THE VALUE OF THE KEELE CAMPUS URBAN FOREST

BASED ON THE USDA'S
URBAN FOREST EFFECTS MODEL –
UFORE

By

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EXECUTIVE SUMMARY

The Urban Forest Effect model (UFORE) was developed by the USDA (United States Department of Agriculture) to assist in quantifying ecosystem services provided by urban forests at the scale of towns and cities. We adapted the methodology and protocols and applied them at a smaller scale, namely York University's Keele campus. Our goals in modifying the protocol were two-fold: (1) to determine the extent to which the UFORE model could be scaled down to more local levels, and (2) to determine whether, what has tended to be a costly undertaking at the municipal level, could be carried out on a smaller, more affordable budget.

This report describes the characteristics, importance and value of the Urban Forest at York University's Keele Campus, including the role that the UFORE model estimates that it plays in removing greenhouse gas pollution. This campus contains urban forest canopies in both existing blocks of natural forests (woodlots) and in man-made urban forests (gardens, recreational areas, and parklands).

Tree and shrub composition were sampled in a total of 70 plots on the Keele Campus, in the summer of 2008, 2007 pollution data were obtained from Environment Canada, and weather data from the USDA. A total of nine people collected data: three ecologists with doctorates, two graduate students from York's Faculty of Environmental Studies, and four IRIS staff and undergraduate students. The project was estimated to cost CAD $21,500: CAD $12,000 in salaries and CAD $9,500 in in-kind contributions. We make a series of recommendations based on our findings, related to future management of this urban forest.

KEY FINDINGS

Description	Measure
Total number of trees on Keele campus	97,575
Percentage of trees in Park areas	86%
Percentage of trees in Building areas	14%
Keele campus tree density	248 tree ha^{-1}
Top 3 tree species by number of individuals	European buckthorn, Box elder, Ironwood
Top 3 species by leaf area	White fir, Swamp white oak and European buckthorn
Plantable areas	Parks: 29%; Buildings: 16%
Annual carbon sequestered	327 mt* yr^{-1}
Estimated amount of pollution removed	Parks: 8.51 mt yr^{-1}; Buildings: 3.29 mt yr^{-1}
Value of pollution removed by Keele urban forest	U.S. $ 64,398 yr^{-1} (CDN $ 74,846 yr^{-1})**
Number of trees susceptible to *Asian Longhorned beetle*	34,940
Value of species susceptible to *Asian Longhorned beetle*	U.S. $ 19.2 million (CDN $22.3 million)

Note: * mt refers to metric tonnes (1,000kg), ** U.S conversion to CDN dollars as of July 6, 2009.

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1. INTRODUCTION

Until recently, relatively little attention had been paid to trees in urban areas, their role in ecosystem functioning, and how this may relate to the health and well-being of the human population. For example, during the late 1990s, the development of the Toronto and Region Conservation Authorities' Terrestrial Natural Heritage Strategy specifically excluded urban areas such as gardens and streets, and focused only on the biodiversity value of natural cover and habitats (D. R. Bazely, unpubl. notes; TRCA, 2004). However, this perspective is shifting amongst ecologists. As the proportion of global land cover that has been converted into human-transformed environments increases, urban forests will play a more strongly recognized ecological role in the 21st century. This is due to increasing awareness of the link between their management and broader issues of sustainability.

The Urban Forest Effects (UFORE) computer model was developed to aid managers and scientists in quantifying urban forest structure and functions. The model was developed by USDA Forest Service researchers David J. Nowak, Daniel E. Crane and Patrick McHale at the Northeastern Research Station in Syracuse (New York, USA). The model uses a GIS (Geographical Information System) approach to estimate and quantify plant species composition and diversity, diameter distribution, leaf area, leaf biomass, tree density and health, and other forest structural components, as well as hourly volatile organic compound emissions, total carbon storage and sequestration and hourly pollution removal (Nowak & Crane, 2000). The UFORE model currently has four modules (A, B C and D).

UFORE-A, The *Anatomy of the Urban Forest* module quantifies the following metrics associated with trees: species composition, density, condition-class distribution, leaf area and leaf biomass. The module also calculates species richness, population distribution by region of origin (% native species), ground cover distribution and Shannon-Wiener diversity index values. Finally, this module predicts the risk of gypsy moth defoliation by calculating the proportions of leaf area and life tree populations in several classes susceptible to gypsy moth feeding (Nowak & Crane, 2000).

UFORE-B: The *Biogenic Volatile Organic Compound (VOC) Emissions* module estimates the hourly emission rates of VOC's by tree species for each land use (i.e. residential, water, institutional, transportation) and series (i.e. park trees or street trees) (Nowak & Crane, 2000). These VOC's are important because they may contribute to the creation of ozone and carbon monoxide (Brasseur, 1991). This estimate quantifies the impact that trees can have on air quality, and has been very useful, for instance, in the Los Angeles Basin, where a shift to low VOC-emitting plants has resulted in decreased ozone concentrations (Taha, 1996).

UFORE-C: The *Carbon Storage and Sequestration* module calculates total stored carbon, and the gross and net carbon that is sequestered annually by the urban forest, based on inputted field data. This module enables the user to recognize the value of urban forests properties in mitigating climate change, and this knowledge may then be applied to planting strategies (Nowak & Crane, 2000). For example, in New York City, forest managers found that of all species in their forests, *Platanus acerifolia* (London planetree), *Quercus rubra* (northern red oak), and *Quercus palustris* (pin oak) stored the most carbon (Nowak, 1993). This information may inform subsequent tree-planting plans.

UFORE-D: The *Dry Deposition of Air Pollution* module calculates the hourly removal of ozone (O_3), sulphur dioxide, nitrogen dioxide, and carbon monoxide, (SO_2, NO_2, CO), and the daily deposition of fine particulate matter (PM_{10}) to tree canopies throughout the year. For example, the trees in New York City were estimated to be removing a total of 1,821 mt of air pollution in 1994, which was subsequently assigned a monetary value, using the median externality values for each pollutant, worth US$9.5 million to society (Nowak and Crane, 2000).

Although the UFORE model was originally designed for the assessment of urban forests in cities and towns, urban forests are not only found in these settings. Indeed, urban forests are also an integral part of university campuses. Campuses such as York University's Keele campus, often cover large areas and encompass most, if not all, the components of a small town, including its vegetation. York University was founded in 1959 and currently includes the Keele campus, the Glendon campus, the Miles S. Nadal Management Centre, and the Osgoode Professional Development Centre. York University has accommodated over 50,000 students and 11 faculties and is Canada's third largest university (York University, 2009). The Keele campus was established in 1965 (York University, 2008). With over 500 acres of property this campus contains a large diversity of buildings, recreational areas, parks and woodlots. As such, an integral part of our natural resources at York is our urban forest. In order to assess the status and sustainability of the forest at the Keele campus, an urban forest project was initiated by the university's Institute for Research and Innovation in Sustainability (IRIS) in 2007, and was initially championed by our former University Campus Planner, Mr. Andrew Wilson (see Student, staff volunteers get down and dirty for Arbour Day in YFile, October 18, 2004; http://www.yorku.ca/yfile/archive/index.asp?Article=3459).

IRIS was established in 2004 as an interdisciplinary university-wide research institute. Its mandate includes initiating and leading research into the sustainability-related activities across York's faculties, and, as such, is intended to bridge diverse faculty and academic expertise, and to move beyond traditional research methods (IRIS, 2008). Therefore IRIS is well placed for undertaking a lead role in sustainability projects relating to York's Keele campus sustainability initiatives. In this project we explored how to adapt the UFORE model for application to a large Canadian university campus, so that it would create opportunities for engaging interested students and provide a basis for sustainable management of the urban forest on campus.

A number of Canadian cities, including Toronto, Calgary and Oakville, have already carried out UFORE assessments and have found that this has helped them in clarifying the importance and hidden values of their urban forest (McNeil *et al*., 2006; Kenney *et al*., 2001). The goal of our study was to implement the UFORE model so as to provide York University with a deeper understanding of the value of the Keele campus urban forest. It is our hope that our findings will be used by York's managers to design and implement management practices that support the University's vision for a sustainable Keele campus.

2. METHODS

We planned to follow the official UFORE manual and protocol (Nowak *et al*., 2003; i-Tree Software Suite v2.1 User's Manual) developed by the USDA Forest Service's Northeastern research station in Syracuse, NY. Initially, in 2007, the study was envisioned as an inventory as per the UFORE protocol (Nowak *et al*., 2003; p.5). However the tree inventory that was carried out produced data that contained many species identification and sampling errors, resulting in the data set being so comprised that it had to be discarded. From this exercise we learned that the inventory approach was too time consuming and required a very high level of technical expertise with respect to species identification, which was not feasible for a graduate student who was working independently most of the time. In 2008, a second summer of data collection was undertaken with much higher levels of quality control over student field assistants and which followed the UFORE ecosystem sampling approach. It also became clear that, as a result of the smaller geographical scale of our project in comparison to larger city-wide projects, the project methodology, specifically sample plot selection, would need to be adapted and modified from the original UFORE protocol.

Four types of data may be included in a UFORE analysis: 1) field data, 2) ground cover, 3) meteorological data and 4) pollution concentration data (Nowak *et al*., 2003). The 2007 local meteorological data were provided by the USDA, while the 2007 hourly pollution data were obtained from the Ontario Ministry of the Environment.

Field data used in the analysis were collected from August 7th to September 19th 2008. A total of 70 plots were sampled across the many different land use types that we identified as being present on the Keele campus, in order to account for the high degree of variability in the campus vegetation cover. For the purpose of this study we grouped areas of different land uses into two main categories designated as a "Buildings" series of land cover types and a "Parks" land cover series. Sample plot locations were predetermined from the Keele campus map (Figure 1), so that plots were sampled across all land use types. The number of plots in each of these two series was determined on the basis of their relative area on the campus. Within each series (Buildings and Parks) the number of plots per land use type was also determined on the basis of the relative area occupied by the different land use types. A starting point was selected using a permanent feature as a reference point (i.e. lamp post) and then a random number was generated for use as the distance from the feature to each UFORE plot centre (e.g. 3 feet north of the light post at Chimneystack Rd. and Albany Rd.).

At each UFORE plot we recorded: 1) location of plot (including reference object), 2) GPS co-ordinates of the plot centre, 3) a unique plot ID, 4) date of data collection, 5) names of all crew members, and 6) actual land use of the plot that was observed by the crew.

The "Buildings" series included all areas with built infrastructure, such as parking lots and institutional buildings, and was estimated with ESRI ArcGIS 9.2 to cover approximately 168 ha of the campus. A total of 50 sample plots were located in the Buildings series, and of these, 26 were located in parking lots, and 24 near to buildings and their surrounding areas (Figure 1 and Table 1). A total of 20 plots were sampled in the second "Parks" series, of which 5 were located within woodlots, 9 were in maintained gardens, and 6 were in sport/recreational areas (Figure 1 and Table 1). The Parks series covered approximately 29 ha of the campus. All UFORE plots were circular, with a radius of 7.3 m (24 feet), which corresponded to approximately 0.2 ha (1/24 acres). At each plot the following were recorded:

<u>Plot Tree Cover (0-100%).</u> This refers to the percentage of the plots covered by tree canopies. It was determined by looking upwards from within the plot and estimating the proportion of sky that was obscured by tree crowns. This figure included the entire tree canopy, even if a portion of it was located outside the plot.

<u>Plot Shrub Cover (0-100%).</u> This refers to the percentage of plot area that is covered by shrub canopies. It was estimated by looking down from above at shrub cover. We did not double count multiple layers of shrubs.

<u>Plantable space (0-100%).</u> This refers to the percentage of the plot that is plantable for trees (i.e. plantable soil that is not filled with tree canopies or other obstructions).

<u>Ground cover (0-100%)</u> information was recorded to the nearest 5%. The sum of all ground cover categories equals 100%, and the categories were: building, cement, tar (asphalt), rock (i.e. patio stones, brick, gravel, sand), soil (includes naturally occurring sand), duff/mulch, herb/ivy, maintained grass, not mowed grass, and water (includes pools and large fountains).

Figure 1. Keele campus map, circles indicate plots within Building series and squares indicate plots within Parks series (Google maps, accessed on April 2009).

Table 1 - Site names and number of plots sampled within the Parks and Buildings series.

Parks series		Buildings series	
Site Name	*Number of Plots*	*Site Name*	*Number of Plots*
Boyer Woodlot	1	360 Assiniboine Rd.	2
Danby Woods	2	Central Utilities Building	3
Osgoode Woodlot	1	Farquharson Greenhouse	3
Saywell Woods	1	Founders Residence Courtyard	2
Keele St. / Pond Rd. Baseball Field	2	Library Lane – Scott Library	3
Pond Rd. Hoover Rd. Baseball Field	2	Norman Bethune Residence	2
NW Recreation Area	2	Seneca Building	3
South of York Blvd.	2	Steacie Library	3
Harry W. Arthur Commons	3	Founders Rd. East Parking Lot	4
Stong Pond Arboretum	4	Founders Rd. West Parking Lot	5
		Northwest Gate Parking Lot	4
		Pond Rd. East Parking Lot (#86)	4
		Sentinel Rd East Parking Lot (#88)	4
		Tait McKenzie Centre	3
		York Blvd. Parking Lot	5
TOTAL	**20**	**TOTAL**	**50**

The following two sections describe in detail the measurements that were taken of trees and shrubs.

2.1 TREES

Each tree was identified to the species level (Farrar, 2006) where possible, and flagged with a unique ID number. An individual was classified as a tree if its diameter at breast height (DBH) was at least 2.5 cm. Multi-stemmed individuals were considered trees if they had at least one stem with DBH over 2.5 cm.

We measured:

DBH, for each dead and living tree at breast height 1.37m (4.5ft) on the uphill side of the tree (see Nowak *et al*., 2003 for special DBH situations). If the point of pith separation was above ground, the plant was considered to be more than one tree. If a single tree had more than six stems, the six largest DBH were recorded at 0.3 m (1ft) above ground. DBH measurement height was recorded only when DBH measurement could not be taken at the standard height of 1.37 m.

Tree height was measured with a clinometer, as the height to the top of a dead or alive tree. For down or leaning trees, height was considered the distance along the main stem from the ground to the tree top.

Height to crown base was measured with the clinometer as the height to the base of the live crown. Dead trees were recorded as 0.

Crown width: Two crew members used a measuring tape to measure the crown widths in two perpendicular directions (North/South and East/West). Dead trees had crown width of zero. If the tree was downed or leaning, measurements were taken perpendicular to the tree bole (i.e. crown base).

Percent Canopy missing (0-100%): is a percentage measurement of the crown volume that is not occupied by leaves. UFORE defines 'typical crown outline' as, a symmetrical silhouette created by the live crown width, total height, and height to base of crown measurements. Normal interior crown voids due to shading were not included. Measurement took into account the natural crown shape for the particular species. Dead trees were recorded as 100%.

Dieback: is the percent of crown where leaves were absent (0-100%), excluding natural dieback due to shading and competition in the lower crown and pruning. However, dieback on the sides and top of the crown due to shading or competition were included. Dead trees were recorded as 100%. For each tree, dieback was estimated in the following categories: E = < 1% dieback, G = 1-10%, F = 11-25%, P = 26-50%, C = 51-75%, D = 76-99%, K = 100%.

Crown Light Exposure (CLE): is a measurement of the number of sides of the tree receiving sunlight. This was determined by visually dividing the crown vertically into four equal sides, counting the top as a fifth side. The number of sides that would receive direct light if the sun were directly above the tree was counted if 1/3 of the live crown was receiving full light in each side. A sliver of a side receiving light did not qualify.

2.2 SHRUBS

A shrub was defined as an individual of at least 30.5 cm in height and DBH less than 2.5 cm. Each shrub was identified to the species level where possible (Soper, 1982). The following data were recorded:

Height of the shrub mass to the nearest 1/10th of a meter for each species. An average height was used.

Percent area of the total ground area of all shrubs in the plot, recorded as the percentage of ground area occupied by each individual species. In presence of multiple layers, the highest layer was counted along with the unshaded portion of the lower layer(s).

Percent Shrub Mass Missing (0-100%) – of the volume (height X ground) of each species – was recorded as the percent of volume that was not occupied by leaves.

2.3 DATA ENTRY AND ANALYSIS

Field data were entered into Excel spreadsheets in the format required by the original version of the UFORE manual. However, upon sending our data in this format USDA refused to accept it, and asked us to re-enter all data into the current version of the application included in the i-Tree software suite (version 2.1). This took a considerable extra amount of time that we had not planned for as the software was designed for larger projects that use PDAs in the field to be more efficient in the data entry. After re-entering all data, data were uploaded to USDA for analysis. This process was time consuming on a number of accounts: for example, the software required us to enter a four letter code for each species names, and much time was spent just looking up these codes. There were also some technical problems associated with using the software itself. To begin with, many of our first efforts at recording field data in the software were futile, as computer errors corrupted data files after saving to disk. The software also required more field data than the minimum requirements described in the UFORE manual. As we were not doing permanent plots, we did not record the following: 1) the direction from plot center to the tree (living or dead) in compass degrees/azimuths and 2) the closest distance from plot center to outside of trunk at DBH, measured parallel to ground (living or dead) and to whole unit. In place of those two missing measurements, and based on Mr. Zelaya's instruction, the number "1" and "2" were respectively entered in the i-Tree data files.

Following the protocol, set out in the UFORE manual, we did not record full species names but rather only the genus for a few species that we could not positively identify - e.g. dead individuals. However, in contrast to the manual directions, the software required a full species name (based on codes) and several entries had to be manually amended (as per consultation with USDA) by choosing one of the available species in the list. If a species identified in the field was not available in the pre-entered species list of the i-Tree software we had to replace it to the closest one in the same genus; fortunately this only occurred for one species, Ironwood (*Ostrya virginiana*) that had to be designated as *Parrotia spp*. for data analysis by USDA staff due to the fact that the species *Ostrya* was not present on the existing UFORE species list. While this clearly would have affected species based outputs we were confident that due to the comparability in growth forms of the two species the results would not be too severely compromised. Other technical problems that we encountered with the software at the data processing and analysis stage included calculations that substituted different species for the following tree species: *Ostrya virginiana* (Ironwood), *Fraxinus* (Ash), *Prunus* (Plum), *Cercis* (Redbud) and *Amelanchier* (Serviceberry) as well as the following shrub species: *Vitis* (Grape), *Euonymus* (Spindletree), *Amelanchier* (Serviceberry), *Crataegus* (Hawthorn) and *Virbunum* (Viburnum). To resolve this issue new data tables had to be entered for the affected species.

Two months after submitting our data for analysis we contacted Mr. Zelaya and Dr. Nowak, about our results and at that time we learned that a USDA generated report was not available to us, because this feature is restricted to projects within the US.

Mr. Zelaya and Dr. Nowak were very helpful, but as a result of our communications with them, we learned that module outputs still required careful checking and this verification was very time consuming. Mr. Zelaya and Dr. Nowak informed us that many of the problems we experienced were commonplace, and our feedback was very much appreciated by them and would be used in future software improvements – with a new version being released in the spring 2010. After attending the "Urban Forest Study Forum II" organized by the Toronto Region and Conservation Authority (TRCA) on April 16 2009 we realized that many of the UFORE users (city of Toronto and city of London) had also experienced similar issues with the data entry and analysis. Also in large, city-wide projects, delays in data analysis by the UFORE were commonplace. These delays are likely to be more problematic for small budget, short- term projects such as ours.

3. RESULTS

3.1 FOREST STRUCTURE AND COMPOSITION

A summary of York's main urban forest characteristics is given in Table 2. Based on the stem count, the total number of trees in York's urban forest was estimated to be 97,575, of which 83,552 were attributed to the Park series, and 14,023 to the Building series. Overall tree density on the Keele campus was estimated at 247 trees ha^{-1}. The Parks series had an estimated tree density of 424 trees ha^{-1}, while the Building series was only 71 trees ha^{-1}. The total leaf area of the Parks and Building series was 6.91 and 1.82 km^2, respectively. Estimated leaf area densities in the Parks and Building series were 35,090 and 9,249 m^2 ha^{-1}, respectively. The campus leaf area was estimated at 8.73 km^2 while leaf area density was 22,170 m^2 ha^{-1}. Leaf biomass density in the Park areas was estimated to be five times greater than that in the Building series, with a total of 2,035 kg ha^{-1} for the entire campus.

The trees and shrubs with the largest leaf areas in the Parks series were: *Abies concolor* (White fir) with 1.52 km^2, *Quercus bicolor* (Swamp white oak) 1.09 km^2, *Rhamnus cathartica* (European buckthorn) 0.70 km^2, *Acer saccharum* (Sugar maple) 0.46 km^2, and *Picea abies* (Norway spruce) 0.32 km^2 (see Appendix 1a). In the Building series, trees and shrubs with the greatest leaf area were: *Rhamnus cathartica* (European buckthorn) with 0.42 km^2, *Acer saccharum* (Sugar maple) with 0.18 km^2, *Acer negundo* (Box elder) with 0.17 km^2, *Juglans nigra* (Black walnut) (0.15 km^2) and *Ostrya virginiana* (Ironwood; designated as *Parrotia spp*. in Appendices) with 0.14 km^2 (see Appendix 1b).

Table 2 - Summary of forest structure characteristics: Parks, Buildings and Campus total.

	Parks	Buildings	Campus Total
Tree Density (number ha^{-1})	424	71.2	247.6
Number of Trees	83,552	14,023	97,575
Leaf Area (km^2)	6.91	1.82	8.73
Leaf Area Density (m^2 ha^{-1})	35,090	9,249	22,170
Leaf Biomass Density (kg ha^{-1})	3,334	736	2,035
Leaf Biomass (mt)	657	145	802

3.1.1 TREES

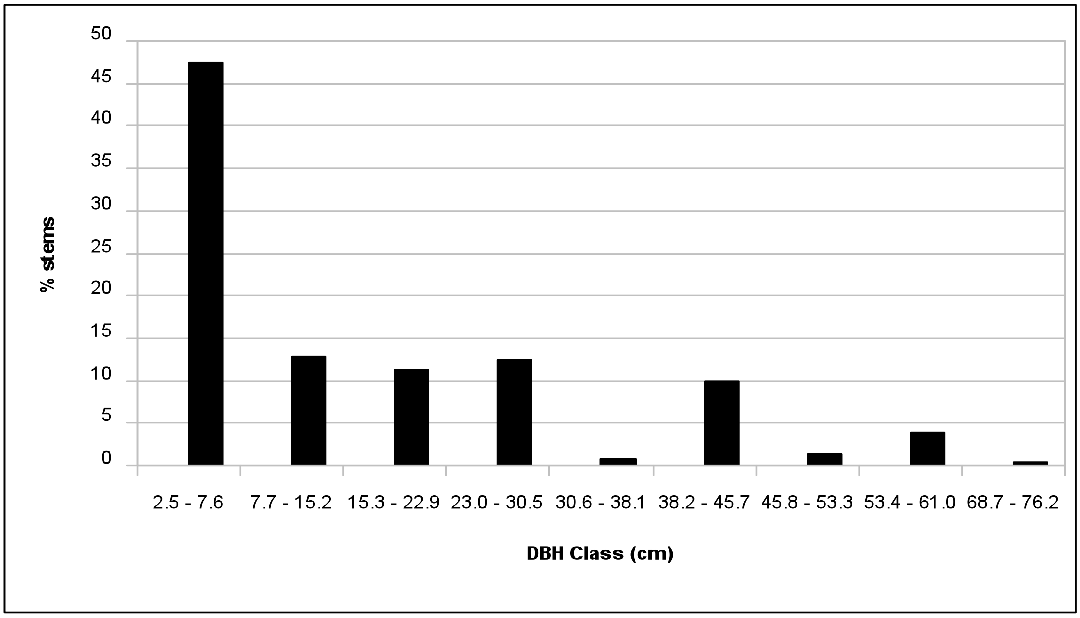
In the Parks series of land use types, the greater percentage of stems was observed in the smaller DBH class, indicating that there is woody regeneration occurring, while in the Building series of land use types, the higher percentage of stems fell into the 15.3-22.9 cm DBH class. Parks and Buildings had similar stem percentages in all other DBH classes (Figure 2, & Appendix 4a & 4b).

The analysis of the DBH distribution by leaf area showed that in the Parks series trees with DBHs of 23-30.5 and 38-45.7cm contributed the most to the total leaf area. A similar scenario was observed in the Building series, where the larger leaf area was generated by trees with DBHs between 15.3 and 45.7 cm. However, the leaf area in those DBH classes was, on average 4.5 times greater for the Parks series then for the Building series (Figure 3). In the Parks series the tree species with the greatest leaf area by DBH class were (Appendix

2a): *Rhamnus cathartica* (European buckthorn) with a leaf area of 0.23 km^2 in the 2.5-7.6 cm DBH class, *Pinus nigra* (Austrian pine) with 0.07 km^2 in the 7.7-15.2 cm, *Amelanchier arborea ssp. laevis* (Smooth serviceberry) with 0.06 km^2 in the 15.3-22.9 cm, *Malus species* (Apple) with 1.52 km^2 in the 23-30.5 cm, *Rhamnus cathartica* (European buckthorn) with 0.07 km^2 in the 30.6-38.1 cm, *Abies concolor* (White fir) with 1.22 km^2 in the 38.2 - 45.7cm, *Quercus bicolour* (Swamp white oak) with 0.2 km^2 in the 45.8-53.3 cm, *Abies balsamea* (Balsam fir) with 0.03 km^2 in the 53.4-61 cm and *Quercus bicolour* (Swamp white oak) with 0.56 km^2 in the 61.1-68.6 cm. In the Building series (see Appendix 2b), the following tree species had the greatest leaf area by DBH class: *Amelanchier* spp. (Serviceberry) with 0.02 km^2 in the 7.7-15.2 cm DBH class, *Amelanchier* spp. (Serviceberry) with 0.15 km^2 in the 15.3-22.9 cm, *Amelanchier* sp. with 0.11 km^2 in the 23.0-30.5 cm, *Amelanchier* spp. with 0.15 km^2 in the 30.6-38.1 cm, *Rhamnus cathartica* (European buckthorn) with 0.13 km^2 in the 38.2 - 45.7 cm DBH, *Juglans nigra* (Black walnut) with 0.07 km^2 in the 45.8-53.3 cm.

Based on the total estimates for each series (see Appendices 3a & b), the ten tree species with the highest number of individuals on the Keele Campus were: *Rhamnus cathartica* (European buckthorn) with 23,254 trees, *Acer negundo* (Box elder) 7,012, *Ostrya virginiana* (Ironwood; designated as *Parrotia spp*. in Appendices) 6,778, *Carya cordiformis* (Bitternut hickory) 6,194, *Acer saccharum* (Sugar maple) 6,194, *Quercus bicolor* (Swamp white oak) 5,375, *Ulmus fulva* (Slippery elm) 4,791, *Carpinus caroliniana* (American hornbeam) 4,207, *Prunus virginiana* (Common chokecherry) 3,973 and *Quercus macrocarpa* (Bur oak) 3,388.

In the Parks series, the most common tree species in terms of stem density was *Rhamnus cathartica* (European buckthorn), with 97.9 trees ha^{-1}; *Abies concolor* (White fir) had the greatest leaf surface area (3,389 m^2 ha^{-1}) while *Quercus bicolour* (Swamp white oak) was the highest valued species (US$ 54,669 ha^{-1}) (Appendix 5a). Whereas, within the Building series, *Rhamnus cathartica* (European buckthorn) was the most common tree, with 20.2 trees ha^{-1}, had the greatest leaf surface area (2,156.6 m^2 ha^{-1}) and the highest value (US$ 45,357) (Appendix 5b). In total it was estimated that the tree density was 424 trees ha^{-1} in the Parks and 71.2 trees ha^{-1} in the Buildings land use cover series.



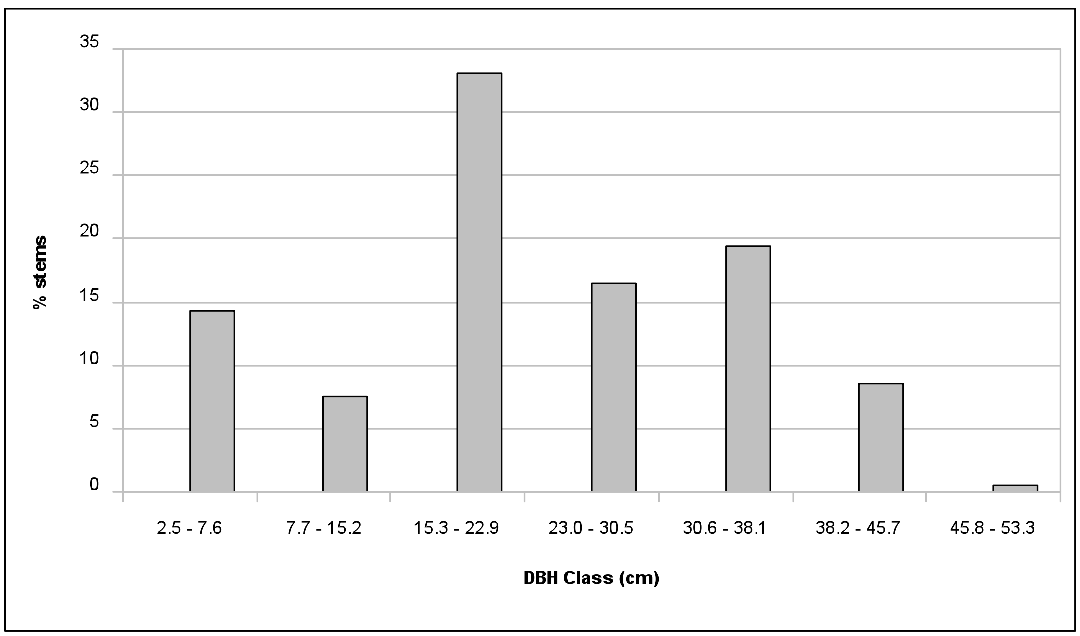


Figure 2. Percentage of stems by DBH Class, Parks (top chart) and Building series (bottom chart).

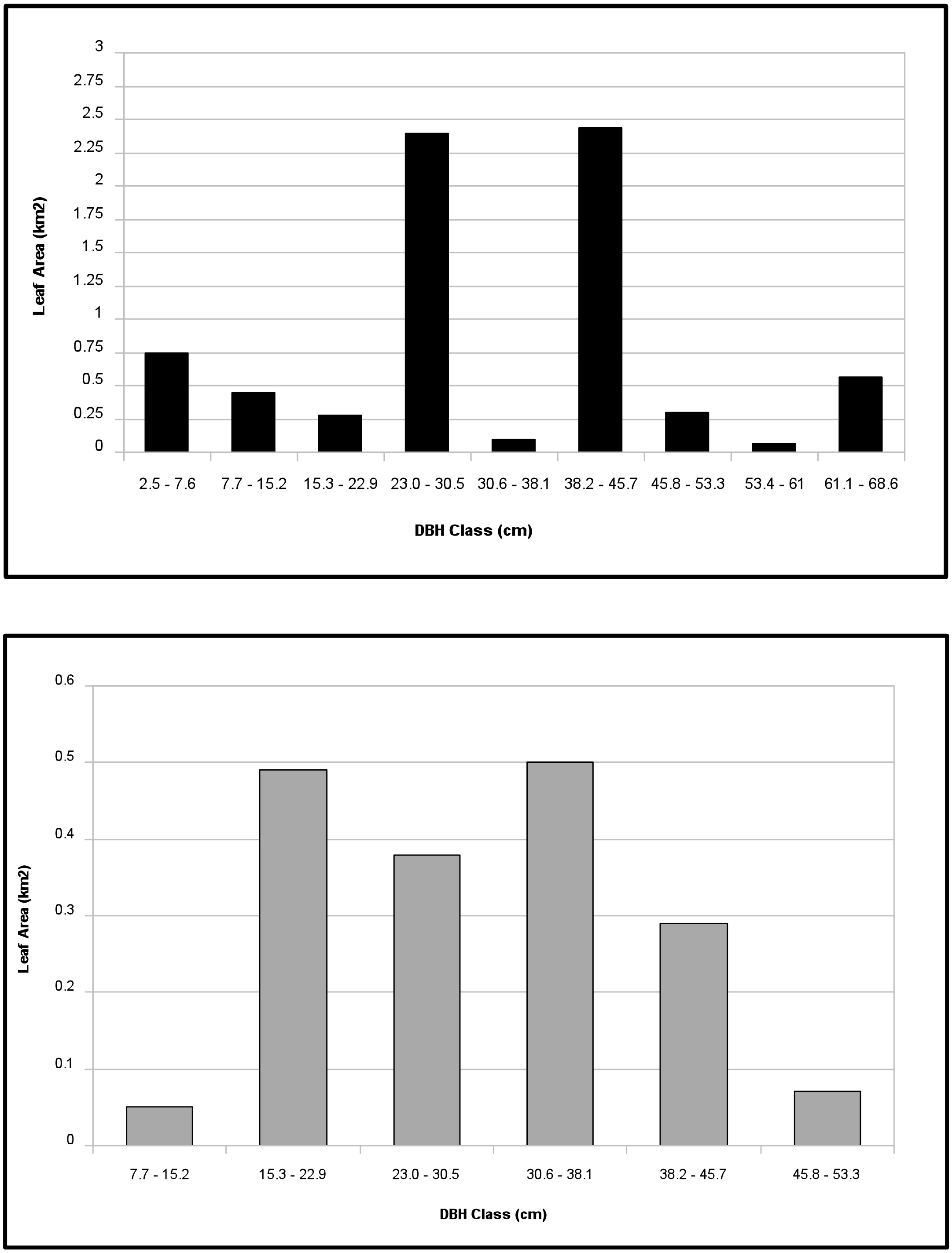


Figure 3. Cumulative species leaf area by DBH Class, Parks (top chart, black bars) and Building series (bottom chart, grey bars).

The percent of tree population distribution by DBH class in the Parks series was as follows (Appendix 4a): 84.8% of the *Rhamnus cathartica* (European buckthorn) had DBH of 2.5-7.6 cm 70% *Acer negundo* (Box elder) had a DBH between 2.5-15.2 cm, 100% of the *Ostrya virginiana* (Ironwood; designated *Parrotia spp*. in Appendices) had a DBH between 2.5-15.2 cm, 55.5% of *Carya cordiformis* (Bitternut hickory) at 2.5-22.9 cm and 44.5% at 23-45.7 cm) and finally 66.7% of *Acer saccharum* (Sugar maple) had a DBH of 2.5-7.6 cm. In the Building series the five most common tree species: 41.2% of *Ramnus cathartica* (European buckthorn) individuals had a DBH of 30.6-38.1 cm, 60% of the *Acer negundo* (Box elder) trees had a DBH of 23-30.5 cm, 75% of *Ostrya virginiana* (Ironwood; designated *Parrotia spp*. in Appendices) had a DBH of 15.3-22.9 cm, 100% of *Carya cordiformis* (Bitternut hickory) had a DBH of 2.5-7.6 cm, and 75% of *Acer saccharum* (Sugar maple) had a DBH of at 23-38.1 cm (Appendix 4b).

In total, 36 tree species (S) were identified on the Keele campus: 35 in the Parks series and 20 in the Buildings series (see Table 3). The Menhinick's diversity index for the Parks series was 2.94, and 2.6 for the Building series. Simpson's Diversity index, an indicator of species dominance, was 12.48 in the Parks series at, and 9.67 in the Building series.

Ground cover in the Parks series plots consisted of 3.5% cement, 4.8% bare soil, 0.8% mulch, 30.5% herbs, 34.3% maintained grass, 9.3% unmaintained grass and 7% water. Whereas, in the Building series, ground cover was composed of 34.3% cement, 3.4% bare soil, 2.6% mulch, 5.9% herbs, 21.3% maintained grass, 0.7% water, and 31.7% buildings. Thus, for the Keele campus as a whole, ground covers included: 29.7% cement, 5.1% bare soil, 2.3% mulch, 9.6% herbs, 23.3% maintained grass, 1.4% unmaintained grass, 1.1% water, 0.6% rock and 26.9% building (Figure 4).

Tree cover was 24.8% in the Parks series, 14.7% in the Building series, and 16.2% in the campus as a whole. Shrubs covered 7.9% of the Parks series, 31.7% of the Building series and 28.1% of the entire campus. The Parks series was estimated to contain 28.9% plantable space, the Building series 16.2% and 18.1% of the campus consisted of plantable space for trees and shrubs (Figure 5).

Within the Parks series, 69% of trees originate from North America, 26.1% are from Eurasia, 4.2% are from Europe and 0.7% of trees are Asian in origin. In the Building series 49.2% were from North America, 44.1% from Eurasia and 6.8% from Europe. In total 59.1% of trees on the Keele campus are of North American origin, 35.1% are from Eurasia and 5.5% of campus trees are of Asian origin (Figures 6).

Table 3 - Species richness and diversity indices: Parks and Buildings series.

	Primary Index						
	S	**SPP/HA**	**Shannon**	**Menhinick**	**Simpson's**	**Evenness**	**Rare fraction**
Parks	35	103.78	2.95	2.94	12.48	0.83	30.8
Buildings	20	23.72	2.58	2.6	9.67	0.86	17.3

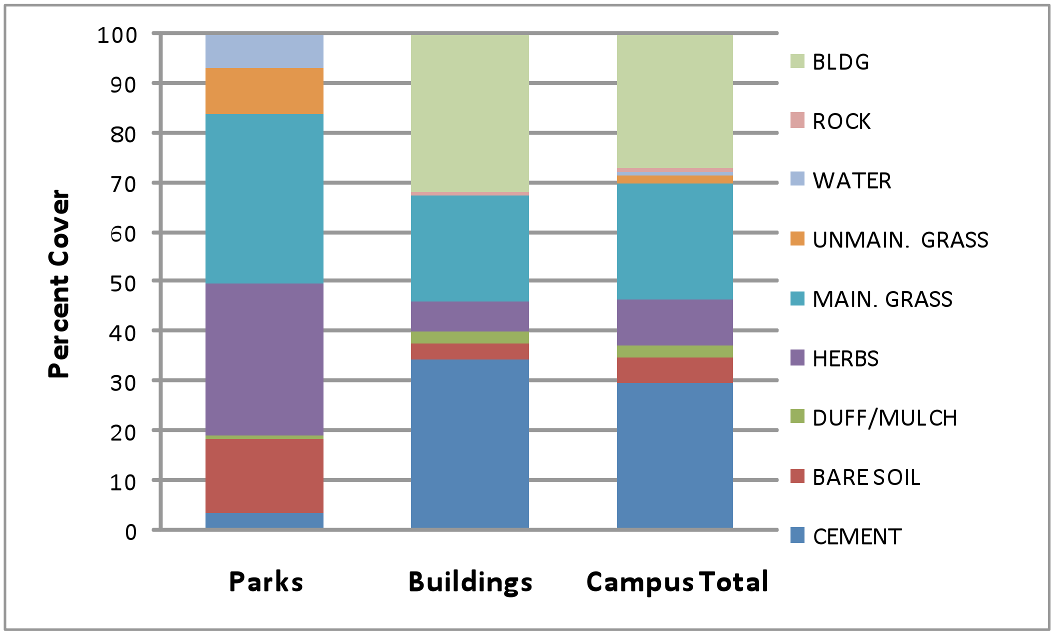


Figure 4. Percent ground cover composition in Parks, Buildings and campus total.

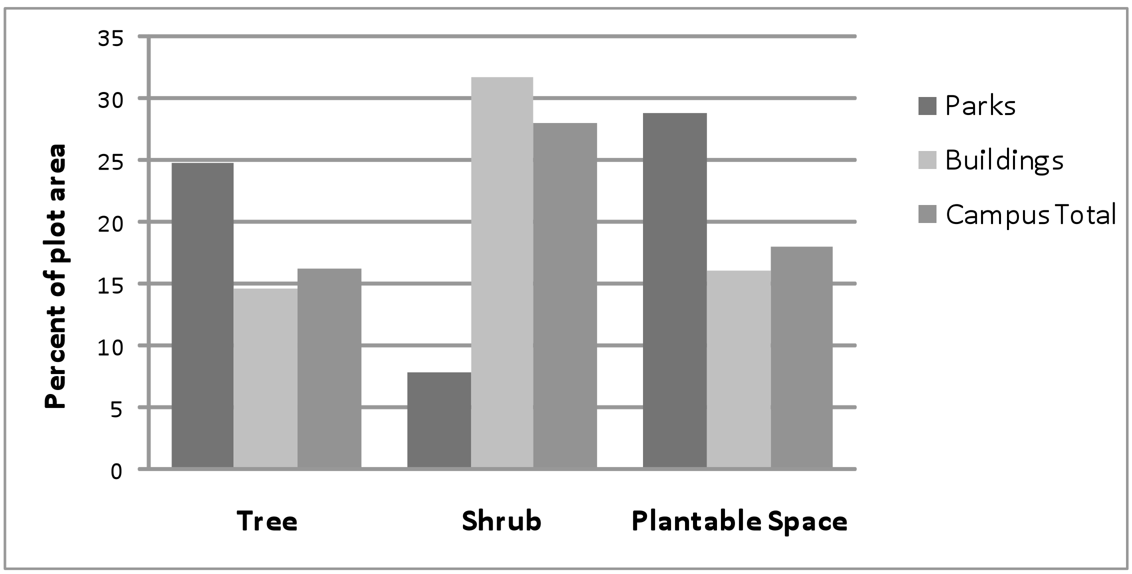


Figure 5. Percent of plot area covered by trees, shrubs, or plantable space in Parks, Buildings and campus total.

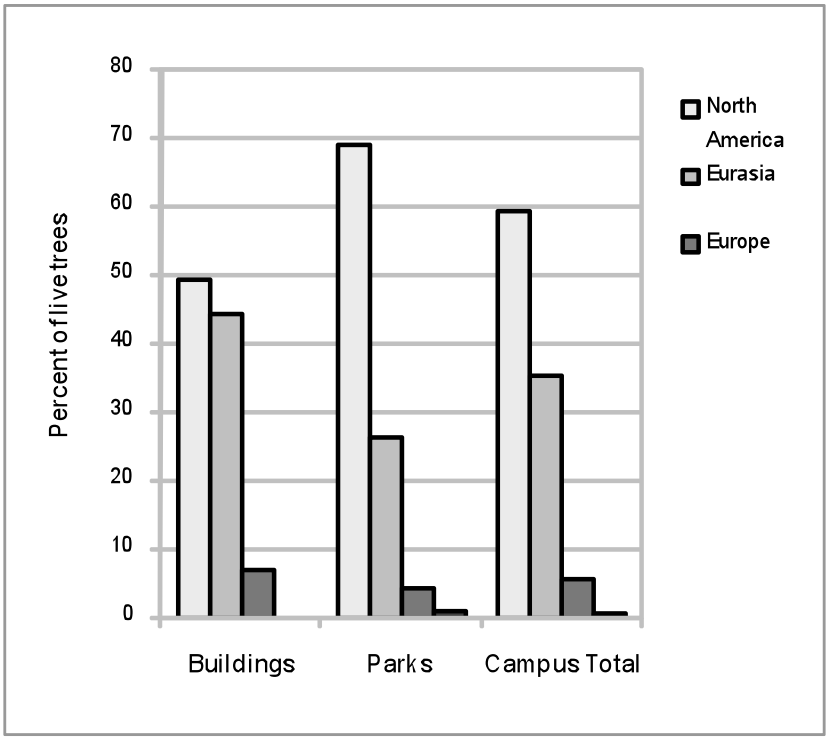


Figure 6. Percent of live trees by origin: Buildings, Parks and campus total.

3.2 CARBON SEQUESTRATION AND POLLUTION

The estimated amount of carbon stored in the Park areas was 82% of the total campus urban forest storage capability (see Table 4). The Park areas were estimated to store and sequester 4.8 times more carbon than the Buildings areas. The tree species providing the greatest Net Sequestration in the Parks series were: *Quercus bicolour* (Swamp white oak) (35.15 mt yr^{-1}), *Rhamnus cathartica* (European buckthorn) (21.78 mt yr^{-1}), *Acer saccharum* (Sugar maple) (19.35 mt yr^{-1}) and *Carya cordiformis* (Bitternut hickory) (16.24 mt yr^{-1}) (see Appendix 2a). In the Building series: *Acer negundo* (Boxelder) (7.42 mt yr^{-1}), *Rhamnus cathartica* (European buckthorn) (5.5 mt yr^{-1}), *Carpinus caroliniana* (American hornbeam) (5.35 mt yr^{-1}) and *Ulmus fulva* (Slippery elm) (3.52 mt yr^{-1}) (see Appendix 3a & b). Based on the total number of trees, leaf area and biomass, the most valuable species in terms of Net sequestration in the Parks series were: *Quercus bicolour* (Swamp white oak) (US$ 10,772,395), *Carya cordiformis* (Bitternut hickory) (US$ 3,692,895), *Acer saccharum* (Sugar maple) (US$ 3,125,799) and *Prunus serotina* (Black cherry) (US$ 2,834,255) (see Appendix 3a). Whereas the most valuable species in the Building series were: *Rhamnus cathartica* (European buckthorn) (US$ 8,937,579), *Acer saccharum* (Sugar maple) (US$ 1,799,796), *Juglans nigra* (Black walnut) (US$ 1,019,533) and *Carpinus caroliniana* (American hornbeam) (US$ 962,118) (see Appendix 3b).

Trees and shrubs in the Parks series were estimated to have removed a total of 8.51 mt of air pollutants (CO, NO, O_3, PM_{10}, SO_2), valued at US $46,706 (see Appendix 6a). Whereas, species within the Building series removed a total of 3.29 mt of air pollution, valued at US $18,232 (see Appendix 6b). In total trees and shrubs on campus removed 11.8 mt, valued at US $64,938 (refer to Appendix 3a and 3b). The amount of each pollutant (CO, NO, SO_2, O_3, PM_{10}) removed by trees and shrubs on Keele campus can be seen in Figures 7-11.

Table 4 - Estimated carbon storage and sequestration: Parks and Buildings series and campus total.

	Parks	Buildings	Campus Total
Carbon Storage (mt)	7,235	1,504	8,739
Carbon Storage Density (kg/ha)	36,718	7,632	22,175
Annual Carbon Sequestration (mt/yr)	263	64	327
Annual Carbon Sequestration Density (kg/yr/ha)	1,336	7,632	4,484

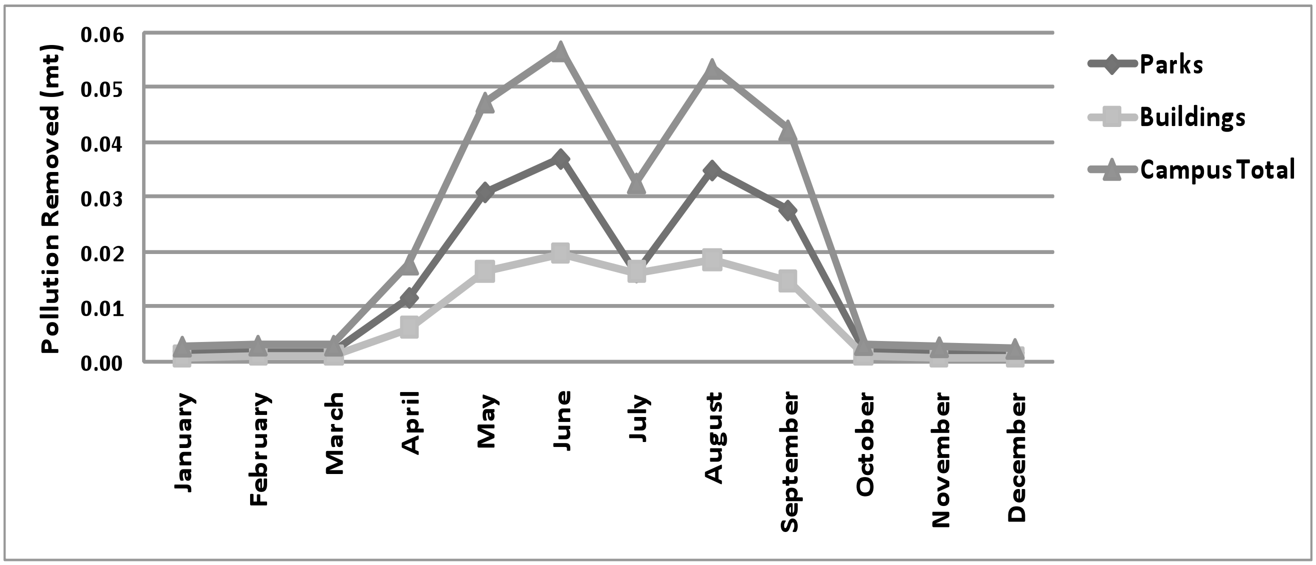


Figure 7. Monthly carbon monoxide (CO) removed by trees and shrubs.

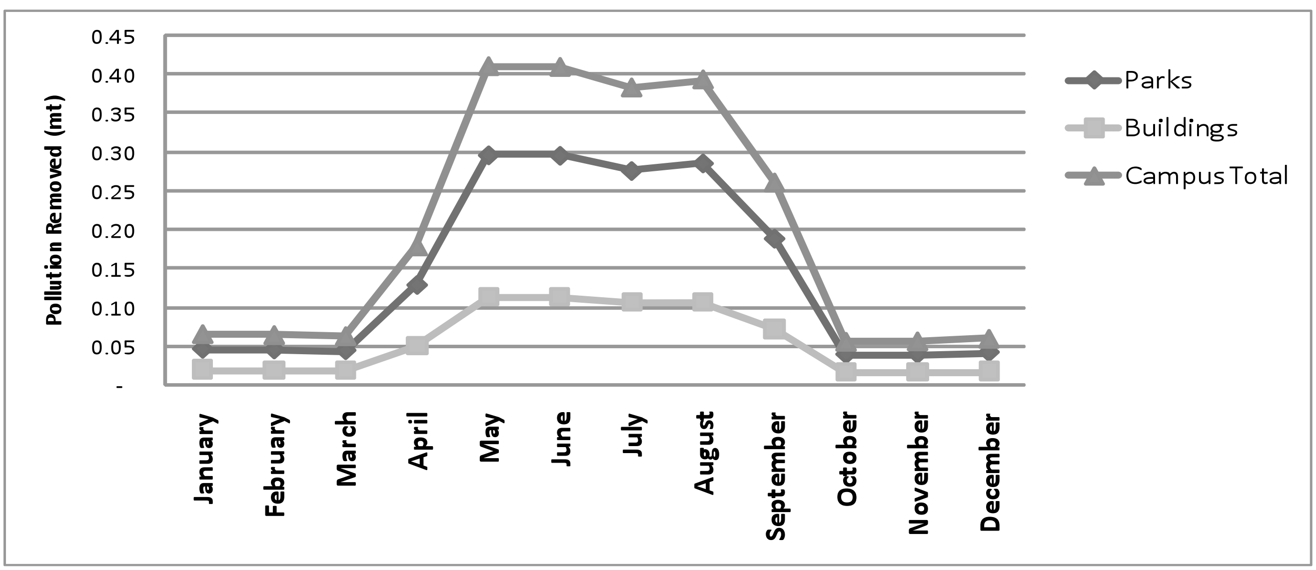


Figure 8. Monthly amount of nitric oxide (NO) removed by trees and shrubs.

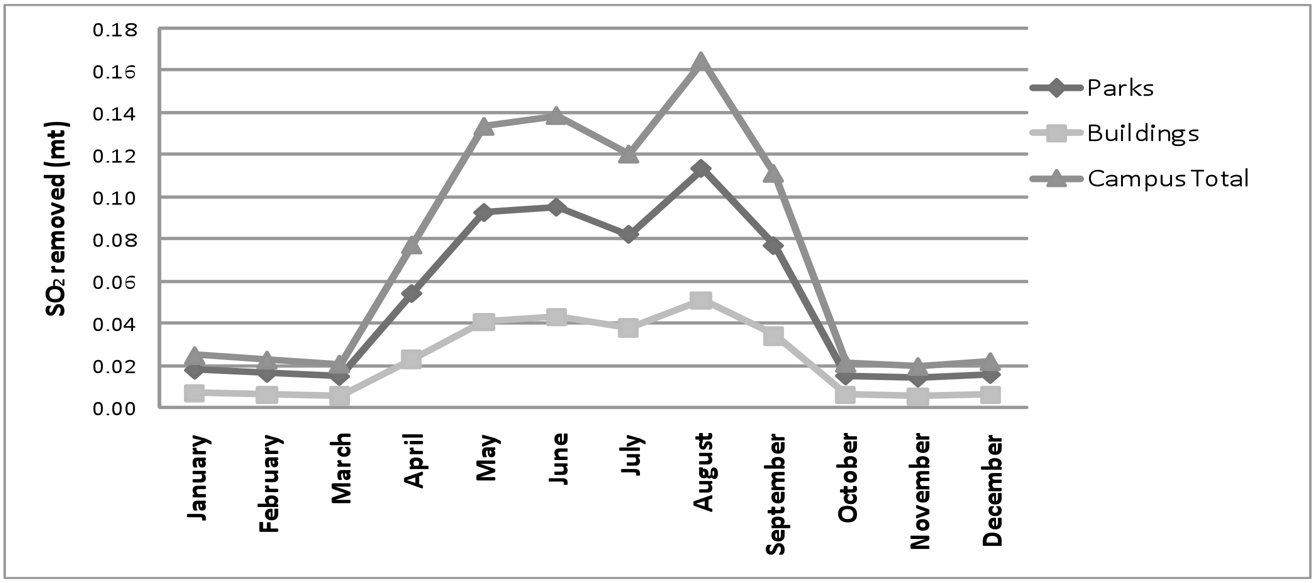


Figure 9. Monthly sulphur dioxide (SO_2) removed by trees and shrubs.

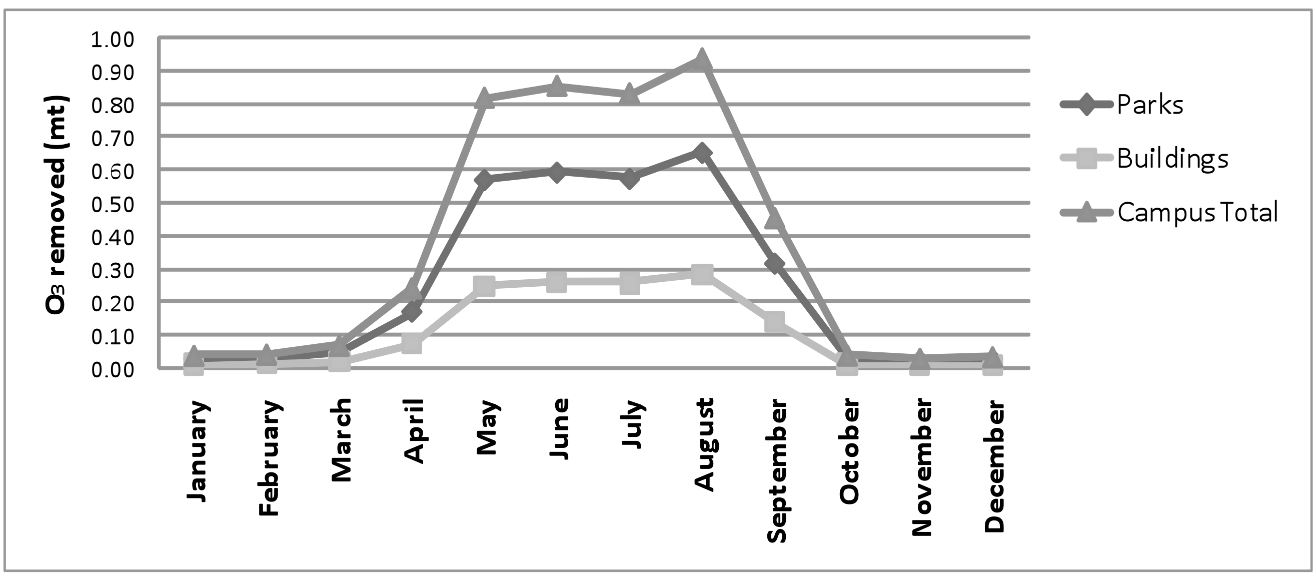


Figure 10. Monthly ground level ozone (O_3) removed by trees and shrubs.

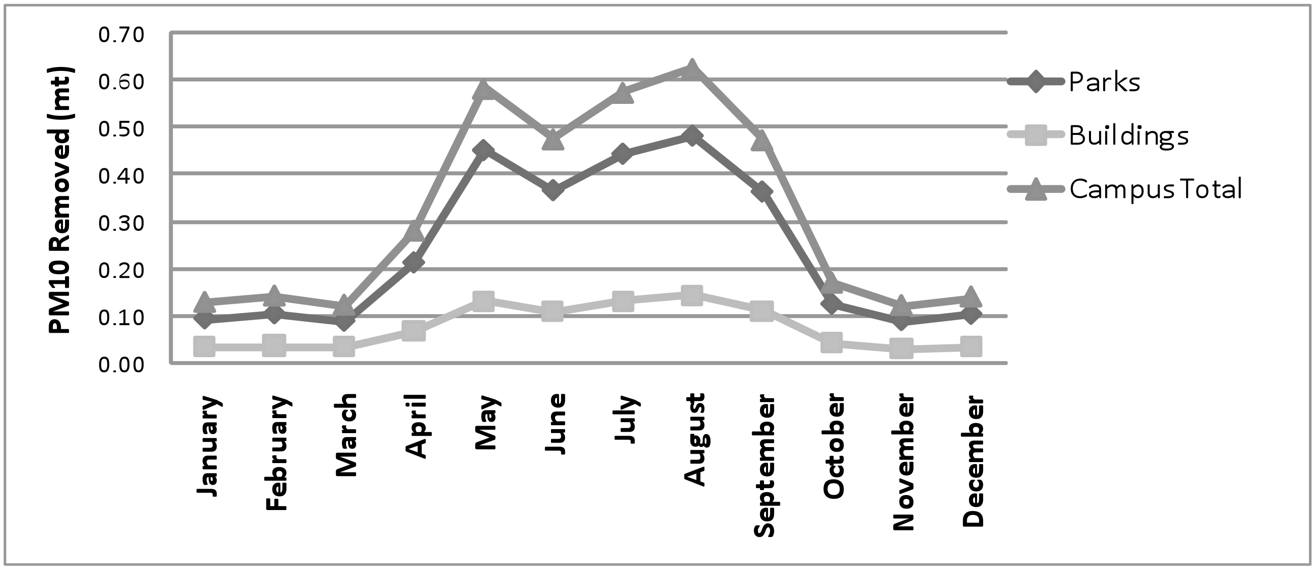


Figure 11. Monthly particulate matter (PM_{10}) removed by trees and shrubs.

3.3 FOREST HEALTH

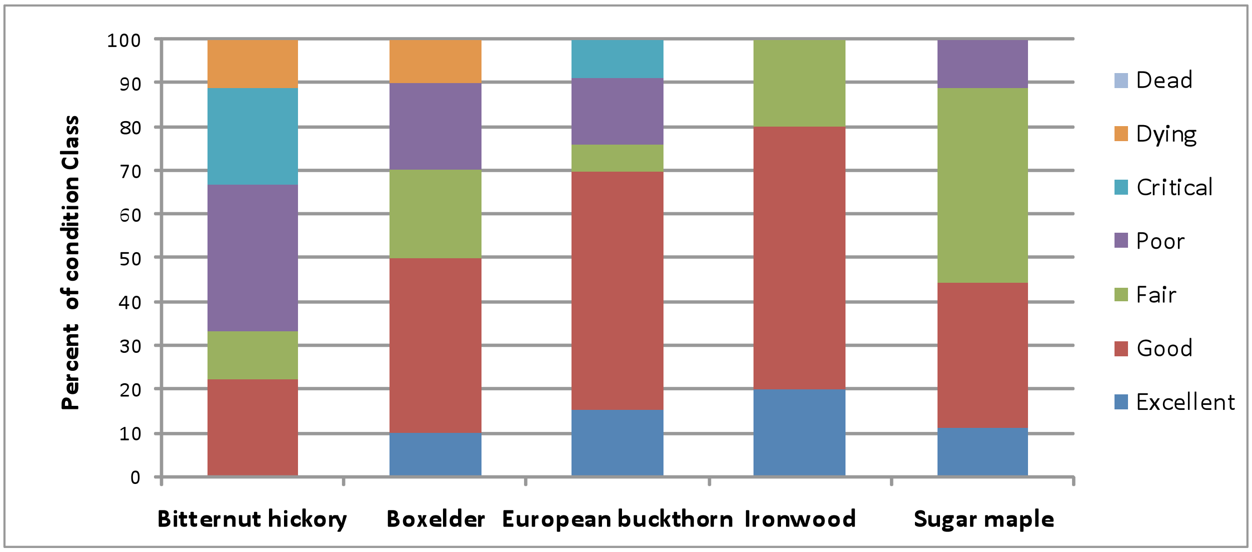
Over the last two centuries, a number of common North American forest trees have been affected by a variety of introduced or non-native insects and pathogens (Myers and Bazely, 2003). These include American Chestnut, *Castanea dentata*, which was wiped out by chestnut blight, and American Elm, *Ulmus americana*, which continues to be affected by Dutch Elm disease in Manitoba. These trees were once common both in forests and, in the case of elms, in towns throughout Ontario, where they were planted as street-shade trees. Recently introduced, invasive insects and pathogens continue to pose a significant threat to North American trees, and they include: Emerald Ash borer, Asian longhorned beetle and Hemlock Woolly adelgid moth (Kimoto and Duthie-Holt, 2006). The Keele campus is in the area of Toronto, which is known to have been invaded by Asian longhorned beetle.

In the Parks series, *Anoplophora glabripennis* (Asian longhorned beetle) could, in the worst-case scenario, potentially affect 29,798 trees valued at US $14 million. Within the Building series, this insect could impact 5,142 trees, valued at US $5,162,077. As such, on the campus as a whole, *A. glabripennis* could potentially infect 34,940 trees valued at US $19,236,032 (Appendix 7). The UFORE model indicated that *Lymantria dispar* (Gypsy moth) also poses a significant threat to York's urban forest. This invasive forest insect could potentially infest 11,101 trees (worth US $13,307,726) in the Parks series, and 2,805 (worth US $3,930,583) in the Buildings series. As a whole, there are 13,906 trees on Keele campus that are susceptible to *L. dispar* which are valued at US $17 million (Appendix 8).

Figure 12 shows the top five tree species and their health condition (see Appendices 10 a & b): *Rhamnus cathartica* (European buckthorn*)*, *Acer negundo* (Box elder) and *Ostrya virginiana* (Ironwood; designated as *Parrotia spp*. in Appendices) and *Acer saccharum* (Sugar maple). In the Parks series, the Bitternut hickory is the tree in worst condition with about 30% of trees categorized as being in critical condition or dying, while in the Building series the European buckthorn (an invasive species) seems to be in the worst condition. Ironwood is the healthiest tree in the Parks series (with condition from Excellent to Fair), while Bitternut hickory is the one in the best (Excellent) condition in the Buildings series.

The healthiest trees and shrubs in the Parks series (i.e. 100% of population in excellent condition) were found to be: *Picea pungens* (Blue spruce), *Syringa vulgaris* (Common lilac), *Pinus strobes* (Eastern white pine), *Amelanchier* spp. (Serviceberry) and *Abies concolor* (White fir) (see Appendix 10a); while the healthiest in the Building series were *Carya cordiformis* (Bitternut hickory) and *Prunus serotina* (Black cherry) (see Appendix 10a).

The most unhealthy trees in the Parks series (i.e. critical or dying) included: *Malus* spp. (Apple) (100% critical), *Prunus serotina* (Black cherry) (33.3% critical), *Carya cordiformis* (Bitternut hickory) (22.2% critical, 11.1% dying) and *Acer negundo* (Box elder) (10% dying) (see Appendices 10a & b); whereas, the most unhealthy trees in the Building series were: *Quercus bicolo*ur (Swamp white oak) (33.3% critical) and *Rhamnus cathartica* (European buckthorn) (11.8% critical and 5.9% dying) (see Appendix 10b).



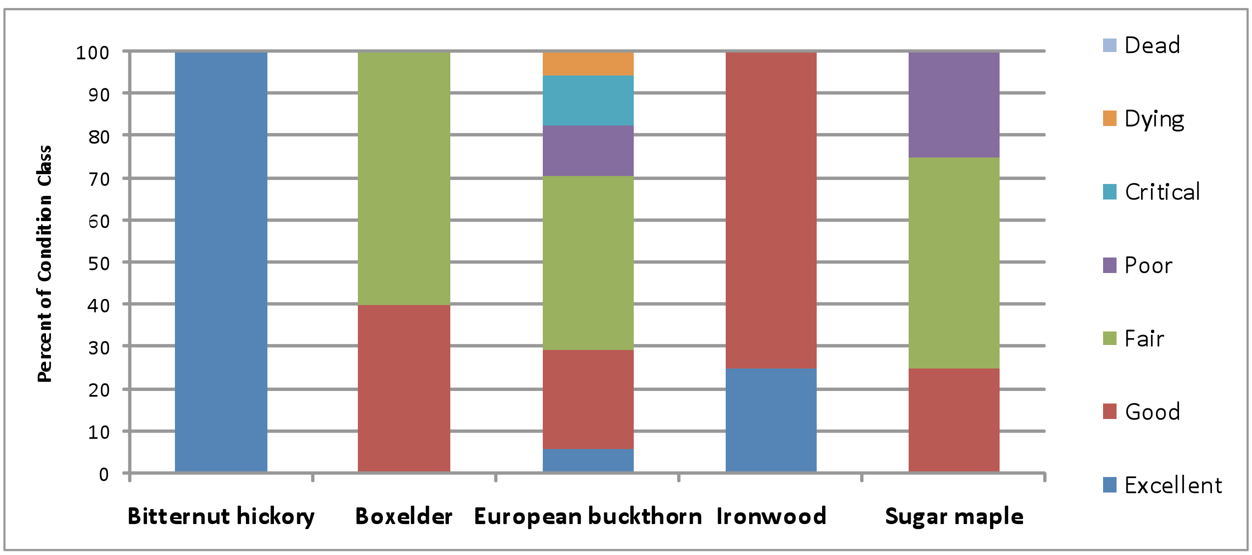


Figure 12. Percent in each condition class of the top five tree species: Parks series (top chart), Buildings series (bottom chart).

4. DISCUSSION

4.1 URBAN FOREST STRUCTURE AND ITS ROLE IN POLLUTION REMOVAL

In order to apply the UFORE protocol for field data collection to a small-scale case study, modifications were required. Specifically, the protocol prescribing the use of aerial photos for the identification of plots on the ground, in which there is a series of prescribed land use categories, was modified. The UFORE protocol assumes the existence of a GIS derived land use map, which was not the case for the Keele campus. Our solution was to create two data subsets or series (Parks and Buildings) to be analysed separately with the UFORE model and to be compared thereafter. We ensured that those two data sets (areas) did not have any type of land uses in common. In terms of the UFORE analysis this meant that the stratification by land use type was not possible, which was rather disappointing considering that we identified many different sub-categories of land use on York's Keele campus. While it will be possible in the future to create land use maps for Keele campus, and therefore use the UFORE GIS random plot selection method allowing for stratification, we view this as being a time-consuming option that is likely to be unfeasible for low budget, small-scale projects.

The modified methodology and the large scale differences between our study and those of cities and towns (e.g. Oakville and Toronto) mean that comparisons between the Keele campus results and those for municipalities must be made with caution. We identified 36 species in our 197 ha study area, while only 92 species were found in the 63,200 ha Toronto study (Kenney *et al*., 2001). Given the finer scale of our investigation we were more likely to identify more tree species and more of the less common species than the broader Toronto study. In addition, the woodlots were a more diverse habitat, and contained tree species that would not normally be found in cities where ornamentals are often preferentially planted. Density measurements are more useful when making comparisons with larger (area) studies: 63 species per ha on average on the Keele campus and 10 per ha in Toronto. Also, York's tree density was higher than Toronto's 119 trees/ha (Kenney et al., 2001), which again was not surprising, given that we sampled woodlots on the campus.

From our data it was clear that the Parks areas contributed much more to the Keele campus' urban forest than the Buildings areas, and also to the role played in air pollution removal and carbon sequestration. For instance, tree density in the Parks series was nearly six times that of the Building series. These differences are largely a result of variation in ground cover type: 66% of the Building area was impervious, while only 3.5% of the Parks area was impervious. However, while tree cover was 10% higher in Parks series, the Building series had nearly 24% more shrub cover.

The Parks area was also composed of 20% more native species (of North American origin) than the Buildings area. There were also differences in age distribution. A large portion (49%) of trees in the Parks series have a small diameter (under 8 cm), whereas only 14% of trees in the Building series were small diameter. This difference can largely be attributed to *Rhamnus cathartica* (European buckthorn) – which typically grows as a small tree, or large shrub. This introduced species (*Rhamnus cathartica,* European buckthorn) has invaded York's unmanaged woodlots and had the greatest leaf area of all species sampled. The large number of European buckthorn trees and shrubs on the campus is problematic. On the one hand they contribute to carbon sequestration and pollution mitigation, while on the other hand, they may be suppressing the regeneration of native trees and shrubs in the woodlots (Myers and Bazely, 2003).

While we did not measure canopy cover (which is not one of the UFORE metrics), leaf area may be used as a correlate. *Acer spp*. contributed the greatest leaf area in both the Toronto and Oakville studies (Kenney *et al*. 2001 and McNeil *et al*. 2006), but they comprised a smaller portion of the Keele campus' urban forest. *Abies concolor* (White fir), *Quercus bicolor* (Swamp white oak), *Rhamnus cathartica* (European buckthorn) were the species with highest leaf area at Keele.

The Keele campus' urban forest makes a major contribution to the mitigation of air pollution, mostly due to the presence of woodlots. The Parks series trees accounted for 72% of all pollution removed by York's urban forest, yet, these areas comprise only 15% of total campus area. In contrast, trees and shrubs in the Building series – which constituted 85% of the total campus area, removed 28% of the pollution sequestered by York's urban forest. The less common silver maples (*Acer saccharinum*) were more valuable, with 5 times the capacity to remove and store carbon, compared to the low levels of carbon sequestered by the many Austrian pines.

All findings illustrated the importance of (1) maximizing the use of plantable space in built areas and, (2) maintaining and enhancing healthy forest cover in the five woodlots and parkland areas.

4.2 FOREST HEALTH

The two insects identified as posing a major threat to Keele's urban forest were *Anoplophora glabripennis* and *Lymantria dispar*. In the worst case scenario, the UFORE model estimated that these pests could cost York approximately US $31 Million in tree damage.

Anoplophora glabripennis (Asian long-horned beetle) is a large shiny black beetle, 20 to 35 mm long and 7 to 12 mm wide in its adult form, which bores into and kills a wide variety of hardwood tree species (see Figure10). (Canadian Food Inspection Agency, 2006a). *Anoplophora glabripennis*'s host trees in North America include: *Acer* (Maple), *Aesculus* (Horsechesnut), *Albizia* (Silk tree), *Betula* (Birch), *Celtis* (Hackberry), *Platanus* (Sycamore), *Populus* (Poplar), *Salix* (Willow), *Sorbus* (Mountain Ash) and *Ulmus* (Elm) (Canadian Food Inspection Agency, 2006B). The susceptibility of *Alnus* (Alder), *Crataegus* (Hawthorn), *Elaeagnus* (Elaeagnus), *Fraxinus*(Ash), *Hibiscus* (Rosemallow), *Malus* (Apple), *Morus* (Mullberry), *Prunus* (Plum), *Pyrus* (Pear), *Quercus* (Oak), *Robinia* (Locust) and *Tilia* (Basswood) is still being determined (Canadian Food Inspection Agency, 2006a). The Asian long-horned beetle affects both healthy and weak trees. Young shoots wither and die as a result of feeding damage. Females chew oval niches to lay a single egg in the tree bark - which appear reddish brown at first in some species and may secrete a frothy sap – staining the bark over time. Niches can be found from ground level up the crown on braches at least 2 to 3 cm in diameter. Signs of advanced infestation include leaf yellowing and wilting, pre-mature leaf drop, branch dieback and eventually death. Other signs of infestation are caused as young larvae feed within the inner bark and sapwood, causing the bark to appear concave. Exit holes where adults chew through the wood are between 6 and 12 mm in diameter and appear anywhere on the larger, above-ground sections of the tree, including branches, truck and exposed roots (Canadian Food Inspection Agency, 2006a).

York University's Keele Campus lies within the Asian long-horned beetle Regulated Area. Until the pest has been eradicated, the Canadian Food Inspection Agency recommends that known host species should not be planted (Canadian Food Inspection Agency, 2006b). However, as our results indicate, many of these host species already constitute a substantial amount of forest cover, especially in the Parks series, where there are an estimated 29,798 host trees.

Lymantria dispar (Gypsy Moth) is a forest pest that defoliates healthy trees and can cause death in combination with other detrimental factors (Canadian Food Inspection Agency, 2006c). Males have a wing span of 35-40 mm and are brown in colour, whereas females are white, with a wingspan of 55-70 mm. The adult has dark crescent-shaped mark on forewings. The larva has five pairs of blue tubercles are followed by six pairs of red. *Quercus* (Oak) is the Gypsy moth's main host tree. Other species include, *Acer* (Maple), *Alnus* (Alder), *Betula* (Birch), *Crataegus* (Hawthorn), *Fagus* (Beech), *Malus* (Apple), *Populus* (Poplar), *Prunus* (Plum), *Salix* (Willow), *Tilia* (Basswood) and many other tree and shrub species (Canadian Food Inspection Agency, 2006c). Females lay egg masses which can be found on tree bark, branches and near other protected areas (e.g. fallen logs, lawn furniture/equipment). As larvae grow they feed on foliage – making large holes in leaves and consuming the leaf margin. Large infestations can completely defoliate a tree – whereas feeding is often barely noticeable at low populations. Tree mortality typically occurs after at least four subsequent years of infection or in combination with other insects or diseases (Canadian Food Inspection Agency, 2006c).

5. CONCLUSIONS AND RECOMMENDATIONS

The successful implementation of the UFORE protocol by informed amateur naturalists and other community members, who have some knowledge of trees and shrubs (e.g. trained Landscape Architects, aided by volunteers) is a challenge. Where members of these groups are professionally trained in forestry or ecology at the postgraduate level, then successful local, community-driven applications of UFORE are feasible. In the absence of such professional support, a simplified protocol would need to be developed, which should include an alternative to the GIS-driven plot selection. This GIS-driven approach and the lack of land-use stratification options for our small-scale study significantly limited the potential power of the UFORE analysis. Nevertheless, there has been much campus-based interest in our project, and it has produced useful and interesting results for the campus community to discuss and debate. We therefore strongly suggest that the UFORE methodology be simplified and adapted so as to be applicable to small-scale, low-tech, low-budget studies.

There is an obvious need for management and conservation of existing vegetation on the Keele campus. Given the enormous negative impact that invasive species have on biodiversity, and the wealth of knowledge available within York's academic community, we also propose that York should lead by example and move towards preferentially planting native species on campus.

We make the following specific recommendations:

- The planting of native trees with high carbon net storage such as: sugar maple, bitternut hickory, and swamp white oak, or trees with high carbon removal capacity, such as silver maple.
- The planting of trees in the areas identified as plantable, especially in and around parking lots.
- The routine inspection of trees for signs of Asian longhorned beetle and gypsy moth infestation and removal of infected individuals.
- The consideration of potential management to remove the invasive European buckthorn in the woodlots. There is much debate and discussion of this issue in municipalities across southern Ontario.
- Every 2-5 years sampling of permanent plots for ongoing long-term monitoring of forest health, especially of the five woodlots.

Suggested future studies include:

- Add UFORE measurements to existing plots to estimate Energy savings.
- Estimates of canopy cover.
- Create a specific Keele land use type map.

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APPENDIX 1A. PARKS SERIES: LEAF AREA AND BIOMASS FOR TREES AND SHRUBS SPECIES.

		Density		Total	
Common name	Scientific name	Leaf Area (m^2/ha)	Leaf Biomass (kg/ha)	Leaf Area (km^2)	Leaf Biomass (mt)
American basswood	*Tilia americana*	205.40	6.00	0.04	1.18
American hornbeam	*Carpinus caroliniana*	708.97	42.71	0.14	8.42
Amur maple	*Acer ginnala*	55.74	3.14	0.01	0.62
Apple	*Malus species*	154.67	13.33	0.03	2.63
Ash	*Fraxinus species*	50.34	3.28	0.01	0.65
Austrian pine	*Pinus nigra*	893.81	86.14	0.18	16.97
Balsam fir	*Abies balsamea*	57.84	6.03	0.01	1.19
Bitternut hickory	*Carya cordiformis*	1,339.13	84.18	0.26	16.59
Black cherry	*Prunus serotina*	684.28	53.07	0.13	10.46
Black maple	*Saccharodendron nigrum*	1061.93	59.77	0.21	11.78
Black spruce	*Picea mariana*	0.75	0.14		0.03
Black walnut	*Juglans nigra*	378.81	30.36	0.07	5.98
Blue spruce	*Picea pungens*	3.08	0.52		0.10
Boxelder	*Acer negundo*	1,214.58	111.11	0.24	21.89
Bur oak	*Quercus macrocarpa*	208.69	19.15	0.04	3.77
Button bush	*Cephalanthus occidentalis*	4.07	0.30		0.06
Cherry plum	*Prunus cerasifera*	116.14	7.06	0.02	1.39
Common chokecherry	*Prunus virginiana*	401.24	31.1	0.08	6.13
Common juniper	*Juniperus communis*	864	240	0.17	47.29
Common lilac	*Syringa vulgaris*	235.8	22.75	0.05	4.48
Dead/Unknown		47.57	6.70	0.01	1.32
Dwarf honeysuckle	*Lonicera xylosteum*	34.20	1.68	0.01	0.33
Eastern white pine	*Pinus strobus*	164.72	10.59	0.03	2.09
European buckthorn	*Rhamnus cathartica*	3,620.08	160.89	0.71	31.70
European larch	*Larix decidua*	46.81	2.52	0.01	0.50
Grape	*Vitis*	28.16	1.88	0.01	0.37
Hawthorn	*Crataegus*	326.31	24.58	0.06	4.84
Ironwood	*Parrotia species*	721.4	53.81	0.14	10.6
Low serviceberry	*Amelanchier humilis*	19.71	1.49		0.29
Nannyberry	*Viburnum lentago*	73.29	5.47	0.01	1.08
Northern red oak	*Quercus rubra*	33.49	2.67	0.01	0.53
Norway maple	*Acer platanoides*	116.06	6.26	0.02	1.23
Norway spruce	*Picea abies*	1,621.21	270.2	0.32	53.24
Peachleaf willow	*Salix amygdaloides*	1,461.63	90.22	0.29	17.78
Pin cherry	*Prunus pensylvanica*	21.6	1.04		0.21
Plum	*Prunus species*	47.55	3.55	0.01	0.7
Red currant	*Ribes rubrum var. alaskanum*	4.07	0.30		0.06
Red hickory	*Carya ovalis*	287.46	15.07	0.06	2.97
Red maple	*Acer rubrum*	40.04	2.70	0.01	0.53
Serviceberry	*Amelanchier*	179.16	10.92	0.04	2.15
Silver maple	*Acer dasycarpum*	1,057.31	55.65	0.21	10.97
Slippery elm	*Ulmus fulva*	520.28	23.29	0.10	4.59
Smooth service berry	*Amelanchier laevis*	126.64	9.59	0.02	1.89
Spindletree	*Euonymus*	146.47	10.92	0.03	2.15
Sugar maple	*Acer saccharum*	2,315.88	139.51	0.46	27.49
Swamp white oak	*Quercus bicolor*	5,539.08	508.3	1.09	100.16
Tartarian honeysuckle	*Lonicera tatarica*	91.32	4.50	0.02	0.89
Virginia creeper	*Parthenocissus quinquefolia*	35.48	1.74	0.01	0.34
White fir	*Abies concolor*	7,724.31	1,087.93	1.52	214.38
TOTAL		**35,090.57**	**3,334.14**	**6.91**	**656.99**

APPENDIX 1B. BUILDING SERIES: LEAF AREA AND BIOMASS FOR TREES AND SHRUBS SPECIES.

		Density		Total	
Common name	Scientific name	Leaf Area (m^2/ha)	Leaf Biomass (kg/ha)	Leaf Area (km^2)	Leaf Biomass (mt)
American basswood	*Tilia americana*	5.87	0.37		0.07
American hornbeam	*Carpinus caroliniana*	521.8	39.3	0.1	7.74
Amur maple	*Acer ginnala*	305.91	15.07	0.06	2.97
Apple	*Malus species*	46.12	2.27	0.01	0.45
Austrian pine	*Pinus nigra*	37.43	2.79	0.01	0.55
Balsam fir	*Abies balsamea*	186.87	13.21	0.04	2.6
Bitternut hickory	*Carya cordiformis*	148.92	14.37	0.03	2.83
Black maple	*Saccharodendron nigrum*	213.12	59.2	0.04	11.67
Black walnut	*Juglans nigra*	786.52	22.96	0.15	4.52
Blue spruce	*Picea pungens*	32.75	2.44	0.01	0.48
Boxelder	*Acer negundo*	863.47	51.28	0.17	10.1
Bur oak	*Quercus macrocarpa*	36.85	2.79	0.01	0.55
Common chokecherry	*Prunus virginiana*	28.94	1.76	0.01	0.35
Common juniper	*Juniperus communis*	22.3	2.98		0.59
Common lilac	*Syringa vulgaris*	147.52	25.03	0.03	4.93
Dead/Unknown		58.92	3.77	0.01	0.74
Eastern white pine	*Pinus strobus*	30.53	2.28	0.01	0.45
European buckthorn	*Rhamnus cathartica*	2,156.57	207.85	0.42	40.96
European larch	*Larix decidua*	52.89	6.37	0.01	1.26
Green ash	*Fraxinus campestris*	89.9	9.41	0.02	1.86
Hawthorn	*Crataegus species*	3.98	0.21		0.04
Ironwood	*Parrotia species*	690.7	37.28	0.14	7.35
Nannyberry	*Viburnum lentago*	285.22	22.73	0.06	4.48
Northern red oak	*Quercus rubra*	28.06	1.05	0.01	0.21
Norway maple	*Acer platanoide*	107.9	11.92	0.02	2.35
Norway spruce	*Picea abies*	299.09	48.05	0.06	9.47
Peachleaf willow	*Salix amygdaloides*	27.95	1.24	0.01	0.24
Plum	*Prunus species*	43.7	2.15	0.01	0.42
Red hickory	*Carya glabra var. odorata*	53.7	4.01	0.01	0.79
Red maple	*Acer rubrum*	0	5.44	0.01	1.07
Silver maple	*Acer dasycarpum*	180.51	13.68	0.04	2.69
Slippery elm	*Ulmus fulva*	363.92	21.92	0.07	4.32
Smooth service berry	*Amelanchier laevis*	66.06	0.01	0.02	0
Sugar maple	*Acer saccharum*	895.36	58.4	0.18	11.51
Swamp white oak	*Quercus bicolor*	242.35	12.76	0.05	2.51
White fir	*Abies concolor*	114.63	6.17	0.02	1.22
TOTAL		**9,249.33**	**736.35**	**1.82**	**145.1**

APPENDIX 2A. PARKS SERIES: LEAF AREA AND BIOMASS FOR TREES BY DBH CLASS.

	DBH Classes (cm)	2.5- 7.6		7.7 - 15.2		15.3 - 22.9		23.0 - 30.5	
Common name	Scientific name	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)
American basswood	*Tilia americana*	0.02	0.59						
American hornbeam	*Carpinus caroliniana*	0.08	4.98			0.03	3.14		
Amur maple	*Acer ginnala*	0.01	0.62			0.02	1.23		
Apple	*Malus species*							1.52	214.38
Austrian pine	*Pinus nigra*			0.07	5.2			0.07	5.66
Balsam fir	*Abies balsamea*	0.01	1.19	0.03	1.47				
Bitternut hickory	*Carya cordiformis*		0.25	0.05	4.21				
Black cherry	*Prunus serotina*		0.17						
Black maple	*Saccharodendron nigrum*					0.04	3.85		
Black walnut	*Juglans nigra*		0.18	0.06	2.65				
Blue spruce	*Picea pungens*		0.1	0.05	2.55				
Boxelder	*Acer negundo*	0.03	3.18			0.03	2.09		
Bur oak	*Quercus macrocarpa*	0.03	2.91	0.06	3.48				
Common chokecherry	*Prunus virginiana*	0.04	3.17						
Common lilac	*Syringa vulgaris*	0.01	0.71					0.01	0.53
Eastern white pine	*Pinus strobus*					0.02	1.21	0.08	4.77
European buckthorn	*Rhamnus cathartica*	0.23	10.25	0.02	0.59				
European larch	*Larix decidua*	0.01	0.5						
Green ash	*Fraxinus campestris*	0.01	0.63						
Ironwood	*Parrotia species*	0.01	0.7	0.01	0.86				
Nannyberry	*Viburnum lentago*	0.01	0.69	0.04	4.03	0.01	0.65		
Northern red oak	*Quercus rubra*	0.01	0.53					0.31	51.39
Norway maple	*Acer platanoides*							0.05	4.3
Norway spruce	*Picea abies*							0.17	10.41
Peachleaf willow	*Salix amygdaloides*					0.01	0.28		
Red hickory	*Carya glabra var. odorata*			0.01	1.85				
Red maple	*Acer rubrum*								
Silver fir	*Abies alba*							0.02	0.69
Silver maple	*Acer dasycarpum*				0.28	0.06	2.97		
Slippery elm	*Ulmus fulva*	0.03	1.25						
Smooth service berry	*Amelanchier arborea ssp. laevis*	0.02	1.89			0.06	2.65		
Sugar maple	*Acer saccharum*	0.11	6.57	0.05	3.01				
Swamp white oak	*Quercus bicolor*							0.15	8.14
Unknown		0.07	5.4						
White fir	*Abies concolor*							0.01	1.32
Apple	*Malus species*								
Austrian pine	*Pinus nigra*			0.08	5.07				
Balsam fir	*Abies balsamea*					0.1	7.56	0.03	2.3
Bitternut hickory	*Carya cordiformis*	0.03	1.72	0.18	16.97				
Black cherry	*Prunus serotina*			0.21	11.78				
Black maple	*Saccharodendron nigrum*			0.12	11.35				

APPENDIX 2A CONT. PARKS SERIES: LEAF AREA AND BIOMASS FOR TREES BY DBH CLASS.

	DBH classes (cm)	30.6 - 38.1		38.2 - 45.7		45.8 - 53.3		53.4 - 61		61.1 - 68.6	
Common name	Scientific name	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)
Boxelder	*Acer negundo*										
European buckthorn	*Rhamnus cathartica*	0.07	2.93					0.03	2.63		
Peachleaf willow	*Salix amygdaloides*			0.29	17.78						
Sugar maple	*Acer saccharum*			0.15	9.29						
Swamp white oak	*Quercus bicolor*			0.19	17.03	0.2	17.98			0.56	51.56
White fir	*Abies concolor*			1.22	89.27						

APPENDIX 2B. BUILDING SERIES: LEAF AREA AND BIOMASS FOR TREES BY DBH CLASS.

DBH classes (cm)		7.7 - 15.2		15.3 - 22.9		23.0 - 30.5		30.6 - 38.1		38.2 - 45.7		45.8-53.3	
Common name	Scientific name	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)	Leaf Area (km^2)	Biomass (mt)
American basswood	*Tilia americana*				0.07								
American hornbeam	*Carpinus caroliniana*					0.02	1.53	0.08	6.2				
Balsam fir	*Abies balsamea*					0.04	2.6						
Black walnut	*Juglans nigra*							0.05	1.58				
Boxelder	*Acer negundo*			0.05	3.11	0.08	5.03						
Common chokecherry	*Prunus virginiana*			0.01	0.75								
Common lilac	*Syringa vulgaris*							0.03	4.92				
European buckthorn	*Rhamnus cathartica*			0.02	2.02	0.05	5.07	0.03	2.93				
Green ash	*Fraxinus campestris*			0.02	1.85								
Nannyberry	*Viburnum lentago*												
Norway spruce	*Picea abies*							0.06	9.45				
Silver fir	*Abies alba*	0.01	0.74										
Silver maple	*Acer dasycarpum*					0.03	1.94						
Slippery elm	*Ulmus fulva*	0.01	0.51	0.06	3.8								
Sugar maple	*Acer saccharum*			0.01	0.83	0.03	1.88	0.1	6.53				
Swamp white oak	*Quercus bicolor*			0.02	1.27	0.02	0.99						
Unknown		0.01	0.47	0.13	6.86								
White fir	Abies concolor			0.02	1.21								
Black walnut	*Juglans nigra*									0.1	2.93	0.07	6.74
European buckthorn	*Rhamnus cathartica*									0.13	12.56		
Nannyberry	*Viburnum lentago*									0.06	4.47		

APPENDIX 3A. PARKS SERIES: TOTAL ESTIMATES FOR TREES BY SPECIES.

Species		Number of Trees	Carbon (mt)	Gross Seq (mt/yr)	Net Seq (mt/yr)	Leaf Area (km^2)	Leaf Biomass (mt)	Values (US$)
Common name	Scientific name							
American basswood	*Tilia americana*	1753	11.82	1.71	1.59	0.04	1.18	82,189
American hornbeam	*Carpinus caroliniana*	3506	13.03	3.15	3.07	0.133	7.98	162,269
Amur maple	*Acer ginnala*	584	0.58	0.3	0.3	0.011	0.62	29,141
Apple	*Malus species*	584	455.54	5.19	-4.6	0.03	2.63	1,008,445
Austrian pine	*Pinus nigra*	584	92.22	3.04	2.83	0.176	16.97	1,509,087
Balsam fir	*Abies balsamea*	584	2.23	0.35	0.31	0.011	1.19	13,041
Bitternut hickory	*Carya cordiformis*	5259	732.97	27.88	16.24	0.254	15.95	3,692,895
Black cherry	*Prunus serotina*	1753	1023.24	17.2	-1.82	0.129	10.04	2,834,255
Black maple	*Saccharodendron nigrum*	584	321.06	9.55	8.83	0.209	11.78	2,052,819
Black walnut	*Juglans nigra*	1753	197.89	9.31	7.4	0.073	5.85	1,228,709
Blue spruce	*Picea pungens*	584	0.37	0.2	0.2	0.001	0.1	31,551
Boxelder	*Acer negundo*	5843	382.59	15.92	9.96	0.237	21.7	1,319,922
Bur oak	*Quercus macrocarpa*	2921	13.84	3.03	2.98	0.041	3.77	153,864
Common chokecherry	*Prunus virginiana*	3506	4.18	1.9	1.88	0.041	3.17	128,062
Common lilac	*Syringa vulgaris*	1169	1.05	0.51	0.5	0.007	0.71	70,114
Eastern white pine	*Pinus strobus*	584	22.38	1.58	1.52	0.032	2.09	391,465
European buckthorn	*Rhamnus cathartica*	19281	254.96	23.24	21.78	0.389	17.3	2,092,412
European larch	*Larix decidua*	584	0.18	0.12	0.12	0.009	0.5	29,141
Green ash	*Fraxinus campestris*	1169	1.73	0.8	0.78	0.01	0.63	55,828
Ironwood	*Parrotia species*	584	1.7	0.5	0.49	0.009	0.7	22,724
Nannyberry	*Viburnum lentago*	1169	6.53	1.16	1.08	0.013	0.97	44,894
Northern red oak	*Quercus rubra*	584	1.52	0.37	0.34	0.007	0.53	22,007
Norway maple	*Acer platanoides*	584	35.6	2.69	2.61	0.023	1.23	253,917
Norway spruce	*Picea abies*	1169	119.69	5.31	5	0.319	53.24	1,045,618
Peachleaf willow	*Salix amygdaloides*	584	250.77	8.78	8.21	0.288	17.78	1,268,826
Red hickory	*Carya glabra var. odorata*	584	51.18	3.75	3.63	0.057	2.97	400,700
Red maple	*Acer rubrum*	584	70.11	4.24	4.08	0.008	0.53	520,372
Silver fir	*Abies alba*	1169	68.7	0.42	-5.2	0.009	1.32	113,787
Silver maple	*Acer dasycarpum*	2921	254.38	14.95	13.8	0.208	10.96	906,577
Slippery elm	*Ulmus fulva*	4090	72	6.48	5.62	0.103	4.59	487,802
Smooth service berry	*Amelanchier arborea ssp. laevis*	584	1.5	0.46	0.46	0.025	1.89	30,675
Sugar maple	*Acer saccharum*	5259	494.26	22.66	19.35	0.456	27.48	3,125,799
Swamp white oak	*Quercus bicolor*	4674	2094.62	56.05	35.15	1.078	98.93	10,772,395
Unknown		5843	42.62	7.85	7.7	0.142	10.6	290,374
White fir	*Abies concolor*	584	138.2	2.5	2.19	1.522	214.38	766,259

APPENDIX 3B. BUILDING SERIES: TOTAL ESTIMATES FOR TREES BY SPECIES

Species		Number of Trees	Carbon (mt)	Gross Seq (mt/yr)	Net Seq (mt/yr)	Leaf Area (km^2)	Leaf Biomass (mt)	Values (US$)
Common name	Scientific name							
American basswood	*Tilia americana*	234	14.19	0.18	-1.8	0.001	0.07	17,932
American hornbeam	*Carpinus caroliniana*	701	128.84	6.33	5.35	0.103	7.74	962,118
Balsam fir	*Abies balsamea*	234	39.23	1.84	0.84	0.037	2.6	227,105
Bitternut hickory	*Carya cordiformis*	935	1.71	0.59	0.58	0.022	2.14	70,114
Black cherry	*Prunus serotina*	234	11.9		-3.27			
Black walnut	*Juglans nigra*	467	88.34	3.08	1.65	0.155	4.52	1,019,533
Boxelder	*Acer negundo*	1169	122.8	8.3	7.42	0.17	10.1	923,125
Bur oak	*Quercus macrocarpa*	467	2.32	0.53	0.51	0.007	0.55	29,908
Common chokecherry	*Prunus virginiana*	467	0.57	0.24	0.24	0.006	0.35	30,675
Common lilac	*Syringa vulgaris*	234	52.52	1.93	1.73	0.029	4.93	724,220
European buckthorn	*Rhamnus cathartica*	3973	574.34	17.05	5.5	0.425	40.96	8,937,579
Green ash	*Fraxinus campestris*	234	10.14	0.92	0.88	0.018	1.86	84,729
Nannyberry	*Viburnum lentago*	234	86.74	3.37	2.55	0.056	4.48	798,701
Norway spruce	*Picea abies*	234	40.56	1.6	1.45	0.059	9.47	529,164
Silver fir	*Abies alba*	234	3.73	0.51	0.5	0.012	0.74	24,323
Silver maple	*Acer dasycarpum*	467	31.83	2.33	2.2	0.036	2.69	328,633
Slippery elm	*Ulmus fulva*	701	45.66	3.7	3.52	0.072	4.32	342,264
Sugar maple	*Acer saccharum*	935	105.13	3.8	2.83	0.176	11.51	1,799,796
Swamp white oak	*Quercus bicolor*	701	73.26	2.26	0.28	0.048	2.51	486,451
Unknown		935	59.11	4.3	4.07	0.136	7.35	495,971
White fir	*Abies concolor*	234	11.01	0.96	0.91	0.023	1.22	94,937

APPENDIX 4A. PARKS SERIES: PERCENT OF TREE (STEMS) POPULATION BY DBH CLASS.

Species		DBH Class (cm)								
		2.5 – 7.6	7.7 - 15.2	15.3 – 22.9	23.0 - 30.5	30.6 - 38.1	38.2 - 45.7	45.8 - 53.3	53.4 - 61.0	68.7 - 76.2
Common name	Scientific name									
American basswood	*Tilia americana*	33.3	66.7							
American hornbeam	*Carpinus caroliniana*	83.3	16.7							
Amur maple	*Acer ginnala*	100								
Apple	*Malus species*								100	
Ash	*Fraxinus species*	100								
Austrian pine	*Pinus nigra*						100			
Balsam fir	*Abies balsamea*	100								
Bitternut hickory	*Carya cordiformis*	11.1	22.2	22.2	11.1	22.2	11.1			
Black cherry	*Prunus serotina*	33.3						33.3	33.3	
Black maple	*Saccharodendron nigrum*						100			
Black walnut	*Juglans nigra*	33.3			66.7					
Blue spruce	*Picea pungens*	100								
Boxelder	*Acer negundo*	40	30	20			10			
Bur oak	*Quercus macrocarpa*	80	20							
Common chokecherry	*Prunus virginiana*	100								
Common lilac	*Syringa vulgaris*	100								
Dead/Unknown		50			50					
Eastern white pine	*Pinus strobus*			100						
European buckthorn	*Rhamnus cathartica*	84.8	6.1	6.1		3				
European larch	*Larix decidua*	100								
Ironwood	*Parrotia species*	70	30							
Nannyberry	*Viburnum lentago*	50	50							
Northern red oak	*Quercus rubra*	100								
Norway maple	*Acer platanoides*			100						
Norway spruce	*Picea abies*		50		50					
Peachleaf willow	*Salix amygdaloides*						100			
Plum	*Prunus species*	100								
Red hickory	*Carya ovalis*			100						
Red maple	*Acer rubrum*				100					
Silver maple	*Acer dasycarpum*		60	20	20					
Slippery elm	*Ulmus fulva*	28.6	57.1		14.3					
Smooth service berry	*Amelanchier laevis*	100								
Sugar maple	*Acer saccharum*	66.7		11.1	11.1		11.1			
Swamp white oak	*Quercus bicolor*		37.5	12.5	12.5		12.5	12.5		12.5
White fir	*Abies concolor*				100					

APPENDIX 4B. BUILDING SERIES: PERCENT OF TREE (STEMS) POPULATION BY DBH CLASS.

Species		DBH Class (cm)						
Common name	Scientific name	2.5 - 7.6	7.7 - 15.2	15.3 - 22.9	23.0 - 30.5	30.6 - 38.1	38.2 - 45.7	45.8 - 53.3
American basswood	*Tilia americana*			100				
American hornbeam	*Carpinus caroliniana*				33.3	66.7		
Balsam fir	*Abies balsamea*				100			
Bitternut hickory	*Carya cordiformis*	100						
Black cherry	*Prunus serotina*			100				
Black walnut	*Juglans nigra*					50	50	
Boxelder	*Acer negundo*			40	60			
Bur oak	*Quercus macrocarpa*	100						
Common chokecherry	*Prunus virginiana*	100		50	50			
Common lilac	*Syringa vulgaris*					100		
Dead/Unknown			100					
European buckthorn	*Rhamnus cathartica*			5.9	11.8	41.2	29.4	11.8
Green ash	*Fraxinus campestris*			100				
Ironwood	*Parrotia species*		25	75				
Nannyberry	*Viburnum lentago*						100	
Norway spruce	*Picea abies*					100		
Slippery elm	*Ulmus fulva*		33.3	66.7				
Sugar maple	*Acer saccharum*			25	25	50		
Swamp white oak	*Quercus bicolor*			33.3	66.7			
White fir	*Abies concolor*			100				

APPENDIX 5A. PARKS SERIES: PER-AREA (DENSITY) ESTIMATES FOR TREES.

Species		Trees (no./ha)	Carbon (kg/ha)	Leaf Area (m^2/ha)	Leaf Biomass (kg/ha)	Values (US$/ha)
Common name	Scientific name					
American basswood	*Tilia americana*	8.9	60	205.4	6	417
American hornbeam	*Carpinus caroliniana*	17.8	66.1	672.6	40.5	823
Amur maple	*Acer ginnala*	3	2.9	55.7	3.1	148
Apple	*Malus species*	3	2,311.8	154.7	13.3	5,118
Austrian pine	*Pinus nigra*	3	468	893.8	86.1	7,658
Balsam fir	*Abies balsamea*	3	11.3	57.8	6	66
Bitternut hickory	*Carya cordiformis*	26.7	3,719.8	1,287.5	80.9	18,741
Black cherry	*Prunus serotina*	8.9	5,192.8	657	51	14,384
Black maple	*Saccharodendron nigrum*	3	1,629.3	1,061.9	59.8	10,418
Black walnut	*Juglans nigra*	8.9	1,004.3	370.3	29.7	6,236
Blue spruce	*Picea pungens*	3	1.9	3.1	0.5	160
Boxelder	*Acer negundo*	29.7	1,941.6	1,203.7	110.1	6,698
Bur oak	*Quercus macrocarpa*	14.8	70.2	208.7	19.2	781
Common chokecherry	*Prunus virginiana*	17.8	21.2	207.6	16.1	650
Common lilac	*Syringa vulgaris*	5.9	5.3	37.6	3.6	356
Eastern white pine	*Pinus strobus*	3	113.6	164.7	10.6	1,987
European buckthorn	*Rhamnus cathartica*	97.9	1,293.9	1,975.8	87.8	10,619
European larch	*Larix decidua*	3	0.9	46.8	2.5	148
Green ash	*Fraxinus campestris*	5.9	8.8	48.8	3.2	283
Iironwood	*Parrotia species*	3	8.6	47.5	3.5	115
Nannyberry	*Viburnum lentago*	5.9	33.1	66.1	4.9	228
Northern red oak	*Quercus rubra*	3	7.7	33.5	2.7	112
Norway maple	*Acer platanoides*	3	180.7	116.1	6.3	1,289
Norway spruce	*Picea abies*	5.9	607.4	1,621.2	270.2	5,306
Peachleaf willow	*Salix amygdaloides*	3	1,272.6	1,461.6	90.2	6,439
Red hickory	*Carya glabra var. odorata*	3	259.7	287.5	15.1	2,034
Red maple	*Acer rubrum*	3	355.8	40	2.7	2,641
Silver fir	*Abies alba*	5.9	348.6	47.6	6.7	577
Silver maple	*Acer dasycarpum*	14.8	1291	1,056.8	55.6	4,601
Slippery elm	*Ulmus fulva*	20.8	365.4	520.3	23.3	2,476
Smooth service berry	*Amelanchier arborea ssp. laevis*	3	7.6	126.6	9.6	156
Sugar maple	*Acer saccharum*	26.7	2,508.3	2315	139.5	15,863
Swamp white oak	*Quercus bicolor*	23.7	10,630	5,470.9	502	54,669
Unknown		29.7	216.3	721.4	53.8	1474
White fir	*Abies concolor*	3	701.4	7,724.3	1,087.9	3,889
TOTAL		**424**	**36,717.9**	**30,970.2**	**2,904.2**	**187,558**

APPENDIX 5B. BUILDING SERIES: PER-AREA (DENSITY) ESTIMATES FOR TREES.

Species		Trees	Carbon	Leaf Area	Leaf	Values
Common name	Scientific name	(no./ha)	(kg/ha)	(m^2/ha)	Biomass (kg/ha)	(US$/ha)
American basswood	*Tilia americana*	1.2	72	5.9	0.4	91
American hornbeam	*Carpinus caroliniana*	3.6	653.9	521.8	39.3	4,883
Balsam fir	*Abies balsamea*	1.2	199.1	186.9	13.2	1,153
Bitternut hickory	*Carya cordiformis*	4.7	8.7	112.7	10.9	356
Black cherry	*Prunus serotina*	1.2	60.4			
Black walnut	*Juglans nigra*	2.4	448.3	786.5	23	5,174
Boxelder	*Acer negundo*	5.9	623.2	863.5	51.3	4,685
Bur oak	*Quercus macrocarpa*	2.4	11.8	36.8	2.8	152
Common chokecherry	*Prunus virginiana*	2.4	2.9	28.9	1.8	156
Common lilac	*Syringa vulgaris*	1.2	266.5	147.5	25	3,675
European buckthorn	*Rhamnus cathartica*	20.2	2,914.7	2,156.6	207.8	45,357
Green ash	*Fraxinus campestris*	1.2	51.5	89.9	9.4	430
Nannyberry	*Viburnum lentago*	1.2	440.2	285.2	22.7	4,053
Norway spruce	*Picea abies*	1.2	205.9	299.1	48	2,685
Silver fir	*Abies alba*	1.2	18.9	58.9	3.8	123
Silver maple	*Acer dasycarpum*	2.4	161.5	180.5	13.7	1,668
Slippery elm	*Ulmus fulva*	3.6	231.7	363.9	21.9	1,737
Sugar maple	*Acer saccharum*	4.7	533.5	895.4	58.4	9,134
Swamp white oak	*Quercus bicolor*	3.6	371.8	242.4	12.8	2,469
Unknown		4.7	300	690.7	37.3	2,517
White fir	*Abies concolor*	1.2	55.9	114.6	6.2	482
TOTAL		**71.2**	**7,632.3**	**8,067.8**	**609.6**	**90,979**

APPENDIX 6A. PARKS SERIES: POLLUTION REMOVED

Pollutants	CO		NO_2		O_3		PM10		SO_2		Total	
Month	Values (US$)	Amount (mt)	Values (US$)	Amount (mt)	Values (US$)	Amount (mt)	Values (US$)	Amount (mt)	Values (US$)	Amount (mt)	Values (US$)	Amount (mt)
January	1.81	0.00	309.94	0.05	187.60	0.03	426.42	0.09	29.64	0.02	955	0.19
February	1.92	0.00	304.25	0.05	205.69	0.03	474.76	0.11	27.13	0.02	1,014	0.20
March	1.92	0.00	297.15	0.04	333.38	0.05	403.19	0.09	24.75	0.01	1,060	0.20
April	11.21	0.01	868.01	0.13	1,154.24	0.17	959.93	0.21	89.78	0.05	3,083	0.58
May	29.76	0.03	2,002.68	0.30	3,854.10	0.57	2,030.33	0.45	153.31	0.09	8,070	1.44
June	35.64	0.04	1,998.16	0.30	4,007.10	0.59	1,648.59	0.37	157.51	0.10	7,847	1.39
July	29.61	0.03	1,865.10	0.28	3,878.06	0.57	1,995.66	0.44	136.21	0.08	7,905	1.41
August	33.62	0.04	1,931.30	0.29	4,413.06	0.65	2,168.92	0.48	187.87	0.11	8,735	1.57
September	26.58	0.03	1,273.05	0.19	2,138.94	0.32	1,635.52	0.36	127.33	0.08	5,201	0.97
October	2.00	0.00	262.71	0.04	191.58	0.03	565.71	0.13	25.18	0.02	1,047	0.21
November	1.75	0.00	265.66	0.04	142.13	0.02	410.50	0.09	23.40	0.01	843	0.17
December	1.54	0.00	281.29	0.04	165.80	0.02	469.34	0.10	26.22	0.02	944	0.19
TOTAL	**177**	**0.18**	**11,659**	**1.73**	**20,672**	**3.06**	**13,189**	**2.93**	**1,008**	**0.61**	**46,706**	**8.51**

APPENDIX 6B. BUILDING SERIES: POLLUTION REMOVED

Pollutants	CO		NO_2		O_3		PM10		SO_2		Total	
Month	Values (US$)	Amount (mt)	Values (US$)	Amount (mt)	Values (US$)	Amount (mt)	Values (US$)	Amount (mt)	Values (US$)	Amount (mt)	Values (US$)	Amount (mt)
January	0.96	0.00	133.06	0.02	72.80	0.01	154.38	0.03	11.33	0.01	373	0.07
February	1.02	0.00	130.57	0.02	79.87	0.01	166.99	0.04	10.35	0.01	389	0.08
March	1.02	0.00	127.98	0.02	130.08	0.02	150.72	0.03	9.53	0.01	419	0.08
April	5.94	0.01	337.76	0.05	484.60	0.07	306.43	0.07	37.93	0.02	1,173	0.22
May	15.76	0.02	768.50	0.11	1,681.35	0.25	599.43	0.13	67.32	0.04	3,132	0.55
June	18.87	0.02	766.50	0.11	1,772.01	0.26	495.38	0.11	71.64	0.04	3,124	0.55
July	15.68	0.02	721.15	0.11	1,748.99	0.26	595.74	0.13	62.70	0.04	3,144	0.55
August	17.80	0.02	725.06	0.11	1,926.59	0.29	652.48	0.14	84.14	0.05	3,406	0.61
September	14.07	0.01	487.02	0.07	935.08	0.14	500.57	0.11	56.47	0.03	1,993	0.37
October	1.06	0.00	113.43	0.02	74.86	0.01	200.40	0.04	9.70	0.01	399	0.08
November	0.93	0.00	114.44	0.02	55.57	0.01	139.53	0.03	9.00	0.01	319	0.06
December	0.82	0.00	120.75	0.02	64.40	0.01	163.85	0.04	10.02	0.01	360	0.07
TOTAL	**94**	**0.10**	**4,546**	**0.67**	**9,026**	**1.34**	**4,126**	**0.92**	**440**	**0.27**	**18,232**	**3.29**

APPENDIX 7. SUSCEPTIBILITY OF TREES TO ASIAN LONGHORNED BEETLE (ANOPLOPHORA GLABRIPENNIS).

Series	% Leaf Area				Leaf Area (km²)			
	Known Host	Genera Host	Immune	Unknown	Known Host	Genera Host	Immune	Unknown
Parks	29.4	18.4	34.1	18.1	1.794	1.126	2.081	1.102
Buildings	49	5.9	32.3	12.8	0.78	0.093	0.513	0.204
TOTAL	**78.4**	**24.3**	**66.4**	**30.9**	**2.574**	**1.219**	**2.594**	**1.306**

Series	Values (US$)				Number of Trees			
	Known Host	Genera Host	Immune	Unknown	Known Host	Genera Host	Immune	Unknown
Parks	14,073,955	10,948,266	3,899,950	8,035,765	29,798	8,180	5,259	39,731
Buildings	5,162,077	1,025,807	10,190,963	1,548,431	5,142	467	4,441	3,739
TOTAL	**19,236,032**	**11,974,073**	**14,090,913**	**9,584,196**	**34,940**	**8,647**	**9,700**	**43,470**

APPENDIX 8. SUSCEPTIBILITY OF TREES TO GYPSY MOTH (*LYMANTRIA DISPAR*).

	% Leaf Area				Leaf Area (km²)			
	Susceptible	Resistant	Immune	Unknown	Susceptible	Resistant	Immune	Unknown
Parks	24.3	35.8	37.3	2.6	1.485	2.182	2.277	0.159
Buildings	32.8	48.5	17.4	1.4	0.521	0.77	0.276	0.022
TOTAL	**57.1**	**84.3**	**54.7**	**4**	**2.006**	**2.952**	**2.553**	**0.181**

	Values (US$)				Number of Trees			
	Susceptible	Resistant	Immune	Unknown	Susceptible	Resistant	Immune	Unknown
Parks	13,307,726	18,757,256	4,509,741	383,212	11,101	33,304	30,967	7,596
Buildings	3,930,583	11,436,345	2,490,236	70,114	2,805	7,712	2,337	935
TOTAL	**17,238,309**	**30,193,601**	**6,999,977**	**453,326**	**13,906**	**41,016**	**33,304**	**8,531**

APPENDIX 9A. PARKS SERIES: PERCENT OF TREE POPULATION BY CONDITION CLASS.

E= Excellent, G = Good, F = Fair, P = Poor, C = Critical, D = Dying, K = Dead.

Tree Species		% of Population by Condition Class						
Common name	Scientific name	E	G	F	P	C	D	K
American basswood	*Tilia americana*	33.3	33.3		33.3			
American hornbeam	*Carpinus caroliniana*	16.7	50	16.7	16.7			
Amur maple	*Acer ginnala*		100					
Apple	*Malus species*					100		
Austrian pine	*Pinus nigra*		100					
Balsam fir	*Abies balsamea*				100			
Bitternut hickory	*Carya cordiformis*		22.2	11.1	33.3	22.2	11.1	
Black cherry	*Prunus serotina*				66.7	33.3		
Black maple	*Saccharodendron nigrum*		100					
Black walnut	*Juglans nigra*	33.3		33.3	33.3			
Blue spruce	*Picea pungens*	100						
Boxelder	*Acer negundo*	10	40	20	20		10	
Bur oak	*Quercus macrocarpa*	80			20			
Common chokecherry	*Prunus virginiana*	16.7	66.7	16.7				
Common lilac	*Syringa vulgaris*	100						
Eastern white pine	*Pinus strobus*	100						
European buckthorn	*Rhamnus cathartica*	15.2	54.5	6.1	15.2	9.1		
European larch	*Larix decidua*		100					
Green ash	*Fraxinus campestris*	50		50				
Ironwood	*Parrotia species*			100				
Nannyberry	*Viburnum lentago*	50			50			
Northern red oak	*Quercus rubra*				100			
Norway maple	*Acer platanoides*		100					
Norway spruce	*Picea abies*	50		50				
Peachleaf willow	*Salix amygdaloides*		100					
Red hickory	*Carya glabra var. odorata*		100					
Red maple	*Acer rubrum*		100					
Silver fir	*Abies alba*						50	50
Silver maple	*Acer dasycarpum*	20	40	40				
Slippery elm	*Ulmus fulva*	14.3	14.3	42.9	28.6			
Smooth service berry	*Amelanchier arborea ssp. laevis*	100						
Sugar maple	*Acer saccharum*	11.1	33.3	44.4	11.1			
Swamp white oak	*Quercus bicolor*	12.5	12.5	62.5	12.5			
Unknown		20	60	20				
White fir	*Abies concolor*	100						

APPENDIX 9B. BUILDING SERIES: PERCENT OF TREE POPULATION BY CONDITION CLASS.

E = Excellent, G = Good, F = Fair, P = Poor, C = Critical, D = Dying, K = Dead.

Tree Species		% of Population by Condition Class						
Common name	Scientific name	E	G	F	P	C	D	K
American basswood	*Tilia americana*						100	
American hornbeam	*Carpinus caroliniana*		33.3	66.7				
Balsam fir	*Abies balsamea*				100			
Bitternut hickory	*Carya cordiformis*	100						
Black cherry	*Prunus serotina*							100
Black walnut	*Juglans nigra*		50		50			
Boxelder	*Acer negundo*		40	60				
Bur oak	*Quercus macrocarpa*	50	50					
Common chokecherry	*Prunus virginiana*	50	50					
Common lilac	*Syringa vulgaris*		100					
European buckthorn	*Rhamnus cathartica*	5.9	23.5	41.2	11.8	11.8	5.9	
Green ash	*Fraxinus campestris*		100					
Nannyberry	*Viburnum lentago*			100				
Norway spruce	*Picea abies*		100					
Silver fir	*Abies alba*	100						
Slippery elm	*Ulmus fulva*		100					
Sugar maple	*Acer saccharum*		25	50	25			
Swamp white oak	*Quercus bicolor*		33.3		33.3	33.3		
Unknown		25	75					
White fir	*Abies concolor*		100					

APPENDIX 10A. PARKS SERIES: PERCENT OF TREES AND SHRUBS POPULATION BY DBH & CONDITION CLASS

E = Excellent, G = Good, F = Fair, P = Poor, C = Critical, D = Dying, K = Dead.

Species		DBH Class (cm)	% Condition Class						
Common name	Scientific name		E	G	F	P	C	D	K
American basswood	*Tilia americana*	2.5 - 7.6		100					
		7.7 - 15.2	50			50			
American hornbeam	*Carpinus caroliniana*	2.5 - 7.6	20	40	20	20			
		7.7 - 15.2		100					
Amur maple	*Acer ginnala*	2.5 - 7.6		100					
Apple	*Malus species*	53.4 - 61.0					100		
Ash	*Fraxinus species*	2.5 - 7.6	50		50				
Austrian pine	*Pinus nigra*	38.2 - 45.7		100					
Balsam fir	*Abies balsamea*	2.5 - 7.6				100			
Bitternut hickory	*Carya cordiformis*	2.5 - 7.6				100			
		7.7 - 15.2		50		50			
		15.3 - 22.9					50	50	
		23.0 - 30.5		100					
		30.6 - 38.1				50	50		
		38.2 - 45.7			100				
Black cherry	*Prunus serotina*	2.5 - 7.6				100			
		45.8 - 53.3				100			
		53.4 - 61.0					100		
Black maple	*Acer nigrum*	38.2 - 45.7		100					
Black walnut	*Juglans nigra*	2.5 - 7.6	100						
Blue spruce	*Picea pungens*	23.0 - 30.5			50	50			
		2.5 - 7.6	100						
Boxelder	*Acer negundo*	2.5 - 7.6	25	50	25				
		7.7 - 15.2		33	33			33	
		15.3 - 22.9		50		50			
		38.2 - 45.7				100			
Bur oak	*Quercus macrocarpa*	2.5 - 7.6	75			25			
		7.7 - 15.2	100						
Common chokecherry	*Prunus virginiana*	2.5 - 7.6	17	67	17				
Common lilac	*Syringa vulgaris*	2.5 - 7.6	100						
Dead/Unknown	*Dead/Unknown*	2.5 - 7.6							100
		23.0 - 30.5						100	
Eastern white pine	*Pinus strobus*	15.3 - 22.9	100						

APPENDIX 10A CONT. PARKS SERIES: PERCENT OF TREES AND SHRUBS POPULATION BY DBH & CONDITION CLASS

E = Excellent, G = Good, F = Fair, P = Poor, C = Critical, D = Dying, K = Dead.

Species		DBH Class (cm)	% Condition Class						
Common name	Scientific name		E	G	F	P	C	D	K
European buckthorn	*Rhamnus cathartica*	2.5 - 7.6	18	57	3.6	11	11		
		7.7 - 15.2				100			
		15.3 - 22.9		100					
		30.6 - 38.1			100				
European larch	*Larix decidua*	2.5 - 7.6		100					
Ironwood	*Parrotia species*	2.5 - 7.6		86	14				
		7.7 - 15.2	67		33	16			
Nannyberry	*Viburnum lentago*	2.5 - 7.6	100						
		7.7 - 15.2				100			
Northern red oak	*Quercus rubra*	2.5 - 7.6				100			
Norway maple	*Acer platanoides*	15.3 - 22.9		100					
Norway spruce	*Picea abies*	7.7 - 15.2			100				
		23.0 - 30.5	100						
Peachleaf willow	*Salix amygdaloides*	38.2 - 45.7		100					
Red hickory	*Carya ovalis*	15.3 - 22.9		100					
Red maple	*Acer rubrum*	23.0 - 30.5		100					
Silver maple	*Acer saccharinum*	7.7 - 15.2	33	67					
		15.3 - 22.9			100				
		23.0 - 30.5			100				
Slippery elm	*Ulmus fulva*	2.5 - 7.6	50			50			
		7.7 - 15.2		25	75				
		23.0 - 30.5				100			
Smooth service berry	*Amelanchier laevis*	2.5 - 7.6	100						
Sugar maple	*Acer saccharum*	2.5 - 7.6	17	50	33				
		15.3 - 22.9				100			
		23.0 - 30.5			100				
		38.2 - 45.7			100				
Swamp white oak	*Quercus bicolor*	7.7 - 15.2	33		67				
		15.3 - 22.9			100				
		23.0 - 30.5			100				
		38.2 - 45.7		100					
		45.8 - 53.3			100				
		68.7 - 76.2				100			
White fir	*Abies concolor*	23.0 - 30.5	100						

APPENDIX 10B. BUILDING SERIES: PERCENT OF TREES AND SHRUBS POPULATION BY DBH & CONDITION CLASS.

E = Excellent, G = Good, F = Fair, P = Poor, C = Critical, D = Dying, K = Dead.

Species		DBH Class (cm)	% Condition Class						
Common name	Scientific name		E	G	F	P	C	D	K
American basswood	*Tilia americana*	30.6 - 38.1		100					
		38.2 - 45.7				100			
Austrian pine	*Pinus nigra*	15.3 - 22.9			100				
		23.0 - 30.5	50		50				
		30.6 - 38.1		28.6	28.6		28.6	14.3	
		38.2 - 45.7		40	40	20			
		45.8 - 53.3			50	50			
Bitternut hickory	*Carya cordiformis*	23.0 - 30.5		66.7	33.3				
		15.3 - 22.9						100	
Black locust	*Robinia pseudoacacia*	15.3 - 22.9		100					
Black oak	*Quercus velutina*	23.0 - 30.5				100			
Blue spruce	*Picea pungens*	30.6 - 38.1		100					
Common lilac	*Syringa vulgaris*	2.5 - 7.6	100						
European white birch	*Betula pendula*	15.3 - 22.9			100				
Green ash	*Fraxinus pennsylvanica*	15.3 - 22.9				100			
		23.0 - 30.5			100				
		30.6 - 38.1		50	50				
Honeylocust	*Gleditsia triacanthos*	15.3 - 22.9		100					
Ironwood	*Parrotia species*	15.3 - 22.9							100
Northern red oak	*Quercus rubra*	38.2 - 45.7			100				
Norway maple	*Acer platanoides*	7.7 - 15.2	100						
		15.3 - 22.9		100					
Redbud	*Cercis species*	7.7 - 15.2	100						
Scarlet hawthorn	*Crataegus pedicellata*	23.0 - 30.5			100				
		30.6 - 38.1		50	50				
Serviceberry	*Amelanchier species*	2.5 - 7.6	100						
		15.3 - 22.9	100						
		23.0 - 30.5		100					
Silver maple	*Acer saccharinum*	15.3 - 22.9		100					
		23.0 - 30.5				50	50		
Smooth service berry	*Amelanchier laevis*	2.5 - 7.6	50	50					
Sugar maple	*Acer saccharum*	7.7 - 15.2		100					
		15.3 - 22.9		100					
White spruce	*Picea canadensis*	30.6 - 38.1		100					