPherson E.G., Simpson J.R., Peper P.J., Gardner S.L., Xiao Q. 2007a. Temperate Interior West Community Tree Guide: Benefits, Costs, and Strategic Planting.

Vargas K.E., McPherson E.G., Simpson J.R., Peper P.J., Gardner S.L., Xiao Q. 2007b. Interior West Tree Guide.

Vargas, K.E., McPherson, E.G., Simpson, J.R., Peper, P.J., Gardner, S.L., Xiao Q. 2008. Tropical community tree guide: benefits, costs, and strategic planting. PSW-GTR-216. Gen. Tech. Rep. PSW-GTR-216. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

58. Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Ibarra, M. 2002. Brooklyn's Urban Forest. Gen.

Tech. Rep. NE-290. Newtown 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. *J. Arboric.* 28(4): 194-199.

59. 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.

60. 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.

61. 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 NO_x power plant emission per kWh from: U.S. Environmental Protection Agency. U.S. Power Plant Emissions Total by Year 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, NO_x, 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 (tons)
from: Residential Wood Burning Emissions in British Columbia, 2005.

http://www.env.bc.ca/air/airquality/pdfs/wood_emissions.pdf.

Emissions per dry ton 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>

62. 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

63. 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.