I-Tree Eco Analysis for Downtown and Suburban Areas of Bath, Maine

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Manomet
Center for Conservation Sciences

 | 14 Maine Street, Suite 410, Brunswick, ME 04011 | www.manomet.org

i-Tree Analysis completed by Andrew Whitman and Ryan Wynne.

Report text and figures generated by i-Tree with additional information supplied by Ethel Wilkerson

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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 Bath's urban forest was conducted during 2013. Data collected from 48 field plots located throughout the downtown and suburban area of Bath were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station. The developed area of Bath is 2.2mi^2.[1] The sampled plots measured 0.274 mi^2, 12.5% of the total developed area. Because plots were selected randomly calculations from the i-Tree model can be extrapolated to estimate contribution of trees across the entire developed area of Bath.

	Plots (0.27 mi2)	Urban and Suburban Area (2.2 mi2)
Number of trees (total)	1870	15015
Tree cover (%)	37.2	--
Tree Per Acre	18.8	--
Pollution removal (tons/year)	1	8.0
Pollution removal (thousand $/yr)	3.2	25.8
Carbon Storage (tons)	1290	10357.7
Carbon Storage (thousand $)	92	738.7
Carbon Sequestration (tons/year)	26	208.8
Carbon Sequestration (thousand $/yr)	1.8	14.8
Oxygen production (tons/year)	39	313.1
Avoided runoff (ft3/yr)	12600	101167.9
Avoided runoff ($/yr)	837	6720.4
Structural values (million $)	4.5	36.5

Ton: short ton (U.S.) (2,000 lbs)
Carbon storage: the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation
Carbon sequestration: the removal of carbon dioxide from the air by plants
Carbon storage and carbon sequestration values are calculated based on $71 per 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 $1136 per ton (carbon monoxide), $1428 per ton (ozone),$133 per ton (nitrogen dioxide), $58 per ton (sulfur dioxide), $7165 per ton (particulate matter less than 10 microns and greater than 2.5 microns), $64646 per ton (particulate matter less than 2.5 microns)
Energy saving value is calculated based on the prices of $158.9 per MWH and $15.71 per MBTU
Monetary values ($) are reported in US Dollars throughout the report except where noted

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[1] Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77(9):858-864.

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I. Tree Characteristics of the Urban Forest

The urban forest of Bath, Maine has an estimated 15,000 trees with a tree cover of 37.2 percent. Trees that have diameters less than 6-inches (15.2 cm) constitute 22.3 percent of the population. The three most common species are Norway maple (46.7 percent), Northern white cedar (8.9 percent), and Apple spp (6.7 percent).

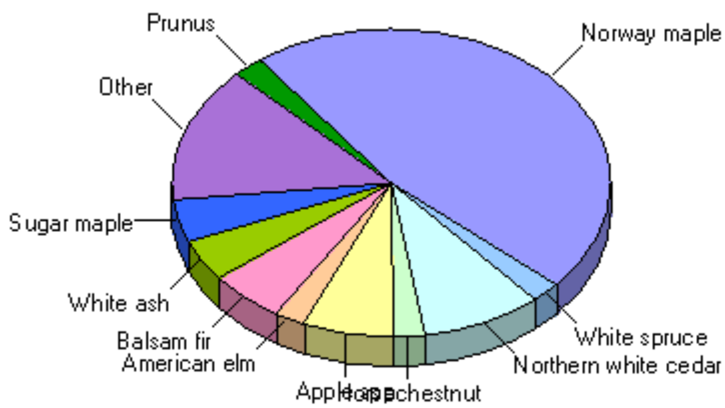


Figure 1. Tree species composition in Bath

The overall tree density in Bath's is 18.8 trees/acre (see Appendix III for comparable values from other cities).

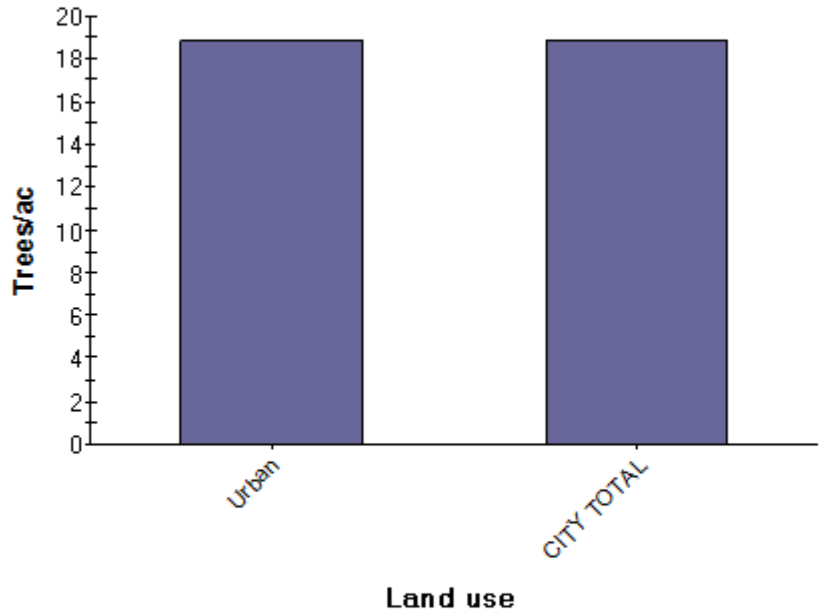


Figure 2. Number of trees/ac in Bath's by land use

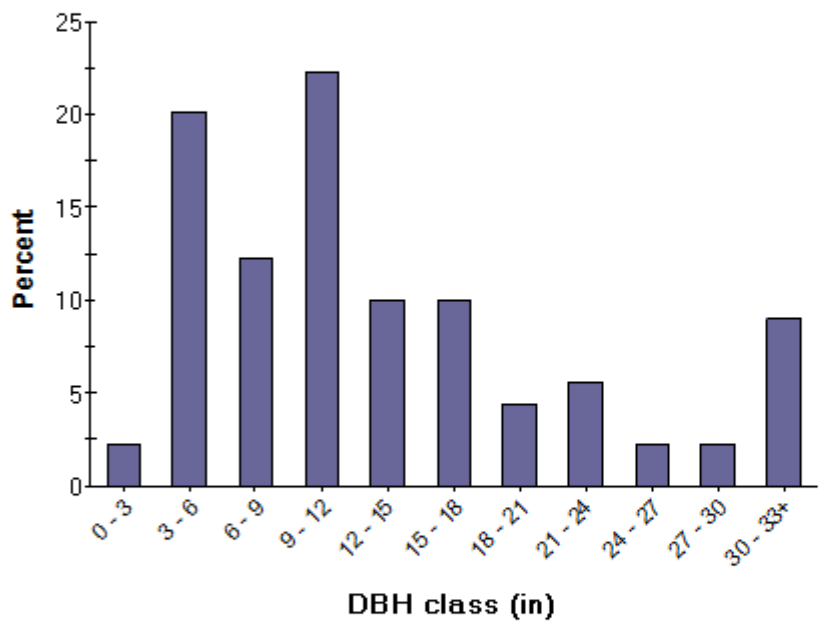


Figure 3. Percent of tree population by diameter class (DBH=stem diameter at 4.5 feet)

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 Bath's urban forest, about 35 percent of the trees are species native to North America, while 33 percent are native to the state or district. Species exotic to North America make up 65 percent of the population. Most exotic tree species have an origin from Europe & Asia (50 percent of the species).

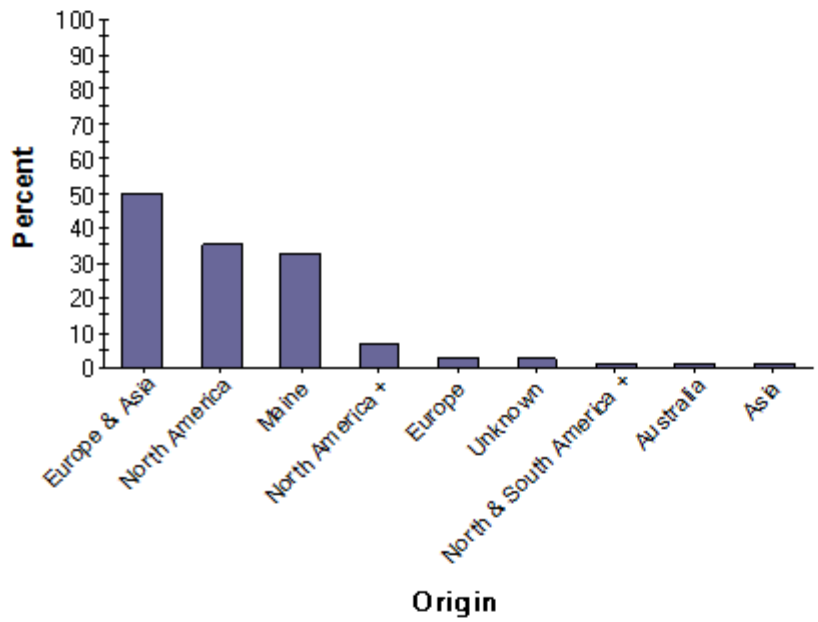


Figure 4. Percent of live trees by species origin

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]. Zero of the 21 tree species sampled in Bath is identified as invasive on the state invasive species list [2].

II. Urban Forest Cover and Leaf Area

Many tree benefits equate directly to the amount of healthy leaf surface area of the plant. In Bath, the most dominant species in terms of leaf area are Norway maple, White ash, and American elm. Trees cover about 37.2 percent of Bath's urban and suburban core.

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 Bath

Species Name	*Percent Population*	*Percent Leaf Area*	*IV*
Norway maple	46.7	51.0	97.6
White ash	4.4	11.7	16.2
Sugar maple	4.4	6.4	10.8
American elm	2.2	7.9	10.1
Northern white cedar	8.9	0.6	9.5
Littleleaf linden	2.2	6.4	8.6
Apple spp	6.7	1.1	7.8
Horsechestnut	2.2	5.1	7.4
Balsam fir	5.6	1.3	6.8
Northern red oak	2.2	1.9	4.2

The most dominant ground cover types are Tar (27.6 percent) and Grass (24.8 percent).

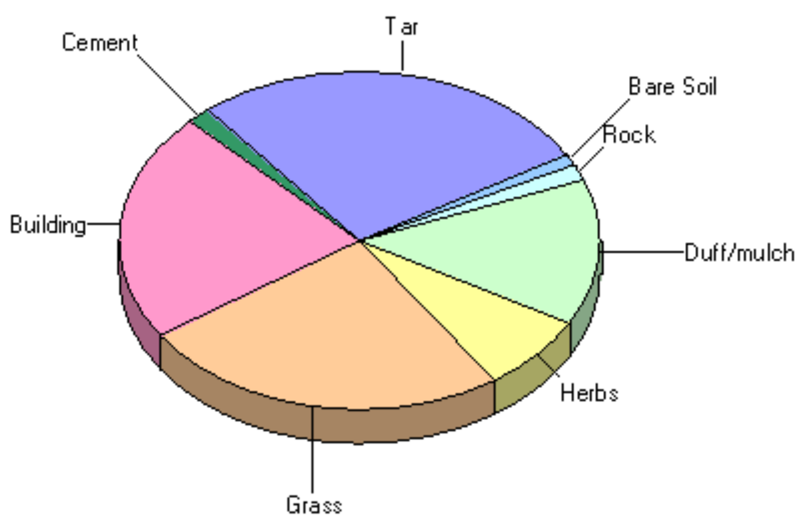


Figure 5. Percent ground cover in Bath

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 Bath's urban and suburban core was estimated using field data and recent available pollution and weather data. Pollution removal was greatest for ozone. Within the 0.27mi^2 sampling area, it is estimated that trees and shrubs remove 1 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 $2.62 thousand (see Appendix I for more details). Across the entire 2.2mi^2 urban and suburban areas of Bath, it was calculated that trees and shrubs remove 8 tons of air pollution per year with an value of $25.8 thousand to the community.

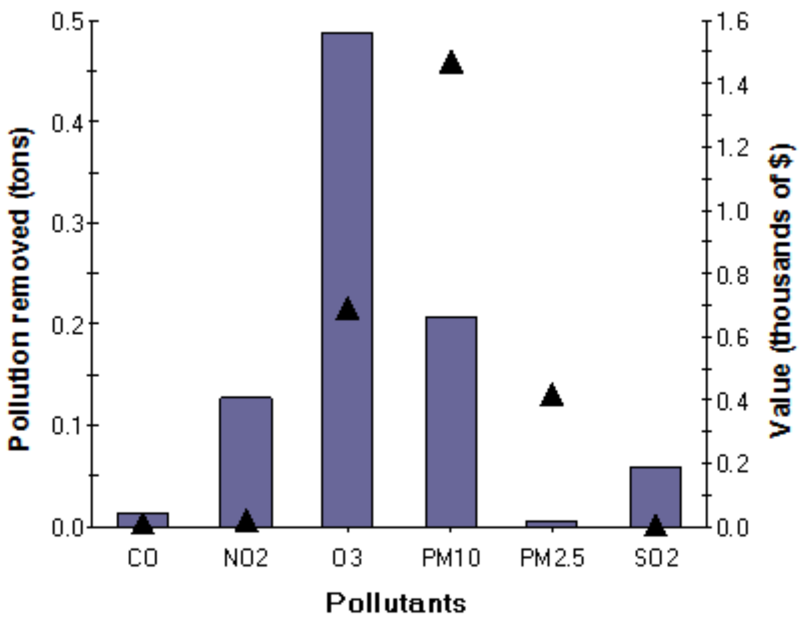


Figure 6. Pollution removal (bars) and associated value (points) for trees in .027 mi2 sampling area

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 $1136 per ton (carbon monoxide), $1428 per ton (ozone),$133 per ton (nitrogen dioxide), $58 per ton (sulfur dioxide), $7165 per ton (particulate matter less than 10 microns and greater than 2.5 microns), $64646 per 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 trees within the 0.27mi^2 sampling area is about 26 tons of carbon per year with an associated value of $1.84 thousand. Net carbon sequestration in the urban forest is about 15 tons. Extrapolated across the 2.2mi^2 urban and suburban area the urban forest sequesters 26 tons of carbon per year with an associated value of $14.8 thousand. Net carbon sequestration is 10,358 tones. Carbon storage and carbon sequestration values are calculated based on $71 per ton (see Appendix I for more details).

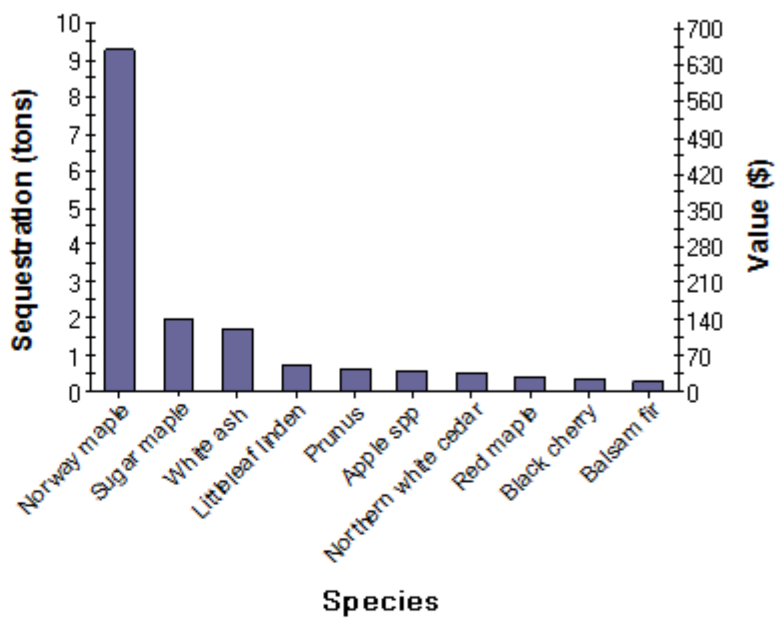


Figure 7. Carbon sequestration and value for species with greatest overall carbon sequestration in Bath sampling area

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 Bath sample area are estimated to store 1,290 tons of carbon ($92.0 thousand). Of all the species sampled, Norway maple stores and sequesters the most carbon (approximately 23.7% of the total carbon stored and 63.4% 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 Bath's are estimated to produce 39 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 (tons)*	*Net Carbon Sequestration (tons/yr)*	*Number of trees*	Leaf Area (square miles)
Norway maple	24.66	9.25	872.00	0.09
Sugar maple	5.20	1.95	83.00	0.01
White ash	4.50	1.69	83.00	0.02
Littleleaf linden	1.97	0.74	42.00	0.01
Prunus	1.70	0.64	42.00	0.00
Apple spp	1.50	0.56	125.00	0.00
Northern white cedar	1.38	0.52	166.00	0.00
Red maple	1.00	0.37	21.00	0.00
Black cherry	0.85	0.32	21.00	0.00
Balsam fir	0.76	0.29	104.00	0.00
Pear spp	0.59	0.22	21.00	0.00
Paper birch	0.41	0.15	21.00	0.00
Plum spp	0.38	0.14	21.00	0.00
Willow acacia	0.24	0.09	21.00	0.00
Butternut	0.18	0.07	21.00	0.00
Horsechestnut	0.15	0.06	42.00	0.01
Hinoki cypress	0.12	0.04	21.00	0.00
Baldcypress	0.03	0.01	21.00	0.00
American elm	-0.32	-0.12	42.00	0.01
White spruce	-0.91	-0.34	42.00	0.00

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 in the 0.27mi^2 sampling area help to reduce runoff by an estimated 12,600 cubic feet a year with an associated value of $837 (see Appendix I for more details). Extrapolated across the urban and suburban area of Bath trees reduce runoff by an estimated 101,168 cubic feet a year with an associated value of $6720.

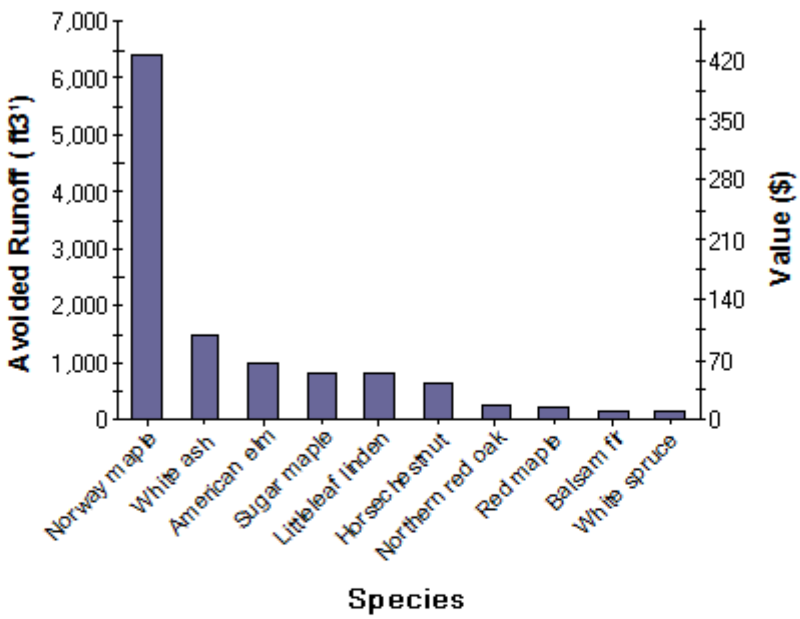


Figure 8. Avoided runoff and value for species with greatest overall impact on runoff in Bath sampling area

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.

<u>Structural values (within the 0.27mi^2 sampling area):</u>

- Structural value: $4.54 million
- Carbon storage: $92.0 thousand

<u>Annual functional values (within the 0.27mi^2 sampling area):</u>

- Carbon sequestration: $1.84 thousand
- Pollution removal: $2.62 thousand

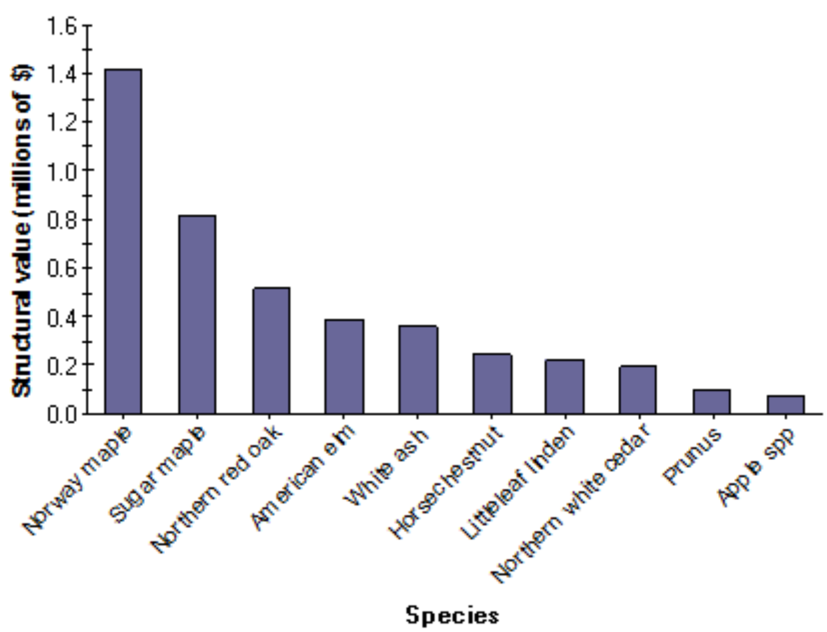


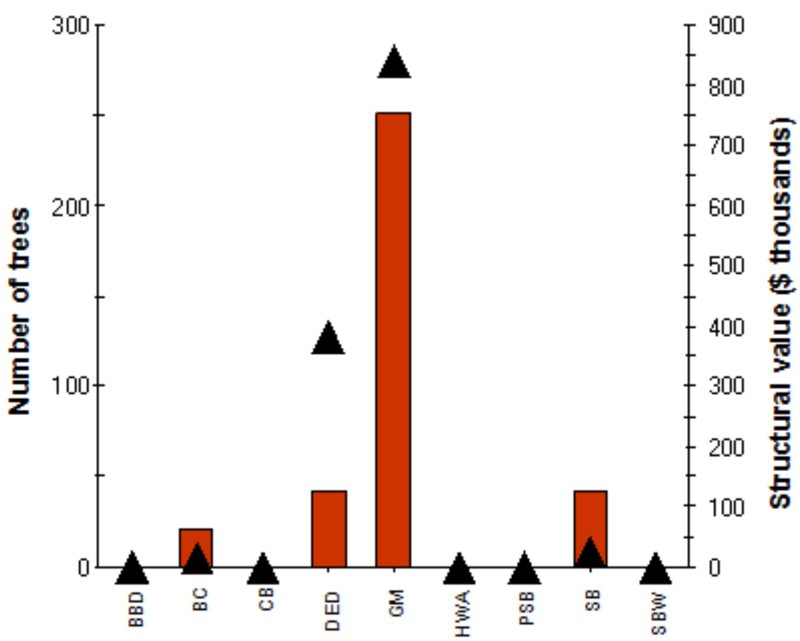
Figure 9. Structural value of the 10 most valuable tree species in Bath sampling area

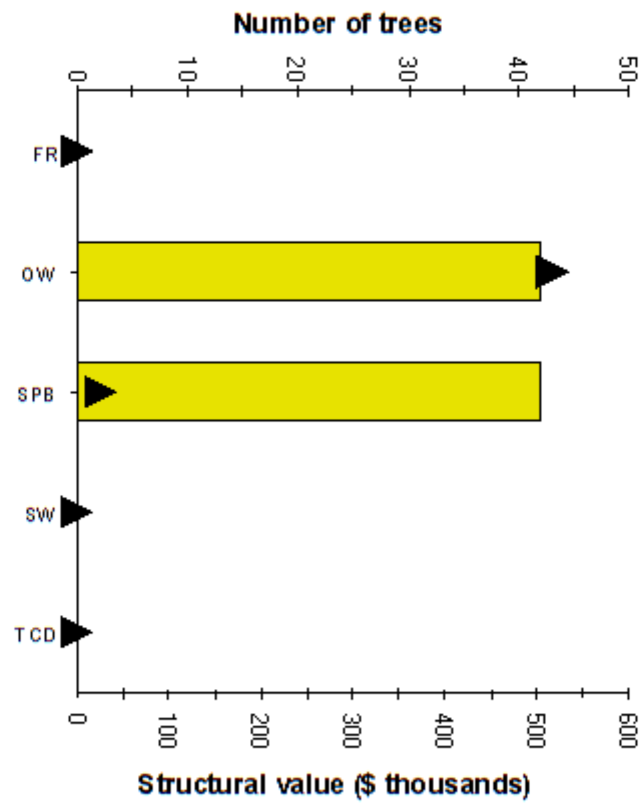
IX. Potential Pest Impacts

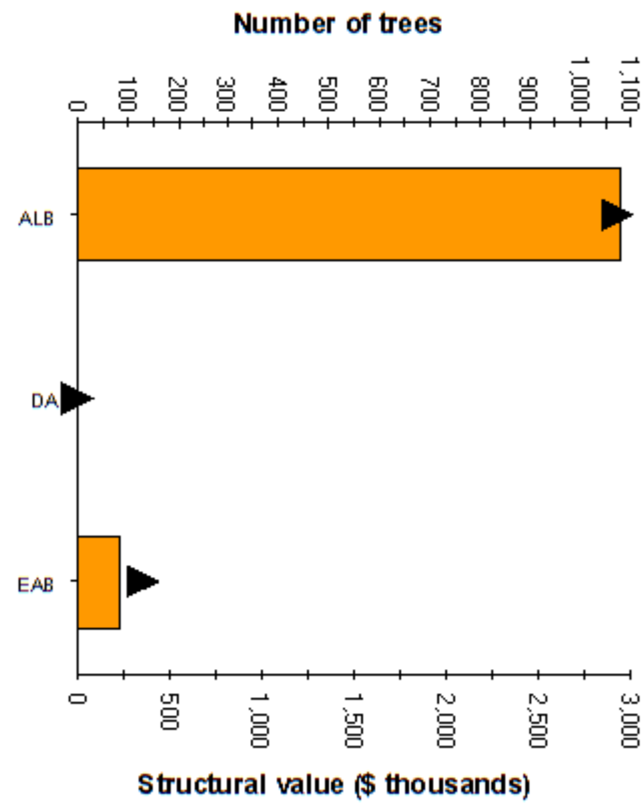
Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. As pests tend to have differing tree hosts, the potential damage or risk of each pest will differ among cities. Thirty-one pests were analyzed for their 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.

Pests currently present in Androscoggin Co that may damage urban trees include gypsy moth (GM, 15.4% of Bath's trees are susceptible), Dutch elm disease (DED, 2.2% of Bath's trees are susceptible, and butternut canker (BC, 1.1% of Bath's trees are susceptible).

Pests found in the region but are not yet present in Bath include Asian longhorn beetle (ALB) and emerald ash borer (EAB). ALB has the potential to damage or kill more than 57.5% of urban trees in Bath and 4.4% of Bath's urban trees are susceptible to EAB.




Number of trees
0
10
20
30
40
50
FR
OW
SPB
SW
TCD
0
100
200
300
400
500
600
Structural value ($ thousands)


Number of trees
0
100
200
300
400
500
600
700
800
900
1,000
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ALB
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EAB
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2,500
3,000
Structural value ($ thousands)

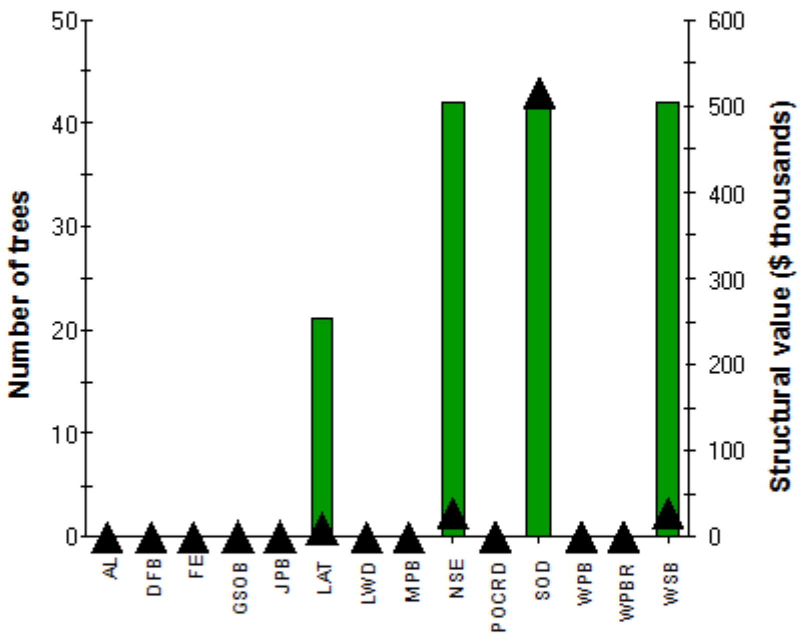

Figure 10. Number of susceptible trees and structural value by pest within the 0.27mi^2 sampling area

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 0.0 percent of the population ($0 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 57.7 percent of the Bath's urban forest, which represents a potential loss of $2.93 million in structural value.

Beech Bark Disease (BBD) [12] is an insect-disease complex that primarily impacts American beech. This disease threatens 0.0 percent of the population, which represents a potential loss of $0 in structural value.

Butternut Canker (,) [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 1.1 percent ($13.9 thousand 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 0.0 percent of the population, which represents a potential loss of $0 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, Bath's could possibly lose 2.2 percent of its trees to this pest ($382 thousand 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 4.4 percent of the population ($356 thousand 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 Bath's 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 13.4 percent of the population, which represents a potential loss of $841 thousand 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 0.0 percent of the population ($0 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 21 percent of the Bath's urban forest, which represents a potential loss of $10.1 thousand 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 0.0 percent of the population ($0 in structural value).

The Northern Spruce Engraver (NSE) [28] has had a significant impact on the boreal and subboreal forests of North America where the pest's distribution overlaps with the range of its major hosts. Potential loss of trees from NSE is 42 ($25.9 thousand 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 2.2 percent of the Bath's urban forest, which represents a potential loss of $516 thousand 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 0.0 percent of the population ($0 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 42 ($25.9 thousand 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 Bath's 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 42 ($516 thousand 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 2.2 percent of the population, which represents a potential loss of $25.9 thousand in structural value.

The Sirex Wood Wasp (SW) [36] is a wood borer that primarily attacks pine species. SW poses a threat to 0.0 percent of the Bath's urban forest, which represents a potential loss of $0 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 2.2 percent of the population, which represents a potential loss of $25.9 thousand 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 0.10 acre 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 O_2 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 Bath's 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].

Within the 0.27mi^2 sampling area:

<u>Carbon storage is equivalent to:</u>
• Amount of carbon emitted in Bath's in 9 days
• Annual carbon (C) emissions from 775 automobiles
• Annual C emissions from 389 single-family houses

<u>Carbon monoxide removal is equivalent to:</u>
• Annual carbon monoxide emissions from 0 automobiles
• Annual carbon monoxide emissions from 0 single-family houses

<u>Nitrogen dioxide removal is equivalent to:</u>
• Annual nitrogen dioxide emissions from 8 automobiles
• Annual nitrogen dioxide emissions from 5 single-family houses

<u>Sulfur dioxide removal is equivalent to:</u>
• Annual sulfur dioxide emissions from 86 automobiles
• Annual sulfur dioxide emissions from 1 single-family houses

<u>Particulate matter less than 10 micron (PM10) removal is equivalent to:</u>
• Annual PM10 emissions from 565 automobiles
• Annual PM10 emissions from 55 single-family houses

<u>Annual carbon sequestration is equivalent to:</u>
• Amount of carbon emitted in Bath's in 0.2 days
• Annual C emissions from 0 automobiles
• Annual C emissions from 0 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 (tons)*	*Carbon Sequestration (tons/yr)*	*Pollution removal (tons/yr)*
Calgary, Canada	7.2	11,889,000	445,000	21,422	326
Atlanta, GA	36.8	9,415,000	1,345,000	46,433	1,662
Toronto, Canada	20.5	7,542,000	992,000	40,345	1,212
New York, NY	21.0	5,212,000	1,351,000	42,283	1,677
Baltimore, MD	21.0	2,627,000	596,000	16,127	430
Philadelphia, PA	15.7	2,113,000	530,000	16,115	576
Washington, DC	28.6	1,928,000	523,000	16,148	418
Boston, MA	22.3	1,183,000	319,000	10,509	284
Woodbridge, NJ	29.5	986,000	160,000	5561.00	210
Minneapolis, MN	26.5	979,000	250,000	8,895	305
Syracuse, NY	23.1	876,000	173,000	5,425	109
Morgantown, WV	35.9	661,000	94,000	2,940	66
Moorestown, NJ	28.0	583,000	117,000	3,758	118
Jersey City, NJ	11.5	136,000	21,000	890	41
Freehold, NJ	34.4	48,000	20,000	545	21
Bath, ME	37.2	15,000	10,000	209	8

II. Per acre values of tree effects

City	*No. of trees*	*Carbon storage (tons)*	*Carbon sequestration (tons/yr)*	*Pollution removal (tons/yr)*
Calgary, Canada	66.7	2.5	0.120	3.6
Atlanta, GA	111.6	15.9	0.550	39.4
Toronto, Canada	48.3	6.4	0.258	15.6
New York, NY	26.4	6.8	0.214	17.0
Baltimore, MD	50.8	11.5	0.312	16.6
Philadelphia, PA	25.0	6.3	0.190	13.6
Washington, DC	49.0	13.3	0.410	21.2
Boston, MA	33.5	9.0	0.297	16.0
Woodbridge, NJ	66.5	10.8	0.375	28.4
Minneapolis, MN	26.2	6.7	0.238	16.4
Syracuse, NY	54.5	10.8	0.338	13.6
Morgantown, WV	119.7	17.0	0.532	23.8
Moorestown, NJ	62.0	12.5	0.400	25.2
Jersey City, NJ	14.3	2.2	0.094	8.6
Freehold, NJ	38.5	16.0	0.437	33.6
Bath, ME	18.8	7.4	0.148	0.01

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 VII. Potential risk of pests

Based on the host tree species for each pest and the current range of the pest [13], it is possible to determine what the risk is that each tree species sampled in the urban forest could be attacked by an insect or disease.

Spp Risk AL ALB BBD BC CB DA DED DFB EAB FE FR GM GSOB HWA JPB LAT LWD MPB NSE OW POCRD PSB SB SBW SOD SPB SW TCD WPB WPBR WSB

			Pest																														
Spp. Risk	**Risk Weight**	**Species Name**	**AL**	**ALB**	**BBD**	**BC**	**CBA**	**DA**	**DED**	**DFB**	**EAB**	**FE**	**FR**	**GM**	**GSOB**	**HWA**	**JPB**	**LAT**	**LWD**	**MPB**	**NSE**	**OW**	**POCRD**	**PSB**	**SB**	**SBW**	**SOD**	**SPB**	**SW**	**TCD**	**WPB**	**WPBR**	**WSB**
	8	Paper birch																															
	8	White spruce																															
	7	American elm																															
	7	Northern red oak																															
	4	Apple spp																															
	4	Butternut																															
	4	Littleleaf linden																															
	4	Pear spp																															
	3	Horsechestnut																															
	3	Norway maple																															
	3	Red maple																															
	3	Sugar maple																															
	3	White ash																															

Note:
Species that are not listed in the matrix are not known to be hosts to any of the pests analyzed.

Species Risk:

- Red indicates that tree species is at risk to at least one pest within county
- Orange indicates that tree species has no risk to pests in county, but has a risk to at least one pest within 250 miles from the county
- Yellow indicates that tree species has no risk to pests within 250 miles of county, but has a risk

to at least one pest that is 250 to 750 miles from the county

- Green indicates that tree species has no risk to pests within 750 miles of county, but has a risk to at least one pest that is greater than 750 miles from the county

Risk Weight:

Numerical scoring system based on sum of points assigned to pest risks for species. Each pest that could attack tree species is scored as 4 points if red, 3 points if orange, 2 points if yellow and 1 point if green.

Pest Color Codes:

- Red indicates pest is within Sagadahoc county
- Orange indicates pest is within 250 miles of Sagadahoc county
- Yellow indicates pest is within 750 miles of Sagadahoc county
- Green indicates pest is outside of these ranges

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