

The Benefits of K-State's Campus Creek Trees: A Pilot Assessment Using i-Tree Eco

i-Tree Academy Final Project

Jessica Canfield

Associate Professor
Landscape Architecture
Kansas State University

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Overview: This pilot application of i-Tree Eco is intended to be an example assessment for students in a future landscape architecture course. In fall 2021 it is anticipated that students in LAR705: Advanced Studio will update the existing 2014 Campus Tree Inventory, collecting more specific data, and re-run i-Tree Eco to create more accurate results.

Site Location: Manhattan, KS.

Data: In June 2014 two landscape architecture students conducted a field survey to develop a tree species inventory for the Campus Creek corridor. The survey was conducted in six distinct sub-areas. Only tree location and species type were recorded. For the purposes of this pilot assessment, data from Sections 1, 4, 5, and 6 were used. Fig.1 shows the spatial extent of Sections 1, 4, 5, and 6 in the Campus Creek corridor, totaling 27.44 acres. Table 1 lists the area of each section.

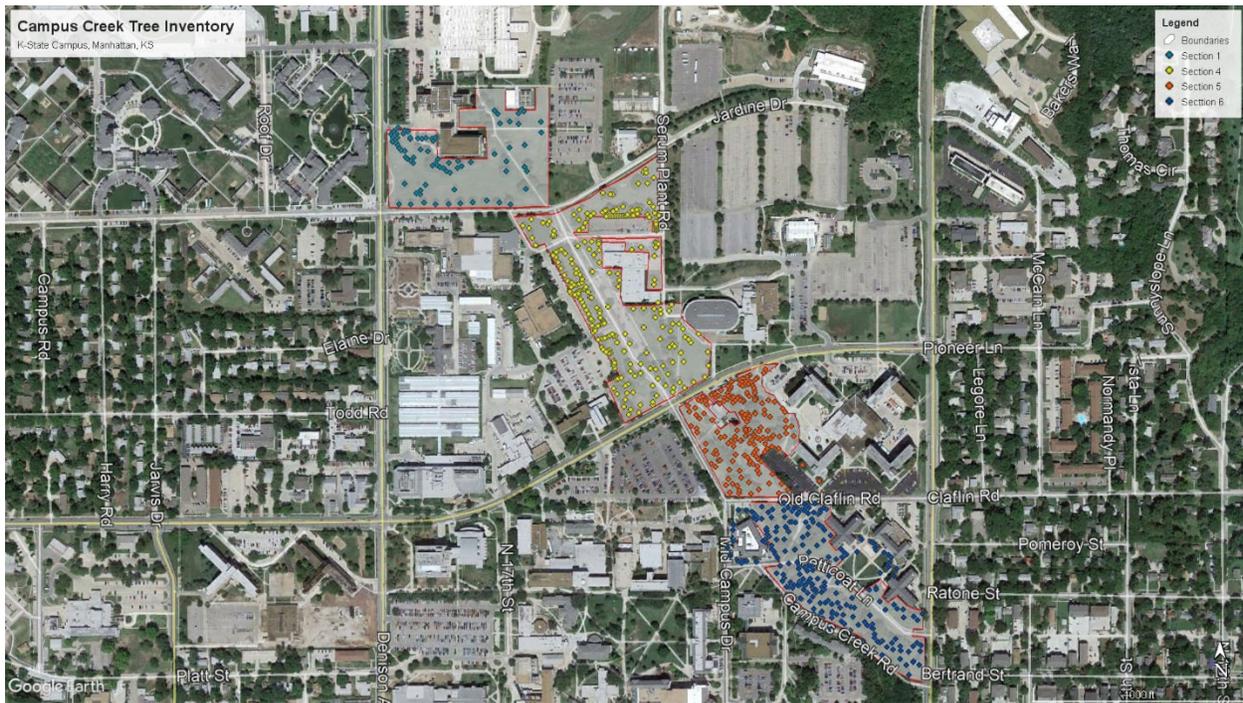


Figure 1: Aerial image of Campus Creek Tree Inventory with section boundaries

Table 1: Area totals of Campus Creek Tree Inventory section boundaries

Section	Acres
1	6.94
4	9.7
5	4.49
6	6.31
TOTAL	27.44

Limitations:

- DBH: Because the existing data only included tree location and species, an average DBH was assigned for each species type (see Table 2). This number was estimated based on a simple visual assessment and cross referenced with USDA species guides.
- Canopy Condition: The trees within the Campus Creek corridor are mostly mature in moderate to good health. Because tree crown health data was not available, the default 13 percent dieback was used.
- Pollution: No pollution data was available for the site location, so this portion of the assessment was null.
- A total of 762 trees were input into i-Tree Eco, however 26 entries were not found within the data base, thus 736 trees were analyzed.

Table 2: Assigned DBH in inches by species type

DBH assigned (inches)	Sci_Name	Comm_Name
24	Acer saccharinum	Silver Maple
6	Acer buergerianum	Trident Maple
4	Acer ginnala	Amur Maple
4	Acer griseum	Paperbark Maple
8	Acer negundo	Box Elder
10	Acer platanoides	Norway Maple
6	Acer rubrum	Red Maple
24	Acer saccharinum	Silver Maple
16	Acer saccharum	Sugar Maple
10	Aesculus flava	Yellow Buckeye
12	Alnus glutinosa	Black Alder
4	Amelanchier	Serviceberry
6	Betula nigra	River Birch
6	Carpinus caroliniana	American Hornbeam
8	Carya illinoensis	Pecan
10	Catalpa speciosa	Catalpa
14	Celtis occidentalis	Common Hackberry
4	Cercis canadensis	Eastern Redbud
4	Chionanthus retusus	Chinese Fringetree
4	Chionanthus virginicus	White Fringetree
4	Cornus asperifolia	Roughleaf Dogwood
4	Cornus mas	Corneliancherry Dogwood
2	Cotinus coggygria	Common Smoketree
4	Crataegus mollis	Downy Hawthorn
4	Crataegus phaenopyrum	Washington Hawthorn
6	Fagus sylvatica	Weeping Beech
14	Fraxinus americana	White Ash
14	Fraxinus pennsylvanica	Green Ash
12	Ginkgo biloba	Ginkgo
14	Gleditsia triacanthos	Honeylocust
12	Gymnocladus dioicus	Kentucky Coffeetree
14	Juglans nigra	Black Walnut
8	Juniperus virginiana	Eastern Redcedar
8	Koelreuteria paniculata	Panicled Goldenraintree
6	Liriodendron tulipifera	Tulip Tree
2	Lonicera maackii	Honeysuckle
10	Maclura pomifera	Osage Orange
6	Malus	Flowering Crabapple
10	Morus alba	White Mulberry
6	Nyssa sylvatica	Black Gum
6	Picea abies	Norway Spruce

6	<i>Picea pungens</i>	Colorado Spruce
6	<i>Picea sp.</i>	Spruce
12	<i>Pinus nigra</i>	Austrian Pine
10	<i>Pinus ponderosa</i>	Ponderosa Pine
8	<i>Pinus strobus</i>	Pine
10	<i>Pinus sylvestris</i>	Pine
24	<i>Platanus acerifolia</i>	London Planetree
18	<i>Platanus occidentalis</i>	Sycamore
24	<i>Populus deltoides</i>	Eastern Cottonwood
8	<i>Prunus serotina</i>	Black Cherry
8	<i>Pyrus calleryana</i>	Callery Pear
18	<i>Quercus alba</i>	White Oak
18	<i>Quercus bicolor</i>	Swamp White Oak
18	<i>Quercus imbricaria</i>	Shingle Oak
18	<i>Quercus macrocarpa</i>	Bur Oak
18	<i>Quercus muehlenbergii</i>	Chinkapin Oak
18	<i>Quercus muehlenbergii</i>	Chinkapin Oak
18	<i>Quercus palustris</i>	Pin Oak
18	<i>Quercus robur</i>	English Oak
18	<i>Quercus rubra</i>	Red Oak
18	<i>Quercus velutina</i>	Black Oak
4	<i>Rhamnus cathartica</i>	Common Buckthorn
8	<i>Robinia pseudoacacia</i>	Black Locust
6	Rubber Tree	Rubber Tree
10	<i>Salix alba</i>	White Willow
24	<i>Salix babylonica</i>	Willow Tree
8	<i>Sapindus drummondii</i>	Western Soapberry
10	<i>Styphnolobium japonicum</i>	Japanese Pagoda
8	<i>Syringa reticulata</i>	Japanese Tree Lilac
18	<i>Taxodium distichum</i>	Baldcypress
4	<i>Thuja orientalis</i>	Oriental Arborvitae
10	<i>Tilia americana</i>	American Linden
10	<i>Tilia cordata</i>	Littleleaf Linden
18	<i>Ulmus americana</i>	American Elm
10	<i>Ulmus parvifolia</i>	Lacebark Elm
12	<i>Ulmus pumila</i>	Siberian Elm
8	<i>Zelkova serrata</i>	Japanese Zelkova

Findings: See “I-Tree Ecosystem Analysis Campus Creek Pilot Assessment” report.

i-Tree Ecosystem Analysis

Campus Creek Pilot Assessment



Urban Forest Effects and Values
May 2021

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 Campus Creek Final Assignment urban forest was conducted during 2021. Data from 736 trees located throughout Campus Creek Final Assignment were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station.

- Number of trees: 736
- Tree Cover: 26.0 %
- Most common species of trees: Amur honeysuckle, Eastern red cedar, Green ash
- Percentage of trees less than 6" (15.2 cm) diameter: 28.8%
- Pollution Removal: 0 tons/year (\$0/year)
- Carbon Storage: 190.9 tons (\$32.6 thousand)
- Carbon Sequestration: 4.33 tons (\$739/year)
- Oxygen Production: 11.55 tons/year
- Avoided Runoff: 12.81 thousand cubic feet/year (\$857/year)
- Building energy savings: N/A – data not collected
- Avoided carbon emissions: N/A – data not collected
- Structural values: \$1.26 million

Ton: short ton (U.S.) (2,000 lbs)

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

Ecosystem service estimates are reported for trees.

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.

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I. Tree Characteristics of the Urban Forest

The urban forest of Campus Creek Final Assignment has 736 trees with a tree cover of 26.0 percent. The three most common species are Amur honeysuckle (11.1 percent), Eastern red cedar (10.5 percent), and Green ash (3.5 percent).

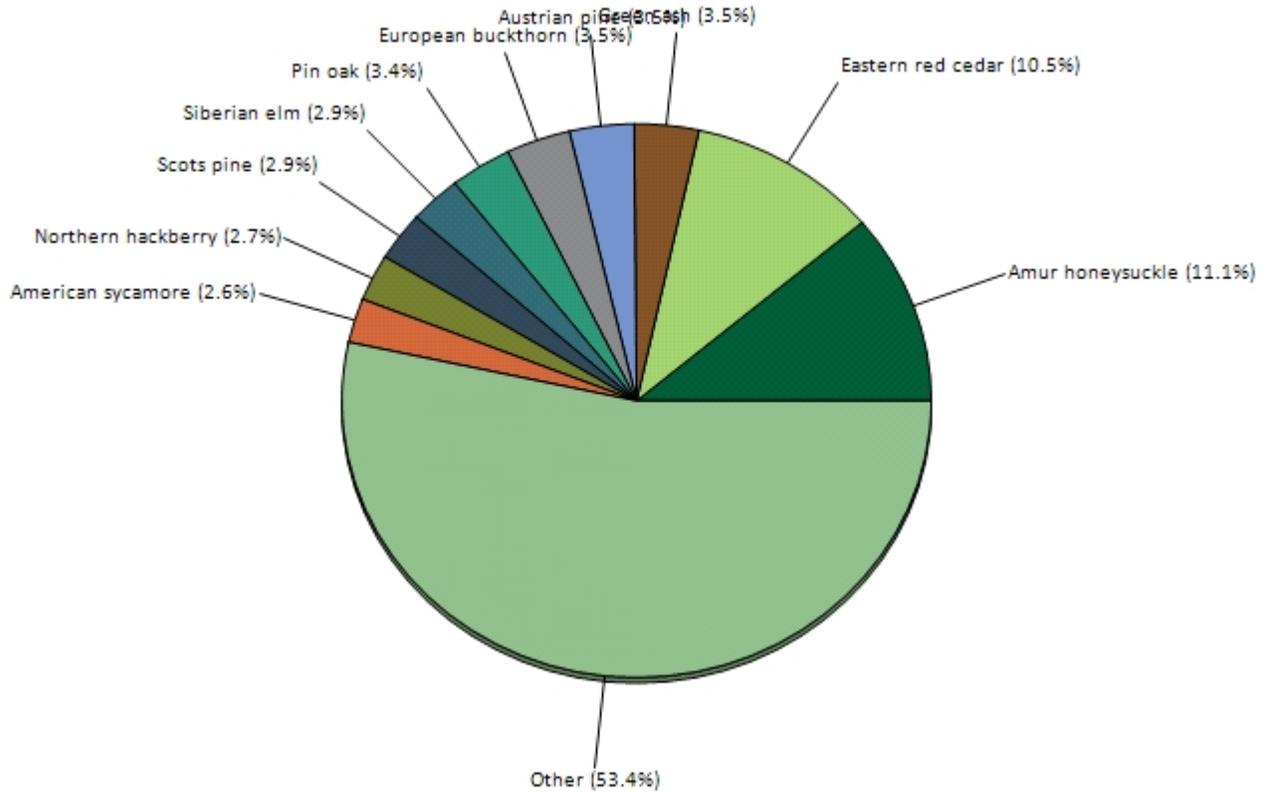


Figure 1. Tree species composition in Campus Creek Final Assignment

The overall tree density in Campus Creek Final Assignment is 27 trees/acre (see Appendix III for comparable values from other cities).

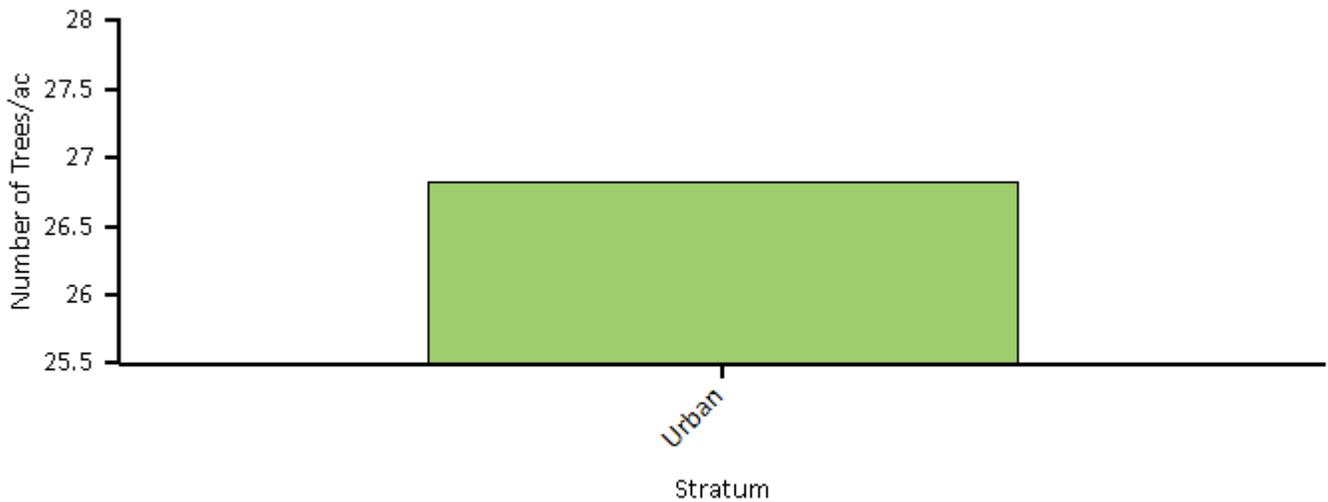


Figure 2. Number of trees/ac in Campus Creek Final Assignment by stratum

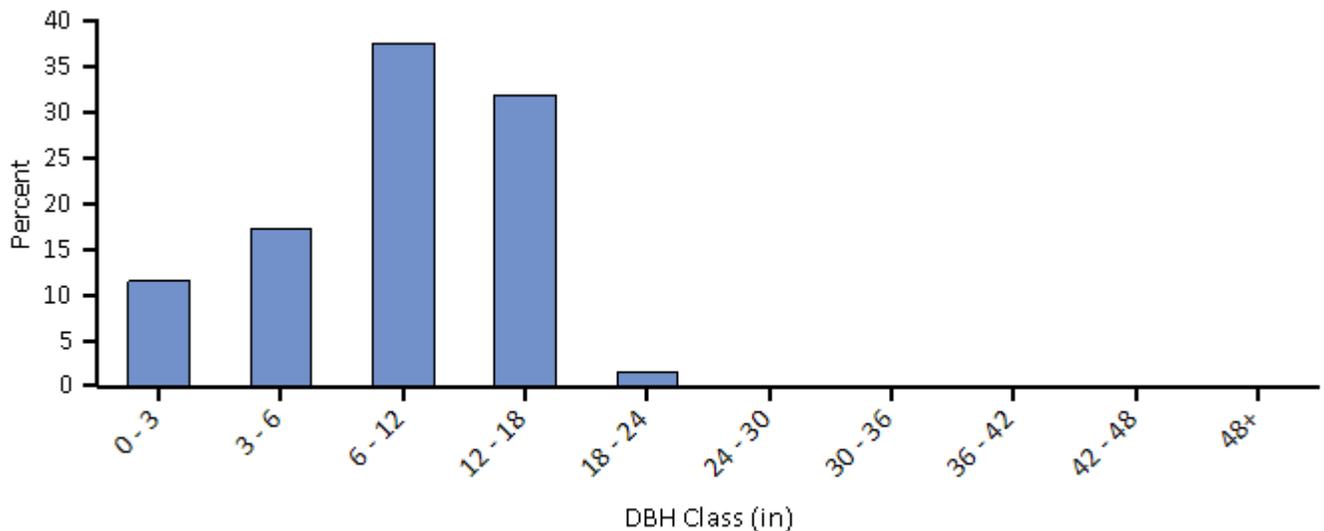


Figure 3. Percent of tree population by diameter class (DBH - stem diameter at 4.5 feet)

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 Campus Creek Final Assignment, about 60 percent of the trees are species native to North America, while 50 percent are native to Kansas. Species exotic to North America make up 40 percent of the population. Most exotic tree species have an origin from Europe & Asia (20 percent of the species).

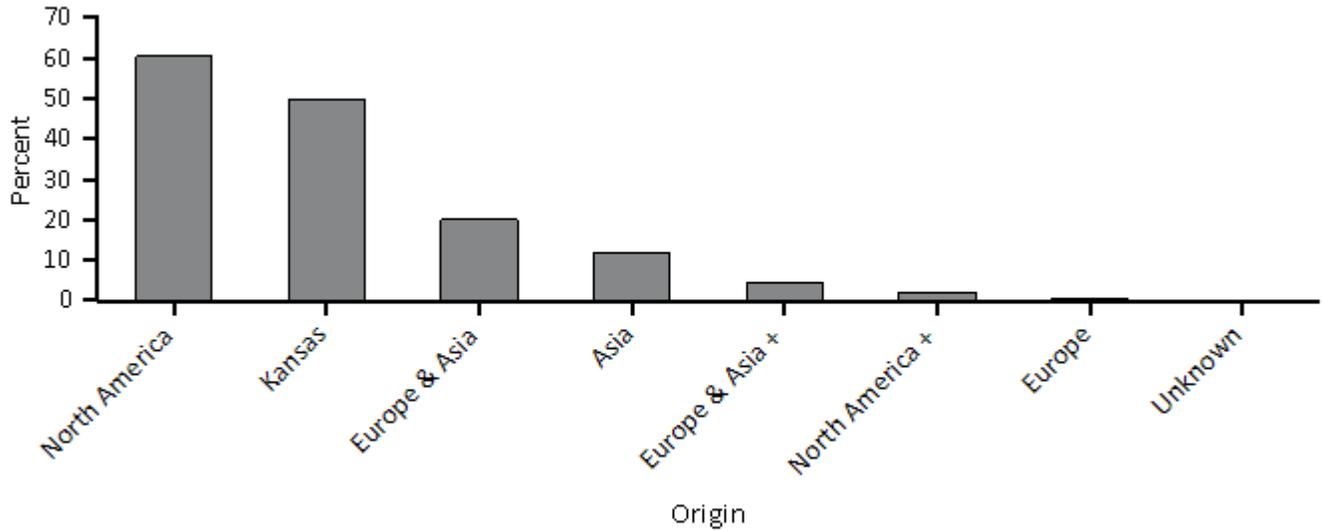


Figure 4. Percent of live tree population by area of native origin, Campus Creek Final Assignment

The plus sign (+) indicates the tree species 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. Four of the 71 tree species in Campus Creek Final Assignment are identified as invasive on the state invasive species list (Kansas Native Plant Society 2006). These invasive species comprise 17.7 percent of the tree population though they may only cause a minimal level of impact. The three most common invasive species are Amur honeysuckle (11.1 percent of population), European buckthorn (3.5 percent), and Callery pear (1.5 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. Trees cover about 26 percent of Campus Creek Final Assignment and provide 45.14 acres of leaf area. Total leaf area is greatest in Urban.

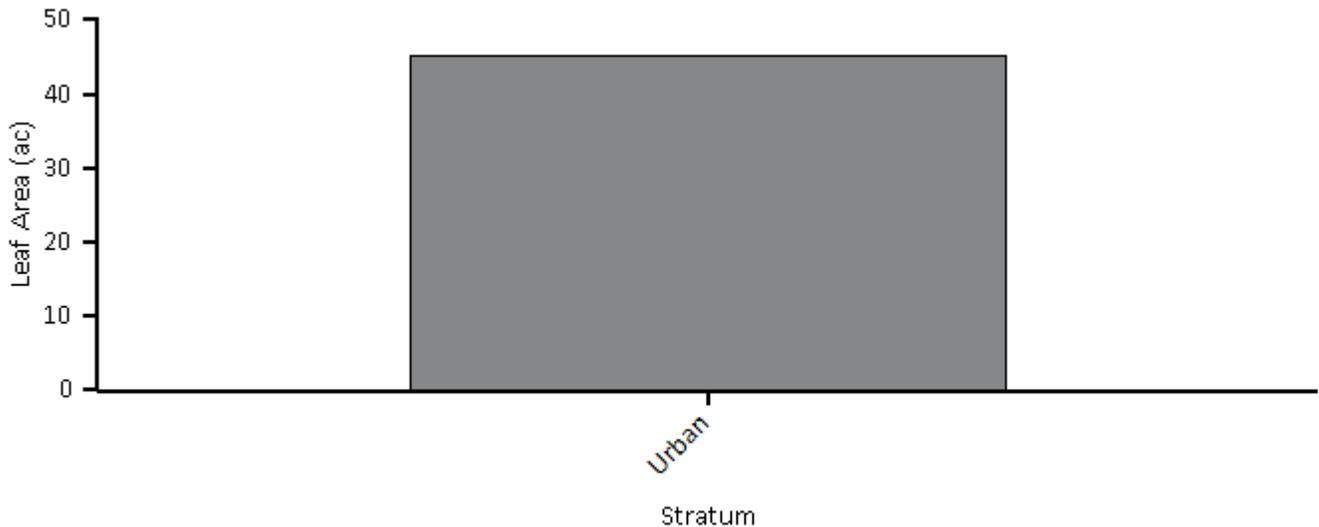


Figure 5. Leaf area by stratum, Campus Creek Final Assignment

In Campus Creek Final Assignment, the most dominant species in terms of leaf area are Pin oak, American sycamore, and Green ash. The 10 species with the greatest importance values are listed in Table 1. Importance values (IV) are calculated as the sum of percent population and percent leaf area. High importance values do not mean that these trees should necessarily be encouraged in the future; rather these species currently dominate the urban forest structure.

Table 1. Most important species in Campus Creek Final Assignment

<i>Species Name</i>	<i>Percent Population</i>	<i>Percent Leaf Area</i>	<i>IV</i>
Eastern red cedar	10.5	4.4	14.8
Pin oak	3.4	8.5	11.9
Amur honeysuckle	11.1	0.4	11.5
Green ash	3.5	5.9	9.5
American sycamore	2.6	6.4	9.0
Northern red oak	2.6	5.8	8.4
Bur oak	2.2	5.8	8.0
Northern hackberry	2.7	5.2	7.9
Sugar maple	2.6	4.8	7.4
Siberian elm	2.9	3.1	6.0

Common ground cover classes (including cover types beneath trees and shrubs) in Campus Creek Final Assignment are not available since they are configured not to be collected.

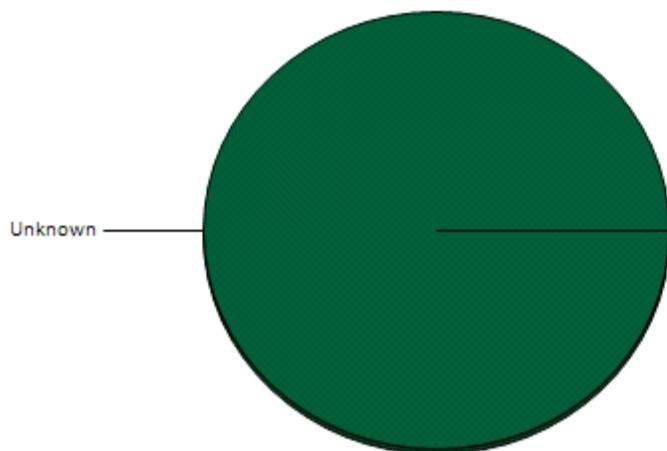


Figure 6. Percent of land by ground cover classes, Campus Creek Final Assignment

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 sources. 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 (Nowak and Dwyer 2000).

Pollution removal¹ by trees in Campus Creek Final Assignment was estimated using field data and recent available pollution and weather data available. Pollution removal was greatest for carbon monoxide (Figure 7). It is estimated that trees remove 0 tons of air pollution (ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 2.5 microns (PM2.5)², and sulfur dioxide (SO2)) per year with an associated value of \$0 (see Appendix I for more details).

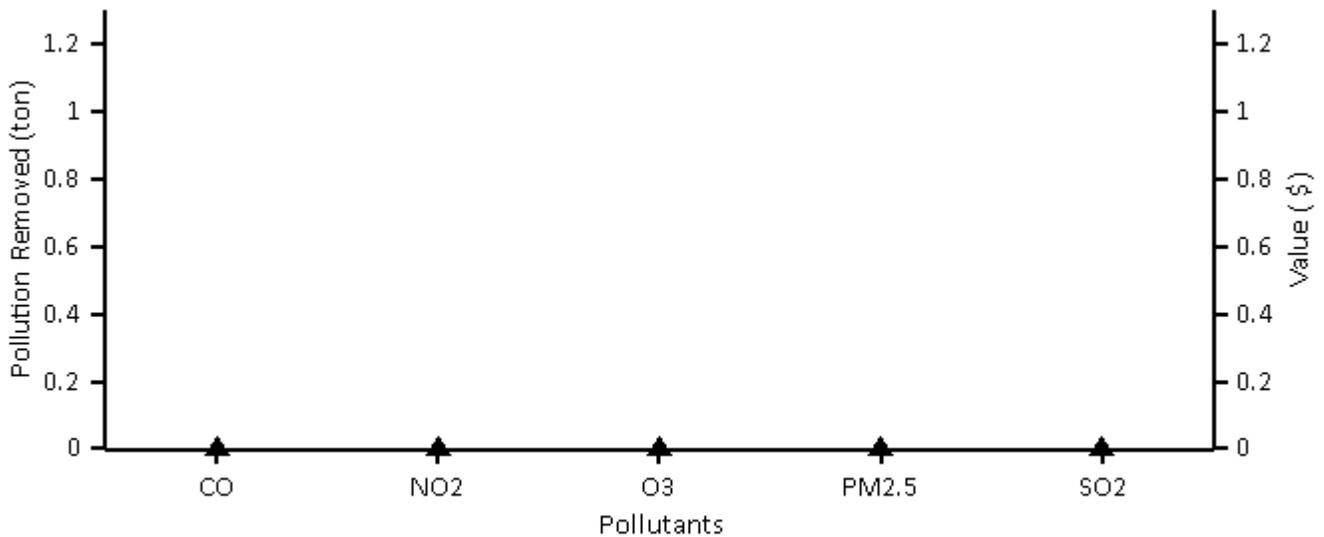


Figure 7. Annual pollution removal (points) and value (bars) by urban trees, Campus Creek Final Assignment

¹ Particulate matter less than 10 microns is a significant air pollutant. Given that i-Tree Eco analyzes particulate matter less than 2.5 microns (PM2.5) which is a subset of PM10, PM10 has not been included in this analysis. PM2.5 is generally more relevant in discussions concerning air pollution effects on human health.

² 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 positive or negative pollution removal and value depending on various atmospheric factors (see Appendix I for more details).

In 2021, trees in Campus Creek Final Assignment emitted an estimated 806.2 pounds of volatile organic compounds (VOCs) (393.1 pounds of isoprene and 413 pounds of monoterpenes). Emissions vary among species based on species characteristics (e.g. some genera such as oaks are high isoprene emitters) and amount of leaf biomass. Thirty- nine percent of the urban forest's VOC emissions were from Pin oak and Bur oak. These VOCs are precursor chemicals to ozone formation.³

General recommendations for improving air quality with trees are given in Appendix VIII.

³ Some economic studies have estimated VOC emission costs. These costs are not included here as there is a tendency to add positive dollar estimates of ozone removal effects with negative dollar values of VOC emission effects to determine whether tree effects are positive or negative in relation to ozone. This combining of dollar values to determine tree effects should not be done, rather estimates of VOC effects on ozone formation (e.g., via photochemical models) should be conducted and directly contrasted with ozone removal by trees (i.e., ozone effects should be directly compared, not dollar estimates). In addition, air temperature reductions by trees have been shown to significantly reduce ozone concentrations (Cardelino and Chameides 1990; Nowak et al 2000), but are not considered in this analysis. Photochemical modeling that integrates tree effects on air temperature, pollution removal, VOC emissions, and emissions from power plants can be used to determine the overall effect of trees on ozone concentrations.

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 sources (Abdollahi et al 2000).

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 Campus Creek Final Assignment trees is about 4.33 tons of carbon per year with an associated value of \$739. See Appendix I for more details on methods.

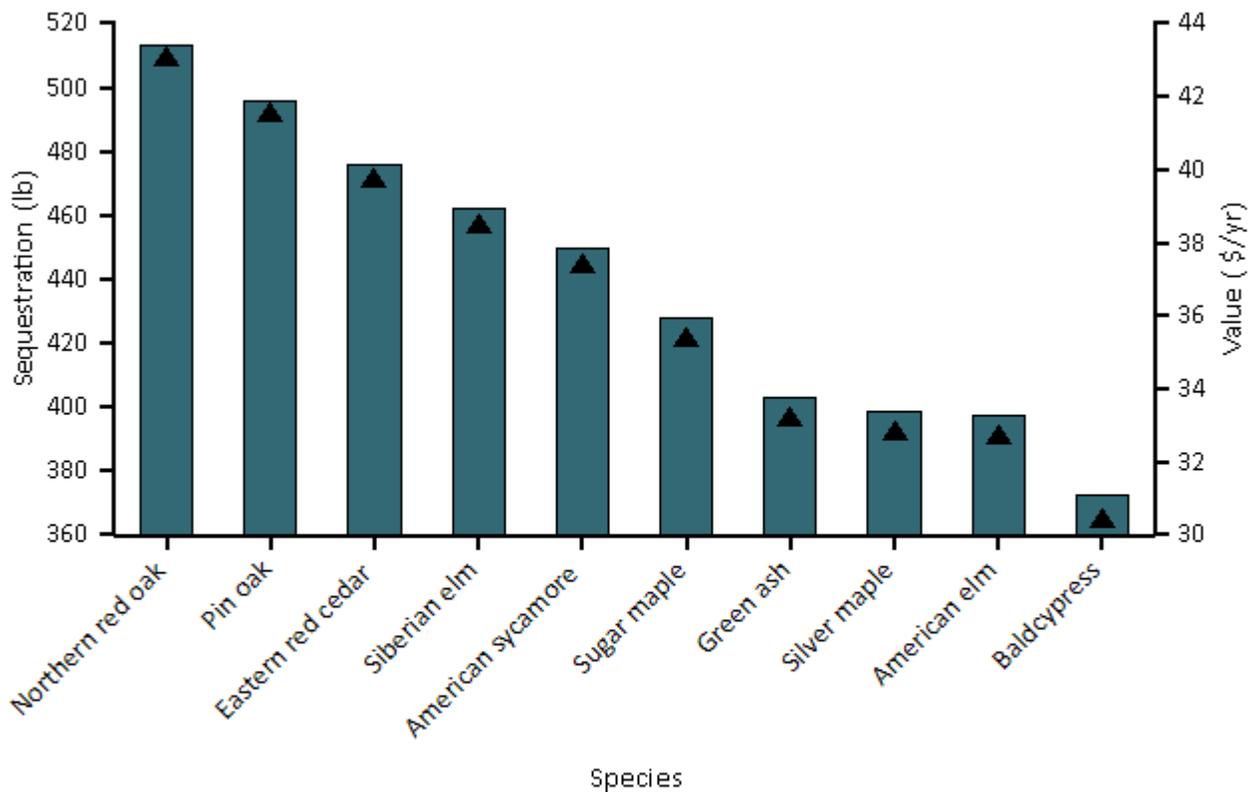


Figure 8. Estimated annual gross carbon sequestration (points) and value (bars) for urban tree species with the greatest sequestration, Campus Creek Final Assignment

Carbon storage is another way trees can influence global climate change. As a tree grows, it stores more carbon by holding it in its accumulated tissue. As a tree dies and decays, it releases much of the stored carbon back into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance can contribute to carbon emissions (Nowak et al 2002c). When a tree dies, using the wood in long-term wood products, to heat buildings, or to produce energy will help reduce carbon emissions from wood decomposition or from fossil-fuel or wood-based power plants.

Trees in Campus Creek Final Assignment are estimated to store 191 tons of carbon (\$32.6 thousand). Of the species sampled, Pin oak stores the most carbon (approximately 9.56% of the total carbon stored) and Northern red oak sequesters the most (approximately 5.88% of all sequestered carbon.)

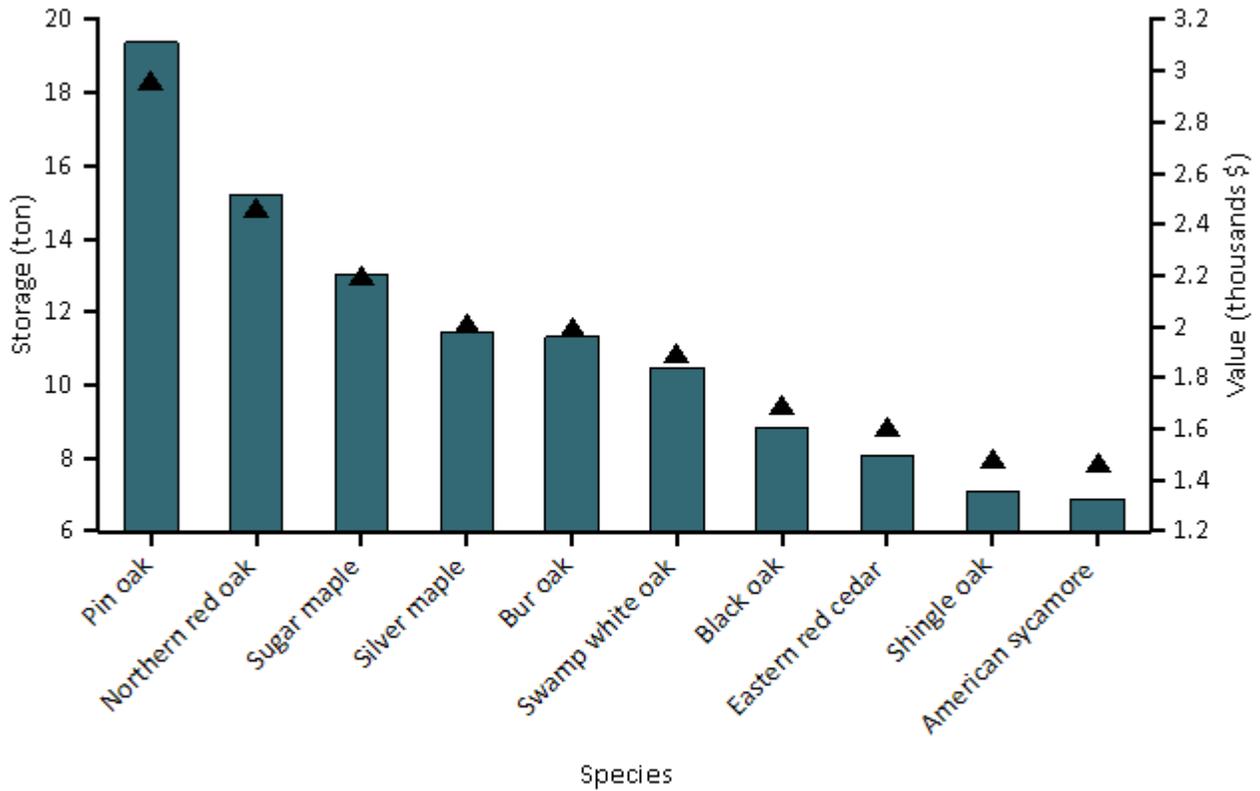


Figure 9. Estimated carbon storage (points) and values (bars) for urban tree species with the greatest storage, Campus Creek Final Assignment

V. Oxygen Production

Oxygen production is one of the most commonly cited benefits of urban trees. The 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 Campus Creek Final Assignment are estimated to produce 11.55 tons of oxygen per year.⁴ 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 (Broecker 1970).

Table 2. The top 20 oxygen production species.

<i>Species</i>	<i>Oxygen (pound)</i>	<i>Gross Carbon Sequestration (pound/yr)</i>	<i>Number of Trees</i>	<i>Leaf Area (acre)</i>
Northern red oak	1,357.52	509.07	19	2.63
Pin oak	1,309.73	491.15	25	3.82
Eastern red cedar	1,255.48	470.81	77	1.97
Siberian elm	1,217.28	456.48	21	1.42
American sycamore	1,183.95	443.98	19	2.89
Sugar maple	1,123.28	421.23	19	2.18
Green ash	1,056.52	396.20	26	2.68
Silver maple	1,044.31	391.62	9	1.67
American elm	1,040.59	390.22	12	1.31
Baldcypress	971.76	364.41	15	1.64
Honeylocust	959.19	359.70	18	1.29
Swamp white oak	948.54	355.70	13	1.87
Bur oak	940.66	352.75	16	2.62
Black oak	814.43	305.41	9	1.13
Amur honeysuckle	675.20	253.20	82	0.17
Austrian pine	616.34	231.13	26	1.04
Scots pine	614.98	230.62	21	1.07
White ash	376.09	141.03	6	0.70
Callery pear	337.33	126.50	11	0.26
Eastern cottonwood	334.62	125.48	2	0.41

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 (Hirabayashi 2012). In urban areas, the large extent of impervious surfaces increases the amount of surface runoff.

Urban trees and shrubs, however, are beneficial in reducing surface runoff. Trees and shrubs intercept precipitation, while their root systems promote infiltration and storage in the soil. The trees and shrubs of Campus Creek Final Assignment help to reduce runoff by an estimated 12.8 thousand cubic feet a year with an associated value of \$860 (see Appendix I for more details). Avoided runoff is estimated based on local weather from the user-designated weather station. In Campus Creek Final Assignment, the total annual precipitation in 2018 was 26.4 inches.

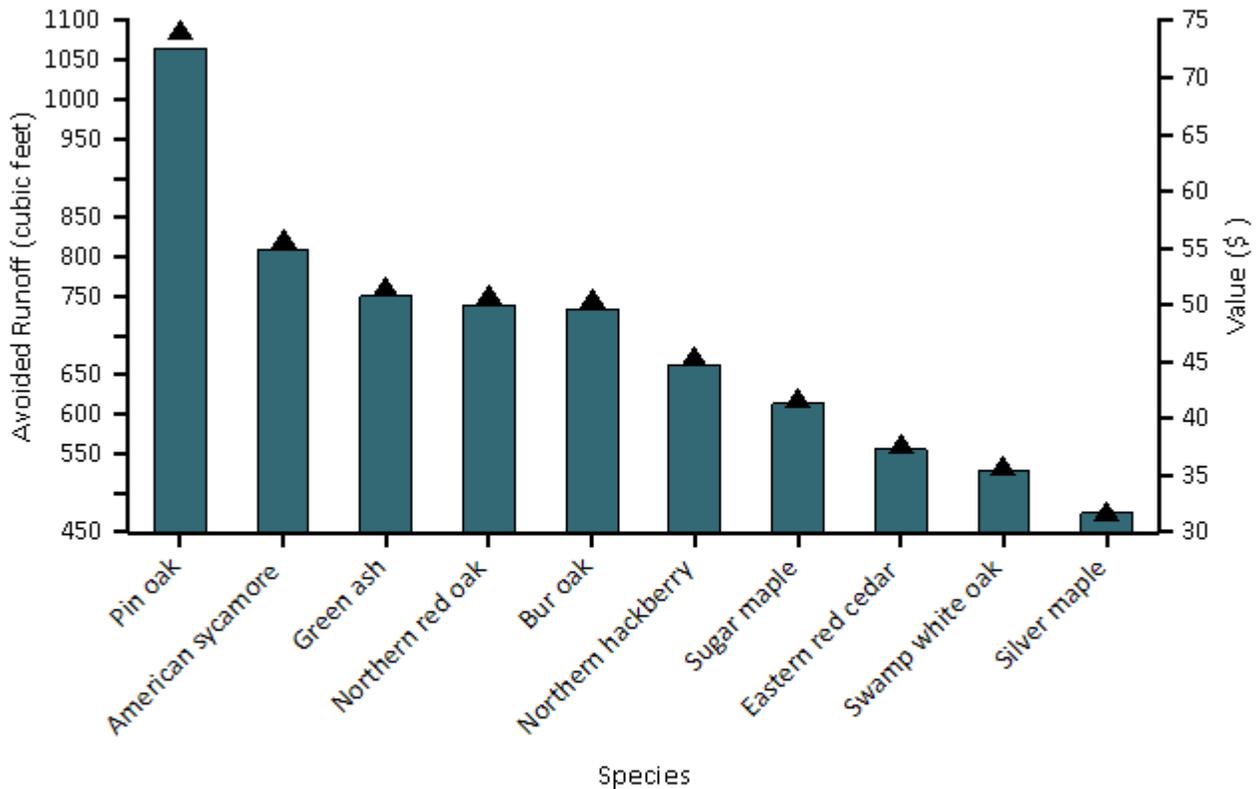


Figure 10. Avoided runoff (points) and value (bars) for species with greatest overall impact on runoff, Campus Creek Final Assignment

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 (McPherson and Simpson 1999).

Because energy-related data were not collected, energy savings and carbon avoided cannot be calculated.

Table 3. Annual energy savings due to trees near residential buildings, Campus Creek Final Assignment

	<i>Heating</i>	<i>Cooling</i>	<i>Total</i>
MBTU ^a	0	N/A	0
MWH ^b	0	0	0
Carbon Avoided (pounds)	0	0	0

^aMBTU - one million British Thermal Units

^bMWH - megawatt-hour

Table 4. Annual savings ^a(\$) in residential energy expenditure during heating and cooling seasons, Campus Creek Final Assignment

	<i>Heating</i>	<i>Cooling</i>	<i>Total</i>
MBTU ^b	0	N/A	0
MWH ^c	0	0	0
Carbon Avoided	0	0	0

^bBased on the prices of \$130.2 per MWH and \$11.3442000317562 per MBTU (see Appendix I for more details)

^cMBTU - one million British Thermal Units

^eMWH - megawatt-hour

⁵ Trees modify climate, produce shade, and reduce wind speeds. Increased energy use or costs are likely due to these tree-building interactions creating a cooling effect during the winter season. For example, a tree (particularly evergreen species) located on the southern side of a residential building may produce a shading effect that causes increases in heating requirements.

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 (Nowak et al 2002a). Annual functional values also tend to increase with increased number and size of healthy trees. 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.

Urban trees in Campus Creek Final Assignment have the following structural values:

- Structural value: \$1.26 million
- Carbon storage: \$32.6 thousand

Urban trees in Campus Creek Final Assignment have the following annual functional values:

- Carbon sequestration: \$739
- Avoided runoff: \$857
- Pollution removal: \$0
- Energy costs and carbon emission values: \$0

(Note: negative value indicates increased energy cost and carbon emission value)

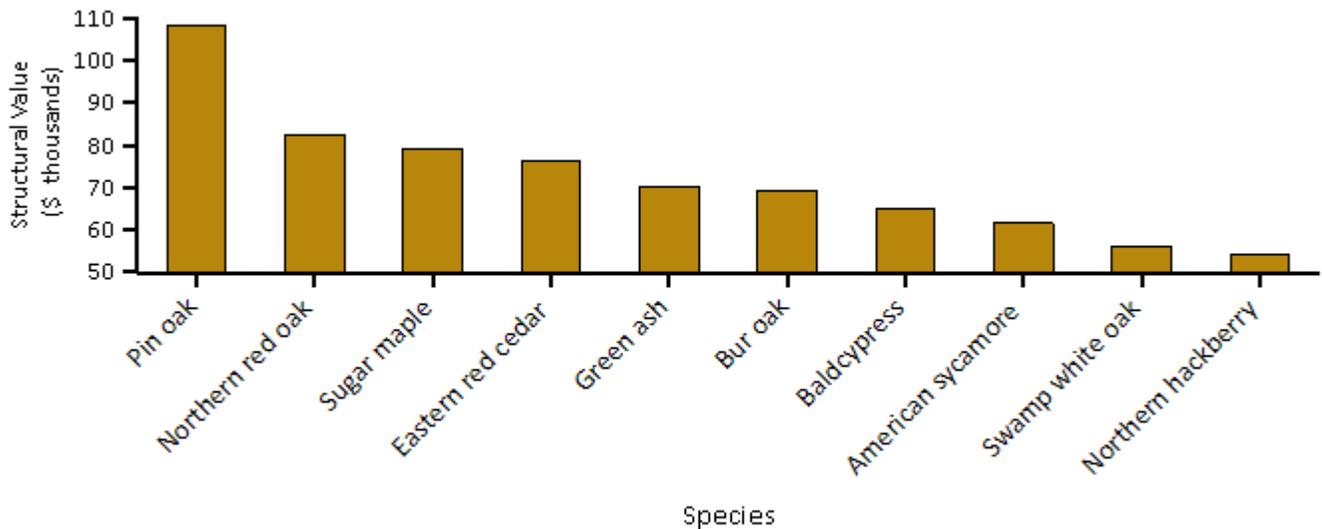


Figure 11. Tree species with the greatest structural value, Campus Creek Final Assignment

IX. Potential Pest Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, structural 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-six pests were analyzed for their potential impact and compared with pest range maps (Forest Health Technology Enterprise Team 2014) for the conterminous United States to determine their proximity to Riley County. One of the thirty-six pests analyzed are located within the county. For a complete analysis of all pests, see Appendix VII.

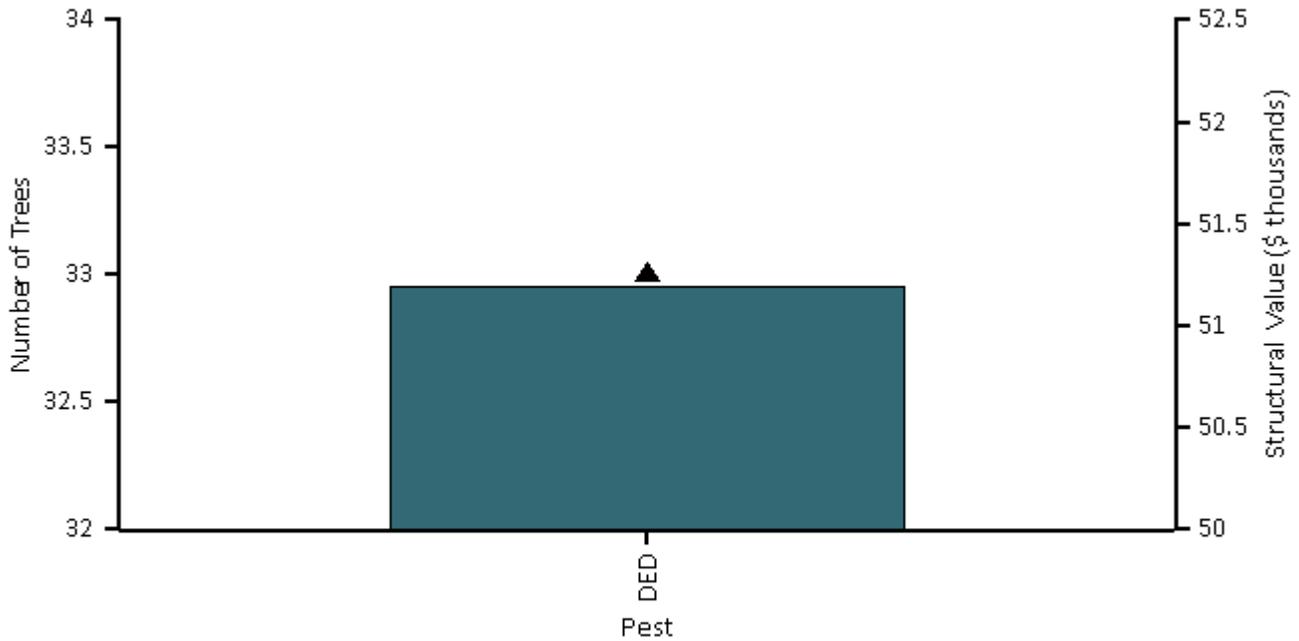


Figure 12. Number of trees at risk (points) and associated compensatory value (bars) for most threatening pests located in the county, Campus Creek Final Assignment

American elm, one of the most important street trees in the twentieth century, has been devastated by the Dutch elm disease (DED) (Northeastern Area State and Private Forestry 1998). 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, Campus Creek Final Assignment could possibly lose 4.5 percent of its trees to this pest (\$51.2 thousand in structural value).

Appendix I. i-Tree Eco Model and Field Measurements

i-Tree Eco is designed to use standardized field data and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects (Nowak and Crane 2000), 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.
- 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 sources.
- 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.

Typically, all field data are collected during the leaf-on season to properly assess tree canopies. 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 (Nowak et al 2005; Nowak et al 2008).

During data collection, trees are identified to the most specific taxonomic classification possible. Trees that are not classified to the species level may be classified by genus (e.g., ash) or species groups (e.g., hardwood). In this report, tree species, genera, or species groups are collectively referred to as tree species.

Tree Characteristics:

Leaf area of trees was assessed using measurements of crown dimensions and percentage of crown canopy missing. In the event that these data variables were not collected, they are estimated by the model.

An analysis of invasive species is not available for studies outside of the United States. For the U.S., invasive species are identified using an invasive species list (Kansas Native Plant Society 2006) 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.

Air Pollution Removal:

Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter less than 2.5 microns. Particulate matter less than 10 microns (PM10) is another significant air pollutant. Given that i-Tree Eco analyzes particulate matter less than 2.5 microns (PM2.5) which is a subset of PM10, PM10 has not been included in this analysis. PM2.5 is generally more relevant in discussions concerning air pollution effects on human health.

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 (Balducchi 1988; Balducchi et al 1987). 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 (Bidwell and Fraser 1972; Lovett 1994) that were adjusted depending on leaf phenology and leaf area.

Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere (Zinke 1967). 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 (Hirabayashi et al 2011; Hirabayashi et al 2012; Hirabayashi 2011).

Trees remove PM_{2.5} when particulate matter is deposited on leaf surfaces (Nowak et al 2013). This deposited PM_{2.5} 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 positive or negative pollution removal and value depending on various atmospheric factors. Generally, PM_{2.5} 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 PM_{2.5} 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 PM_{2.5} but increase concentrations and thus have negative values during periods of positive overall removal. These events are not common, but can happen.

For reports in the United States, default air pollution removal value is 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 less than 2.5 microns using data from the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP) (Nowak et al 2014). The model uses a damage-function approach that is based on the local change in pollution concentration and population. National median externality costs were used to calculate the value of carbon monoxide removal (Murray et al 1994).

For international reports, user-defined local pollution values are used. For international reports that do not have local values, estimates are based on either European median externality values (van Essen et al 2011) or BenMAP regression equations (Nowak et al 2014) that incorporate user-defined population estimates. Values are then converted to local currency with user-defined exchange rates.

For this analysis, pollution removal value is calculated based on the prices of \$0 per ton (carbon monoxide), \$0 per ton (ozone), \$0 per ton (nitrogen dioxide), \$0 per ton (sulfur dioxide), \$0 per ton (particulate matter less than 2.5 microns).

Carbon Storage and Sequestration:

Carbon storage is the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation. 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 (Nowak 1994). 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.

Carbon sequestration is the removal of carbon dioxide from the air by plants. 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 (U.S. Environmental Protection Agency 2015, Interagency Working Group on Social Cost of Carbon 2015) and converted to local currency with user-defined exchange rates.

For this analysis, carbon storage and carbon sequestration values are calculated based on \$171 per ton.

Oxygen Production:

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 (Nowak et al 2007). For complete inventory projects, oxygen production is estimated from gross carbon sequestration and does not account for decomposition.

Avoided Runoff:

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 (McPherson et al 1999; 2000; 2001; 2002; 2003; 2004; 2006a; 2006b; 2006c; 2007; 2010; Peper et al 2009; 2010; Vargas et al 2007a; 2007b; 2008).

For this analysis, avoided runoff value is calculated based on the price of \$0.07 per ft³.

Building Energy Use:

If appropriate field data were collected, seasonal effects of trees on residential building energy use were calculated based on procedures described in the literature (McPherson and Simpson 1999) 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.

For this analysis, energy saving value is calculated based on the prices of \$130.20 per MWH and \$11.34 per MBTU.

Structural Values:

Structural value is the value of a tree based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree). Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information (Nowak et al 2002a; 2002b). Structural value may not be included for international projects if there is insufficient local data to complete the valuation procedures.

Potential Pest Impacts:

The complete potential pest risk analysis is not available for studies outside of the United States. The number of trees at risk to the pests analyzed is reported, though the list of pests is based on known insects and disease in the United States.

For the U.S., potential pest risk is based on pest range maps and the known pest host species that are likely to

experience mortality. Pest range maps for 2012 from the Forest Health Technology Enterprise Team (FHTET) (Forest Health Technology Enterprise Team 2014) 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 (Eastern Forest Environmental Threat Assessment Center; Worrall 2007).

Relative Tree Effects:

The relative value of tree benefits reported in Appendix II is calculated to show what carbon storage and sequestration, and air pollutant removal equate to in amounts of municipal carbon emissions, passenger automobile emissions, and house emissions.

Municipal carbon emissions are based on 2010 U.S. per capita carbon emissions (Carbon Dioxide Information Analysis Center 2010). Per capita emissions were multiplied by city population to estimate total city carbon emissions.

Light duty vehicle emission rates (g/mi) for CO, NO_x, VOCs, PM₁₀, SO₂ for 2010 (Bureau of Transportation Statistics 2010; Heirigs et al 2004), PM_{2.5} for 2011-2015 (California Air Resources Board 2013), and CO₂ for 2011 (U.S. Environmental Protection Agency 2010) were multiplied by average miles driven per vehicle in 2011 (Federal Highway Administration 2013) to determine average emissions per vehicle.

Household emissions are 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 in 2009 (Energy Information Administration 2013; Energy Information Administration 2014)

- CO₂, SO₂, and NO_x power plant emission per kWh are from Leonardo Academy 2011. CO emission per kWh assumes 1/3 of one percent of C emissions is CO based on Energy Information Administration 1994. PM₁₀ emission per kWh from Layton 2004.
- CO₂, NO_x, SO₂, 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 Leonardo Academy 2011.
- CO₂ emissions per Btu of wood from Energy Information Administration 2014.
- CO, NO_x and SO_x emission per Btu based on total emissions and wood burning (tons) from (British Columbia Ministry 2005; Georgia Forestry Commission 2009).

Appendix II. Relative Tree Effects

The urban forest in Campus Creek Final Assignment 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, average passenger automobile emissions, and average household emissions. See Appendix I for methodology.

Carbon storage is equivalent to:

- Amount of carbon emitted in Campus Creek Final Assignment in 0 days
- Annual carbon (C) emissions from 135 automobiles
- Annual C emissions from 55 single-family houses

Carbon monoxide removal is equivalent to:

- Annual carbon monoxide emissions from 0 automobiles
- Annual carbon monoxide emissions from 0 single-family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 0 automobiles
- Annual nitrogen dioxide emissions from 0 single-family houses

Sulfur dioxide removal is equivalent to:

- Annual sulfur dioxide emissions from 0 automobiles
- Annual sulfur dioxide emissions from 0 single-family houses

Annual carbon sequestration is equivalent to:

- Amount of carbon emitted in Campus Creek Final Assignment in 0.0 days
- Annual C emissions from 0 automobiles
- Annual C emissions from 0 single-family houses

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)
Toronto, ON, Canada	26.6	10,220,000	1,221,000	51,500	2,099
Atlanta, GA	36.7	9,415,000	1,344,000	46,400	1,663
Los Angeles, CA	11.1	5,993,000	1,269,000	77,000	1,975
New York, NY	20.9	5,212,000	1,350,000	42,300	1,676
London, ON, Canada	24.7	4,376,000	396,000	13,700	408
Chicago, IL	17.2	3,585,000	716,000	25,200	888
Phoenix, AZ	9.0	3,166,000	315,000	32,800	563
Baltimore, MD	21.0	2,479,000	570,000	18,400	430
Philadelphia, PA	15.7	2,113,000	530,000	16,100	575
Washington, DC	28.6	1,928,000	525,000	16,200	418
Oakville, ON , Canada	29.1	1,908,000	147,000	6,600	190
Albuquerque, NM	14.3	1,846,000	332,000	10,600	248
Boston, MA	22.3	1,183,000	319,000	10,500	283
Syracuse, NY	26.9	1,088,000	183,000	5,900	109
Woodbridge, NJ	29.5	986,000	160,000	5,600	210
Minneapolis, MN	26.4	979,000	250,000	8,900	305
San Francisco, CA	11.9	668,000	194,000	5,100	141
Morgantown, WV	35.5	658,000	93,000	2,900	72
Moorestown, NJ	28.0	583,000	117,000	3,800	118
Hartford, CT	25.9	568,000	143,000	4,300	58
Jersey City, NJ	11.5	136,000	21,000	890	41
Casper, WY	8.9	123,000	37,000	1,200	37
Freehold, NJ	34.4	48,000	20,000	540	22

II. Totals per acre of land area

City	Number of Trees/ac	Carbon Storage (tons/ac)	Carbon Sequestration (tons/ac/yr)	Pollution Removal (lb/ac/yr)
Toronto, ON, Canada	64.9	7.8	0.33	26.7
Atlanta, GA	111.6	15.9	0.55	39.4
Los Angeles, CA	19.6	4.2	0.16	13.1
New York, NY	26.4	6.8	0.21	17.0
London, ON, Canada	75.1	6.8	0.24	14.0
Chicago, IL	24.2	4.8	0.17	12.0
Phoenix, AZ	12.9	1.3	0.13	4.6
Baltimore, MD	48.0	11.1	0.36	16.6
Philadelphia, PA	25.1	6.3	0.19	13.6
Washington, DC	49.0	13.3	0.41	21.2
Oakville, ON , Canada	78.1	6.0	0.27	11.0
Albuquerque, NM	21.8	3.9	0.12	5.9
Boston, MA	33.5	9.1	0.30	16.1
Syracuse, NY	67.7	10.3	0.34	13.6
Woodbridge, NJ	66.5	10.8	0.38	28.4
Minneapolis, MN	26.2	6.7	0.24	16.3
San Francisco, CA	22.5	6.6	0.17	9.5
Morgantown, WV	119.2	16.8	0.52	26.0
Moorestown, NJ	62.1	12.4	0.40	25.1
Hartford, CT	50.4	12.7	0.38	10.2
Jersey City, NJ	14.4	2.2	0.09	8.6
Casper, WY	9.1	2.8	0.09	5.5
Freehold, NJ	38.3	16.0	0.44	35.3

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 (Nowak 1995):

- 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 (Nowak 2000). Local urban management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include (Nowak 2000):

<i>Strategy</i>	<i>Result</i>
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 tree species were listed as invasive on the Kansas invasive species list (Kansas Native Plant Society 2006):

Species Name ^a	<i>Number of Trees</i>	<i>% of Trees</i>	<i>Leaf Area (ft²)</i>	<i>Percent Leaf Area</i>
Amur honeysuckle	82	11.1	0.0	0.4
European buckthorn	26	3.5	0.0	0.3
Callery pear	11	1.5	0.0	0.6
Black locust	11	1.5	0.0	0.7
Total	130	17.66	0.04	1.93

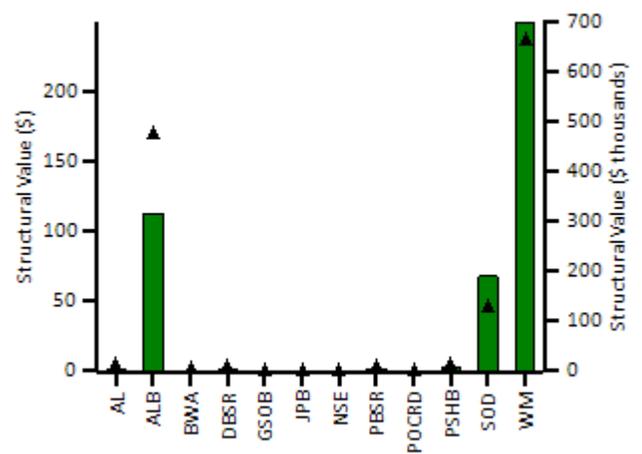
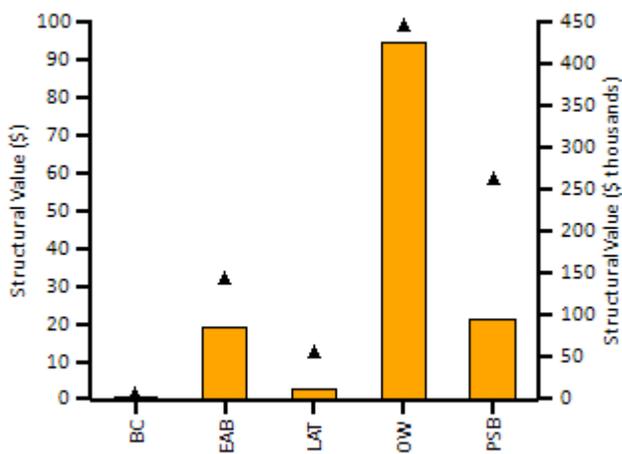
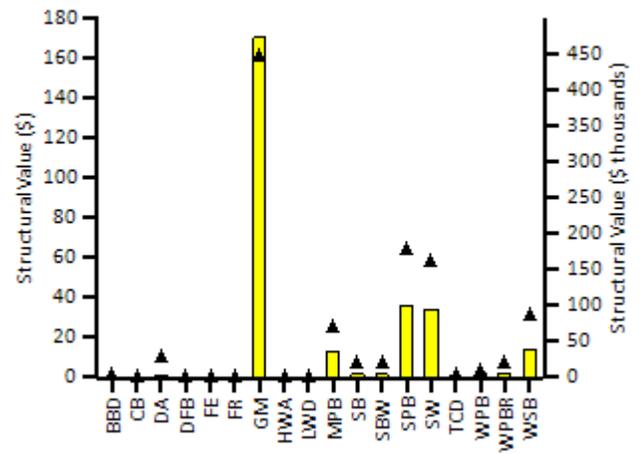
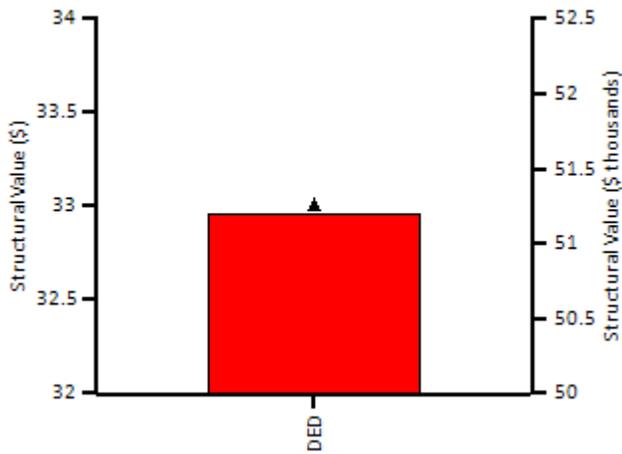
^aSpecies are determined to be invasive if they are listed on the state's invasive species list

Appendix VI. Potential Risk of Pests

Thirty-six insects and diseases were analyzed to quantify their potential impact on the urban forest. As each insect/disease is likely to attack different host tree species, the implications for {0} will vary. The number of trees at risk reflects only the known host species that are likely to experience mortality.

Code	Scientific Name	Common Name	Trees at Risk (#)	Value (\$ thousands)
AL	<i>Phyllocnistis populiella</i>	Aspen Leafminer	4	3.48
ALB	<i>Anoplophora glabripennis</i>	Asian Longhorned Beetle	170	317.65
BBD	<i>Neonectria faginata</i>	Beech Bark Disease	1	0.67
BC	<i>Sirococcus clavignenti juglandacearum</i>	Butternut Canker	1	1.68
BWA	<i>Adelges piceae</i>	Balsam Woolly Adelgid	1	0.40
CB	<i>Cryphonectria parasitica</i>	Chestnut Blight	0	0.00
DA	<i>Discula destructiva</i>	Dogwood Anthracnose	10	1.67
DBSR	<i>Leptographium wageneri</i> var. <i>pseudotsugae</i>	Douglas-fir Black Stain Root Disease	3	4.44
DED	<i>Ophiostoma novo-ulmi</i>	Dutch Elm Disease	33	51.20
DFB	<i>Dendroctonus pseudotsugae</i>	Douglas-Fir Beetle	0	0.00
EAB	<i>Agrilus planipennis</i>	Emerald Ash Borer	32	86.43
FE	<i>Scolytus ventralis</i>	Fir Engraver	0	0.00
FR	<i>Cronartium quercuum</i> f. sp. <i>Fusiforme</i>	Fusiform Rust	0	0.00
GM	<i>Lymantria dispar</i>	Gypsy Moth	161	473.96
GSOB	<i>Agrilus auroguttatus</i>	Goldspotted Oak Borer	0	0.00
HWA	<i>Adelges tsugae</i>	Hemlock Woolly Adelgid	0	0.00
JPB	<i>Dendroctonus jeffreyi</i>	Jeffrey Pine Beetle	0	0.00
LAT	<i>Choristoneura conflictana</i>	Large Aspen Tortrix	12	12.15
LWD	<i>Raffaelea lauricola</i>	Laurel Wilt	0	0.00
MPB	<i>Dendroctonus ponderosae</i>	Mountain Pine Beetle	25	35.94
NSE	<i>Ips perturbatus</i>	Northern Spruce Engraver	0	0.00
OW	<i>Ceratocystis fagacearum</i>	Oak Wilt	99	426.71
PBSR	<i>Leptographium wageneri</i> var. <i>ponderosum</i>	Pine Black Stain Root Disease	3	4.44
POCRD	<i>Phytophthora lateralis</i>	Port-Orford-Cedar Root Disease	0	0.00
PSB	<i>Tomicus piniperda</i>	Pine Shoot Beetle	58	95.66
PSHB	<i>Euwallacea</i> nov. sp.	Polyphagous Shot Hole Borer	4	7.51
SB	<i>Dendroctonus rufipennis</i>	Spruce Beetle	7	4.41
SBW	<i>Choristoneura fumiferana</i>	Spruce Budworm	7	4.41
SOD	<i>Phytophthora ramorum</i>	Sudden Oak Death	45	191.09
SPB	<i>Dendroctonus frontalis</i>	Southern Pine Beetle	64	99.66
SW	<i>Sirex noctilio</i>	Sirex Wood Wasp	58	95.66
TCD	<i>Geosmithia morbida</i>	Thousand Canker Disease	1	1.68
WM	<i>Operophtera brumata</i>	Winter Moth	237	699.29
WPB	<i>Dendroctonus brevicomis</i>	Western Pine Beetle	3	4.44
WPBR	<i>Cronartium ribicola</i>	White Pine Blister Rust	7	6.67
WSB	<i>Choristoneura occidentalis</i>	Western Spruce Budworm	31	39.95

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.



Note: points - Number of trees, bars - Structural value

Based on the host tree species for each pest and the current range of the pest (Forest Health Technology Enterprise Team 2014), it is possible to determine what the risk is that each tree species in the urban forest could be attacked by an insect or disease.

Spp. Risk	Risk Weight	Species Name	AL	ALB	BBD	BC	BWA	CB	DA	DBSR	DED	DFB	EAB	FE	FR	GM	GSOB	HWA	JPB	LAT	LWD	MPB	NSE	OW	PBSR	POCRD	PSB	PSHB	SB	SBW	SOD	SPB	SW	TCD	WM	WPB	WPBR	WSB					
16		Norway spruce					■															■				■																	
15		Ponderosa pine								■																■		■										■					
11		Scots pine																					■																				
9		Eastern white pine																									■																
8	■	Blue spruce																											■	■											■		
8		White willow	■	■													■				■																■						
7		Austrian pine																									■																
7		Pin oak																								■																	
7		Northern red oak																								■																	
7		River birch		■																	■																						
6	■	Siberian elm		■							■																																
6		Bur oak																								■																	
6		Swamp white oak																								■																	
6	■	American elm		■							■															■																	
6		Black oak																								■																	
6		Shingle oak																								■																	
6		White oak																								■																	
6		Chinkapin oak																								■																	
6		English oak																								■																	
5		Green ash		■									■															■															
5	■	Boxelder		■																								■															
5		Black walnut				■																																					
4		White ash											■																														
3	■	apple spp		■																																							
3	■	American basswood																																									
3	■	Downy hawthorn																																									
3	■	European alder																																									
3	■	Chinese elm		■																																							
3	■	European beech				■																																					
2	■	Sugar maple		■																																							
2	■	Red maple		■																																							
2	■	Callery pear																																									
2	■	Silver maple		■																																							
2	■	Cornelian cherry								■																																	

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