

TOWN OF NEWMARKET
URBAN FOREST STUDY

Technical Report
March, 2016

Acknowledgements

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Executive Summary

The Town of Newmarket Urban Forest Study – Technical Report has been prepared by Lake Simcoe Region Conservation Authority (LSRCA) in partnership with York Region, Town of Newmarket, and Toronto and Region Conservation Authority (TRCA). The purpose of the study was to assess the distribution, structure and function of the urban forest, and to provide management recommendations for enhancing the sustainability of both the urban forest resource and the community as a whole. The study serves as a baseline for future research and monitoring, and will equip managers with information necessary to direct forest structure to deliver desired ecosystem services, including climate change mitigation and adaptation, air pollution removal, storm water management, residential energy savings, wildlife habitat, and community aesthetics.

The objectives of the Technical Report are:

- To quantify the existing distribution, structure (e.g. composition and condition), and function (e.g. carbon sequestration and air pollution removal) of Newmarket's urban forest;
- To establish a baseline for future monitoring and applied research; and
- To recommend preliminary actions that can be taken to enhance the capacity of the urban forest to provide essential ecosystem services

Summary of Results

A suite of tools of analysis created by the United States Department of Agriculture (USDA) Forest Service, Northern Research Station and the University of Vermont, Spatial Analysis Laboratory were used to quantify the distribution, structure and function of the urban forest.

Tree Cover and Leaf Area:

Newmarket's existing tree canopy is 24% with the estimated total of 300,000 trees provide 51.1 km^2 of total leaf area. The greatest proportion of the urban forest is located in the residential areas of the municipality; approximately 30% of the total tree and shrub cover in the town is found within this land use. The greatest opportunity to increase canopy cover through tree planting efforts is found in the open space land use; approximately 20% of the total vegetated areas available for additional tree planting are in open spaces i.e. parks, meadows etc.

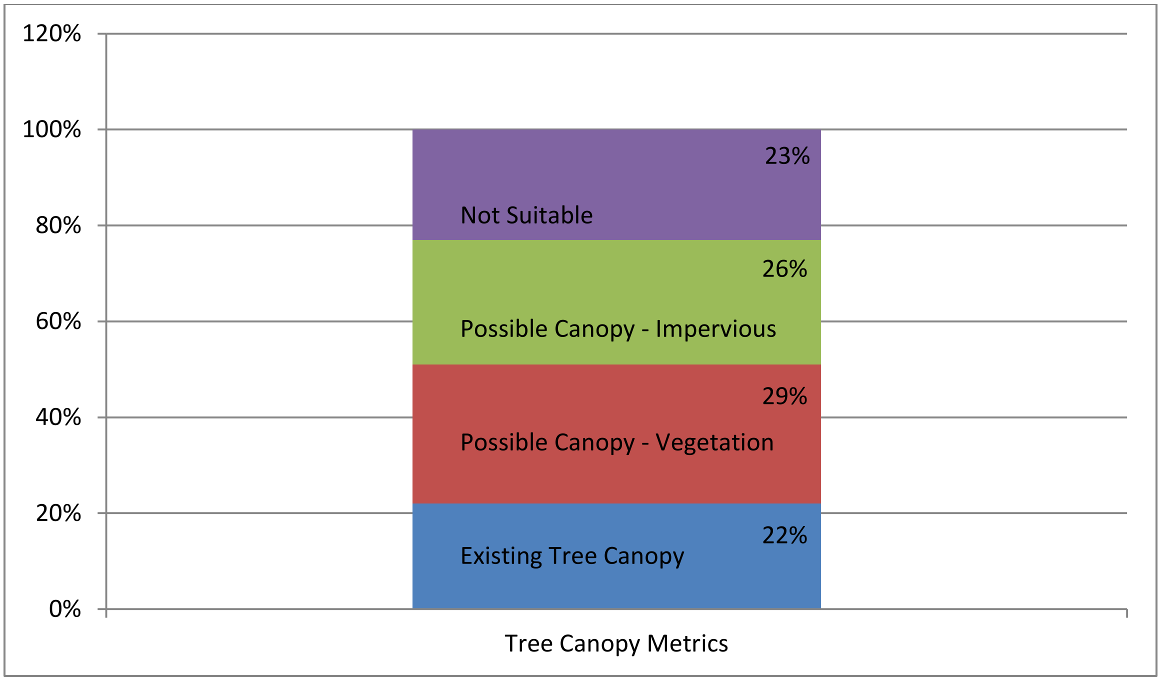

Figure a. Tree canopy metrics for Newmarket as calculated through Urban Tree Canopy Analysis

Tree Cover by Land Use

- Residential: 27%
- Industrial/Commercial: 11%
- Open Space: 32%
- Agricultural and Institutional: 30%
- Utilities and Transportation: 10%
- Natural Cover: 53%

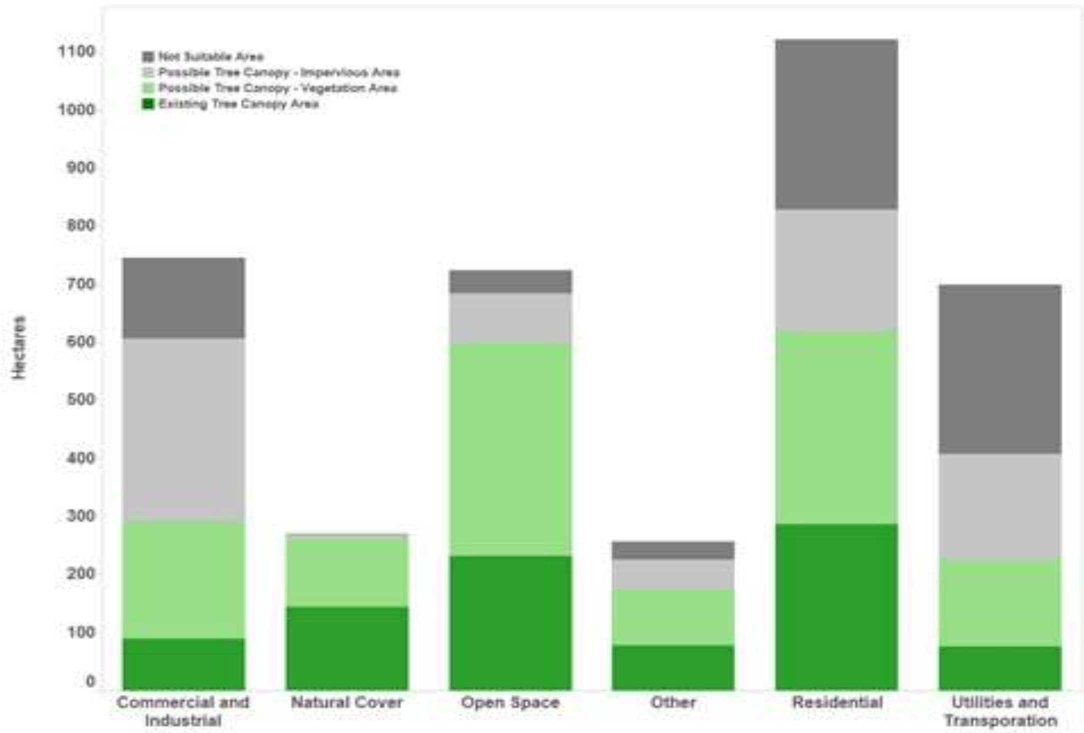

Figure b. Tree canopy metrics by land use for Newmarket (Urban Tree Canopy Analysis)

Tree Size:

Newmarket has a fairly well distributed tree population in terms of diameter class distribution. However, it could be a challenge to maintain an ideal DBH distribution. As urban trees increase in size, their environmental, social and economic benefits increase as well. For example, in Newmarket a tree that's 68.6-76.2cm DBH, stores 13 times more carbon as compared to a tree between 7.6-15.2 cm DBH. However the smallest size category (7.6-15.2cm) is dominated by species that are known to have smaller sizes at maturity, jeopardizing the future size distribution of the urban forest.

Structural Value of Trees in Newmarket:

The estimated structural value of all trees in Newmarket as of 2015 is approximately $364 million. This value does not include the ecological or societal value of the forest but rather represents an estimate of tree replacement costs and/or compensation for loss of a tree.

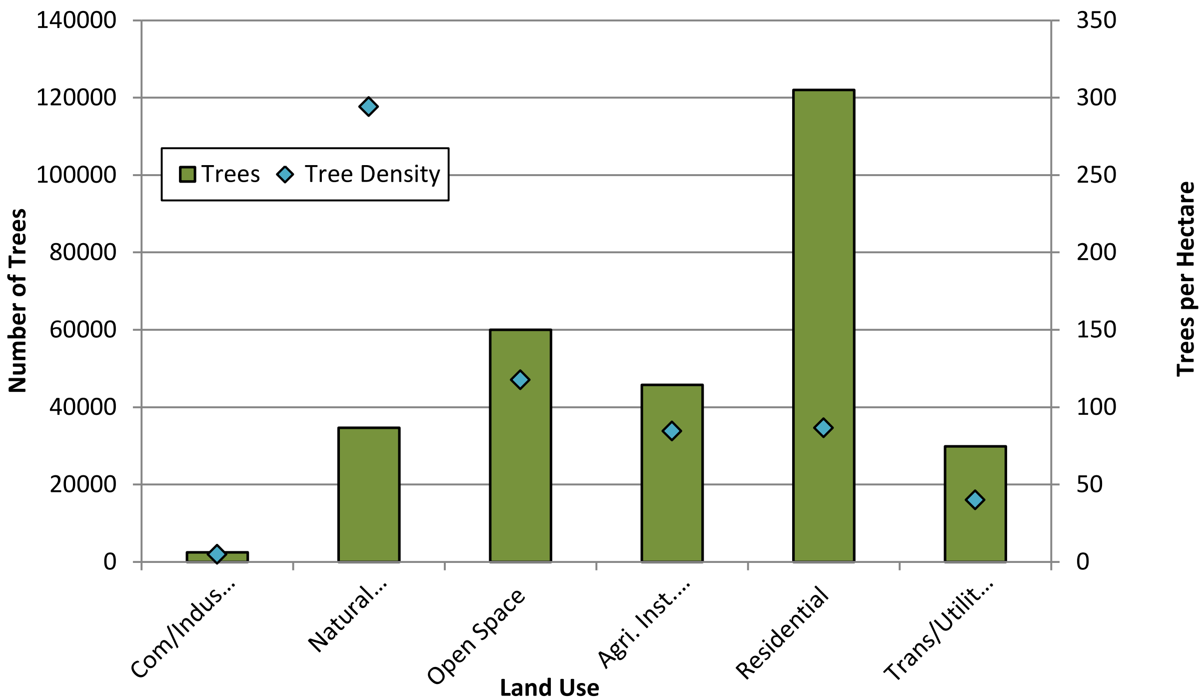

Figure c. Tree density and total tree by land use as calculated by i-Tree Eco

Carbon Storage and Sequestration:

As a tree grows, it removes carbon dioxide from the atmosphere; this process is referred to as carbon sequestration, which is expressed as an annual rate of removal. Carbon is then stored in the woody biomass of the tree; this can be expressed as total carbon storage. When a tree dies, much of the stored carbon is slowly released back to the atmosphere through decomposition. Trees in Newmarket sequester approximately 1,558 metric tonnes of carbon per year, with an associated annual value of $120,408. Trees in Newmarket store approximately 35,345 metric tonnes of carbon, with an associated value of $2.74 million.

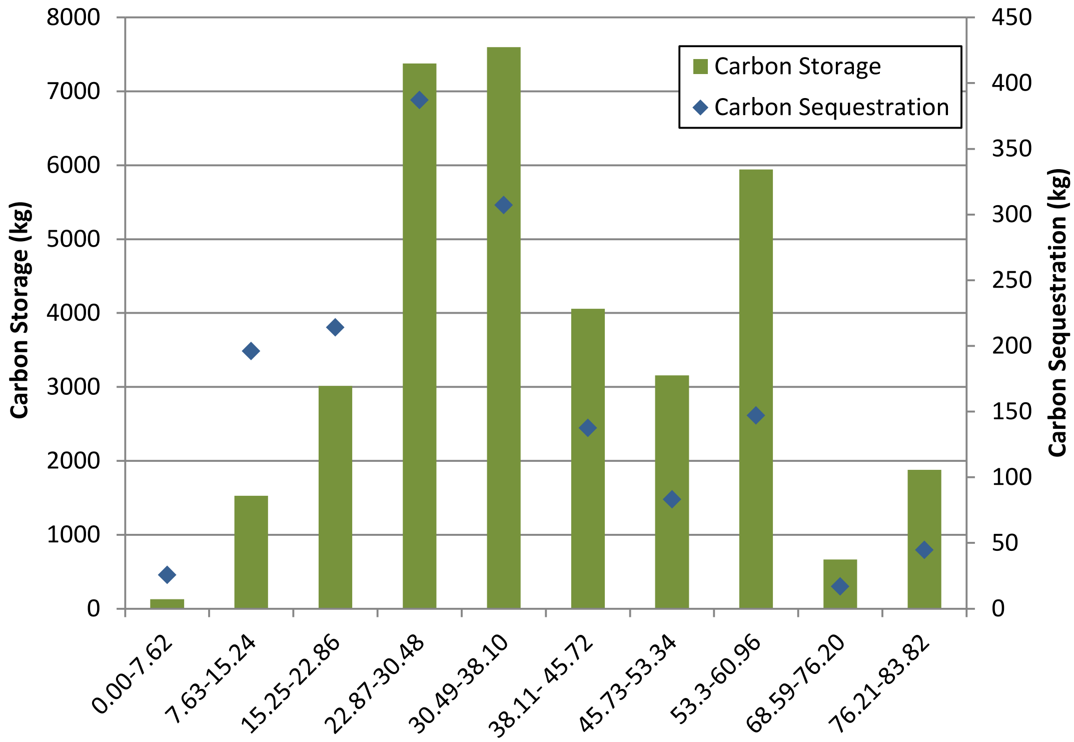

Figure d. Carbon storage and sequestration by tree size as calculated by i-Tree Eco

Air Quality Improvements:

The urban forest can improve local air quality by absorbing and intercepting airborne pollutants. Newmarket's urban forest removes 40 metric tonnes of air pollution annually; this ecosystem service is valued at approximately $321,564 annually.

- Ozone: 33.17 metric tonnes
- Particulate matter (<2.5 microns): 1.7 metric tonnes
- Nitrogen dioxide: 3.4 metric tonnes
- Sulfur dioxide: 0.94 metric tonnes
- Carbon monoxide: 0.38 metric tonnes

Residential Energy Savings:

Trees reduce local air temperature due to shading effects and the release of water vapour through evapotranspiration. This reduces energy used for heating by reducing wind speeds as well. In Newmarket the urban forest reduces the annual residential energy consumption by approximately 23,914 MBTUS and 1,127 MWH, with an associated annual financial savings of approximately $3,345,533. As a result of this reduced demand on heating and cooling the production of 457 metric tonnes of carbon emissions is avoided annually (associated savings of $35,371).

Table 1. Average annual financial savings through energy conservation in residential areas due to the presence of trees as calculated by i-Tree Eco.

Energy Units	Heating	Cooling	Total
Natural Gas (Million British Thermal Units)	$250,008	n/a	$250,008
Electricity (Megawatt-hour)	$15,300	$69,225	$84,525
Carbon Avoided (tonnes)	$30,882	$4,489	$35,371

Hydrologic Effects of the Urban Forest:

Trees carry a major hydrological impact for their surroundings. Presence of trees decreases surface run off and stream flow as they lead to a reduction in impervious surfaces and soil compaction while increasing water percolation. In addition to this, tree canopies also directly decrease surface run off by intercepting rainfall. The Newmarket urban forest helps avoid 215,058.84 m^3/year of runoff with an associated value of $499,950.30. This number can be further increased with an increase in canopy area through maturation and additional plantings.

Recommendations

Planning and Regulations

Refine the results of the Urban Forest Study to develop a canopy cover target and plan to reach it through shrewd planting strategies based on various models prepared by the report i.e. Priority Planting Index, Land Use Tree Canopy Metrics. An informed canopy establishment plan should not only increase canopy cover but also provide a boost in ecological services provided by the Urban Forest.

- Increase leaf area in canopied areas by planting suitable tree and shrub species under existing tree cover. Planting efforts should continue to be focused in areas of the municipality that currently support a high proportion of ash species.
- Utilize the Pest Vulnerability Matrix during species selection for municipal tree and shrub planting.
- Establish a diverse tree population in which no species represents more than 5% of the tree population, no genus represents more than 10% of the tree population, and no family represents more than 20% of the intensively managed tree population both municipal-wide and at the neighbourhood level.
- Utilize native planting stock grown from locally adapted seed sources in both intensively and extensively managed areas.
- Increase overall tree density in the town by planting in priority areas
- Build on the results of UTC analysis and the priority planting index to prioritize tree planting and establishment efforts to improve the distribution of ecosystem services, including urban heat island mitigation and stormwater management.
- Use the Land Use tree canopy metrics to plan a variety of tree planting schemes that are socially, economically and environmentally appropriate to each land use.

Management and Operations

With the assistance of the Urban Forest Study, develop and implement an Urban Forest Management Plan for Newmarket that not only plans the establishment of future canopy cover but also maintains the current tree canopy. Urban Forest Study shows management policies that encourage the protection of trees in private properties and provides incentives to residents and business owners for strategic tree establishment around buildings can significantly increase the ecological benefits of the urban forest.

- Explore the development and implementation of a municipal staff training program to enhance awareness of tree health and maintenance requirements generally, and of proper tree protection practices to be used during construction activities more specifically.
- Evaluate and develop the strategic steps required for tree preservation in order to increase the proportion of large, mature trees in the urban forest. This can be achieved using a range of tools including Official Plan planning policy, by-law enforcement and public education. Where tree preservation cannot be achieved, Official Plan policy can be considered that will require compensation for the loss of mature trees and associated ecosystem services.
- Reduce energy consumption and associated carbon emissions by providing direction, assistance and incentives to residents and businesses for strategic tree planting and establishment around buildings and private properties.
- Encourage the protection of privately owned natural cover areas
- Develop municipal guidelines and regulations for sustainable streetscape and subdivision design that ensure adequate soil quality and quantity for tree establishment and eliminate conflict between natural and grey infrastructure.
- Acquire staff to implement urban forest management plan and manage operations with respect to Urban Forest Study – Technical Report, results and recommendations.

Communication and Education

Pursue the development of an urban forest communication plan that guides the dissemination of key messages to target audiences. A communication and education plan that provides the stakeholders with implications and repercussions of poor or ill-informed decisions in the maintenance of the urban forest and related green and grey infrastructure is essential.

- Educate residents regarding the threat of invasive horticultural species
- Public education and outreach will be required to communicate benefits and to provide direction for strategic planting around buildings to enhance energy savings
- Explore the development and implementation of a municipal staff training program to enhance awareness of tree health and maintenance requirements generally, and of proper tree protection practices to be used during construction activities more specifically.
- Introduction of an incentive based program for businesses and residents to help meet canopy cover targets in land use types.

- Research and pursue new partnerships and opportunities to enhance urban forest stewardship in Newmarket.

Research and Monitoring

Support future urban forest research partnerships with the Conservation Authority and Region, this will improve the knowledge and increased the certainty of the model projections and the implications of the management plan. Monitor the distribution, structure and function of the urban forest using the methods employed in this baseline study. A potential monitoring scenario may consist of a cover mapping assessment (UTC) at a five year interval and a field-based assessment (i-Tree Eco) at a ten year interval.

- Build an urban forest research and monitoring team in partnership with neighboring municipalities, conservation authorities and region to inform and advise the management and planning team to improve the efforts to reach targets
- Analyze current species distribution by size data and use it as a successful size guide and baseline for future studies
- Explore and develop green infrastructure (i.e. green roofs, vines) in order to provide urban heat island mitigation.
- Support research partnerships that pursue the study of climate change and its impacts on the urban forest and that evaluate the potential for planting more hardy and southern species in select locations.
- Develop an open map community urban forest monitoring system that allows public data input and update
- Explore the application of subsurface cells and other enhanced rooting environment techniques for street trees. Utilizing these technologies at selected test-sites in the short-term may provide

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1.0 Introduction

Newmarket's urban forest is a dynamic system located on public and private properties that includes trees and shrubs, as well as the soils that sustain them. It is a mix of intensively managed trees and managed natural areas including: remnant woodlots, plantation forests, and riparian forest patches. Newmarket's urban forest is an efficient and cost effective natural infrastructure asset that provides an array of benefits and services to the community. The town has the potential to significantly improve the existing urban forest and many of the benefits associated with it. These benefits include stormwater management, residential energy use reduction, air quality improvement, local wildlife habitat improvement and community cohesion.

This assessment of Newmarket's urban forest is timely as a tool to guide urban forest management to support recent changes in Newmarket's landscape and new challenges faced by municipal urban forest managers. Recent growth and future projections show expansion of residential zones and increased density. Demands to maintain the health of the urban forest despite limited growth space will force urban forest managers to identify creative approaches to protect grow and sustain the urban forest. Southern Ontario forests are under threat from a variety of pests. Emerald ash borer (*Agrilus planipennis*) and Asian long-horned beetle (*Anoplophora glabripennis*) are both major threats to Newmarket's urban forest. Emerald ash borer is already present in Newmarket and is infesting trees at an immense rate. Asian long-horned beetle is still quarantined within Mississauga and west Toronto; however, it still poses a great risk to the urban forest. Climate change-related events like drought, extreme weather events and shifting plant hardiness zones will also need to be considered by urban forest managers while planning for the future. Careful consideration of the implications of climate change will enable managers to increase ecosystem resilience and effectively integrate the urban forest into municipal and regional climate change mitigation and adaptation strategies. In order to successfully address such challenges, a comprehensive understanding of urban forest structure and functions will be necessary.

1.1 Purpose

The *Town of Newmarket Urban Forest Study – Technical Report* has been prepared by the Lake Simcoe Region Conservation Authority (LSRCA), in partnership with York Region, the Town of Newmarket and Toronto and Region Conservation Authority (TRCA). The study provides an assessment of the distribution, structure and function of the urban forest. Ultimately, the study will inform and guide the creation of an Urban Forest Management Plan that will assist the Town of Newmarket in fulfilling multiple social, environmental, and economic objectives through sustainable urban forest management.

1.2 Objectives

The objectives of the Technical Report are:

- To quantify the existing distribution, structure (e.g. composition and condition), and function (e.g. carbon sequestration and air pollution removal) of Newmarket's urban forest;
- To establish a baseline for future monitoring and applied research; and

- To recommend preliminary actions that can be taken to enhance the capacity of the urban forest to provide essential ecosystem services

2.0 Background

2.1 Demographic and Ecological Context

The Town of Newmarket is one of nine local area municipalities found within the Regional Municipality of York. Newmarket is a growing municipality with a 7.6% increase in population from 2006 to 2011 (Statistics Canada, 2015). The total population of the town in 2011 was 84,600 with a high per square kilometer density (2,086.3) when compared to the neighbouring York Region municipalities (York Region Vison, 2021).

Newmarket is located in Plant Hardiness Zone 5B (Natural Resources Canada Plant Hardiness Zone Map of 2000), and ecodistrict 6E-6 (Lake Simcoe Area) in the Lake Simcoe – Rideau Ecoregion corresponding with Great Lakes – St Lawrence forest region (Crins and Uhlig, 2000). Newmarket drains primarily into the East Holland river sub-watershed, with a portion in the northwest corner in the West Holland river subwatershed. This region is characterized by a mixture of broad leaf and coniferous trees, such as eastern white pine (*Pinus strobus*), red oak (*Quercus rubra*), sugar maple (*Acer saccharum*), red pine (*Pinus resinosa*), white ash (*Fraxinus americana*), American beech (*Fagus grandifolia*), and eastern white cedar (*Thuja occidentalis).*The town also includes 382ha of the Oak Ridges Moraine in the south west part. While Newmarket is north of the Carolinian forest zone some species representative of that zone such as American sycamore (*Platanus occidentalis*) and black walnut (*Juglans nigra*) are present.

Several decades of urbanization, agricultural and industrial activity has led to the loss of nearly all pre-European settlement natural cover in York region. From 1975 to 1988 York Region's forest cover declined between 30 to 50% (Schmitt and Suffling, 2006). Concurrent with the loss of natural cover has been a decline in the services provided by natural systems, including water management and climate regulation. Some of these services are mimicked by man-made grey infrastructure, which has a limited ability to meet the demands of a growing urban population. However, in recent years mainstream thinking has begun to recognize the importance of natural or green infrastructure in maintaining sustainable options for the future.

2.2 Policy and Management Context

Provincial Policy

The Environmental Assessment Act (1990) applies to public sector and large private sector projects with the aim of conserving and wisely managing the environment. *The Planning Act (1990)* provides for land use planning systems, including the integration of urban forest features. *The Endangered Species Act (2007)* provides for the protection of endangered species and their habitats, including some, such as butternut (*Juglans cinerea*), that might be found in the Town of Newmarket.

Town of Newmarket Official Plan

The town's official plan was adopted by council in 2006, section 9 relates to natural heritage systems and preserving the town's woodlots and natural heritage feature. It also acknowledges the current low forest cover in the town of Newmarket and the need to maintain and enhance all elements of the natural heritage system. In addition it creates policies that prohibit development and alterations to areas adjacent to woodlots.

By-Laws and Tree Maintenance

In 2005, the Town of Newmarket enacted a tree preservation, protection, replacement and enhancement policy; this policy was then revised in 2008 in accordance with the town's official plan enacted in 2006[1]. The policy intends to educate and increase the awareness of tree preservation and protection for the health of the community within the development industry. The policy applies to all medium to large sized trees situated within 4.5 meters of the lands subject to development application. The policy makes it mandatory to acquire approval from the town before removing, pruning, injuring or destroying any significant trees. This encourages the protection of trees during development activities.

In June 2007, Woodlot By-law (2007-71) was enacted by Newmarket; this by-law prohibits or regulates the destruction or injuring of woodlot trees. The by-law prohibits the destruction of any woodland without a permit unless exempted under certain cases such as acquisition of a development permit or interference with utilities. In addition the By-law dictates that the commissioner shall not issue a permit in environmentally sensitive areas.

York Regions Forest Conservation By-law 2013-68 which replaces the older By-law, repealed 2005-036 on October 1, 2013, prohibits and regulates the destruction and injuring of trees in woodlands. York Region Forestry is responsible for the maintenance of trees on all regional roads and owns and manages a 19ha forested property in the north-west corner of Newmarket.

The Town of Newmarket has a complete inventory of street trees which is used to schedule pruning and hazard tree management. The inventory is also used to identify species susceptible to pests i.e. emerald ash borer.

Stewardship and Education Programs

In partnership with York Region, Local Enhancement and Appreciation of Forests (LEAF) offers a backyard tree planting program to residents of York Region. The program provides residents with native trees and shrubs at subsidized prices, as well as site and tree care consultations, and a full tree planting service.

The Town of Newmarket, together with Towns of East Gwillimbury, Aurora and LSRCA, partners with Neighbourhood Network to engage youth volunteers in an annual community tree planting event that occurs in Newmarket each spring. LSRCA carries out various tree planting events and programs across

[1] Refer to Town of Newmarket's website for additional details: www.newmarket.ca/livinghere/pages/

the town throughout the year as well as workshops and activities on forest management, invasive species, wildlife identification and others.

York Natural Planting Program, funded by the Region of York provides funding to its partners to assist the growth of forest cover across York Region. LSRCA and other York Region partners utilize this funding to improve the regions forest cover and meet the forest cover target set by the region.

2.3 Collaborative Urban Forest Studies

In April 2007, TRCA coordinated the meeting of key stakeholders from across southern Ontario to explore the possibility of using compatible methodologies in the Greater Toronto Area (GTA) and beyond. Consequently, the Regional Municipalities of Peel and York, Cities of Toronto, Mississauga, Brampton, Vaughan and Pickering, and the Towns of Markham, Richmond Hill, Ajax, and Caledon all became part of an informal collaborative that ensued from the discussions. Following these preliminary discussions the members of this collaborative agreed to move forward with urban forest studies using the i-Tree Eco model (formerly known as UFORE) and the additional suite of tools offered by the United States Depart of Agriculture - Forest Service and partners. To date, the TRCA has coordinated the studies for the municipalities of Mississauga, Brampton, Caledon, Vaughan, Markham, Richmond Hill, Aurora, Pickering and Ajax. As Newmarket falls within LSRCA's watershed boundary the Newmarket study has been conducted by LSRCA under TRCA's guidance. The City of Toronto led its own concurrent urban forest study using the same methodology and tools. See Figure 1 for an illustration of the municipalities engaged in collaborative urban forest studies. Such advancements in regional urban forest studies comprise important strides toward enhancing urban well-being in the GTA. These results also encourage positive momentum for further studies in York Region municipalities.

The primary objective of this collaborative effort was to develop a standardized methodology that would allow for further comparative and complimentary research at the regional scale. Carreiro and Zipperer (2008) highlight the value of such research, asserting that comparative ecological research will lay a foundation for distinguishing common urban effects and responses from those specific to a particular city or group of cities due to variations in factors such as geography, climate, soil, urban morphology, cultural values, and political and economic systems.

2.4 Literature Review

See Appendix A for a review of the relevant literature and research. This review explores the variables that affect and shape urban forest structure and function, and highlights the existing threats to urban forest health. Theories and concepts of sustainable urban forest management are also examined.

3.0 Methodology

Five complementary tools of analysis have been utilized in the study:

1. i-Tree Eco model
2. Urban Tree Canopy (UTC) Spatial Analysis
3. Priority Planting Index (PPI)
4. i-Tree Forecast
5. i-Tree Hydro

Each tool is examined in more detail below. Taken together, these analyses provide a broad and comprehensive understanding of Newmarket's urban forest. These tools have been developed by the United States Department of Agriculture Forest Service, Northern Research Station in partnership with the Spatial Analysis Laboratory at the Rubenstein School of Environment and Natural Resource at the University of Vermont. The combination of the three i-Tree tools have not only been used in North America but in various cities across the world i.e. Lisbon, London, Sydney etc.

While the i-Tree Eco analysis and the UTC analysis each represent stand-alone assessments capable of supporting an urban forest management plan, the technical working group opted to employ both of these complementary tools. By incorporating the data collected in the field, the i-Tree Eco analysis quantified critical attributes such as tree species and tree height, which cannot be obtained from aerial imagery. In contrast, using high resolution satellite imagery, the UTC analysis conducted by University of Vermont's Spatial Analysis Laboratory digitally mapped the actual and potential location of all individual trees in the study area (rather than only those trees measured within the i-Tree Eco sample plots), and projected future cover estimates based on a variety of different planting and mortality scenarios.

3.1 The i-Tree Eco Model

Several models and software packages have been developed to assist urban forest managers in obtaining quantitative structural data. Following a review of the various applications, the technical working group, together with the regional collaborative, concluded that the i-Tree Eco model would provide the level of structural detail required for urban forest studies across the Greater Toronto Area (GTA). Furthermore, i-Tree Eco model has been previously employed by other Canadian cities and can therefore produce standardized and comparable results at both the provincial and national levels.

3.1.1 Study Design

Study area boundaries were defined according to the municipal boundaries of Newmarket. In accordance with the randomized grid sampling method recommended by the USDA Forest Service, a grid was overlaid on a GIS-based map of the entire study area and a sample plot was generated randomly within each grid cell. A total of 200 plots were used in the analysis (one from each grid cell), with a density of approximately 1 plot for every 24 hectares. Each one of these circular plots was approximately 0.04 hectares in size. Data from the plots were then statistically extrapolated upward to estimate the projections and standard errors for the entire study area.

Although increasing the number of plots would have led to lower variances and increased certainty in the results, it would also have increased the cost of the data collection. Thus, the number of plots surveyed provided an acceptable level of standard error when weighted against the time and financial costs required for additional field data collection. As a general rule, 200 (0.04 ha) plots in a stratified random sample in a city will yield a standard error of approximately 10% (USDA, 2007). In the past, large cities such as New York and Baltimore have used 200 sample plots and have obtained accurate results with acceptable levels of standard error.

A high resolution aerial orthophotograph that illustrated the location of plot centres and plot boundaries was uploaded on a tablet equipped with GPS and mapping software. The availability of a high resolution aerial image and GPS not only oriented the field crew but also helped with some of the visual assessments such as canopy cover and total plantable space for the sample plots.

3.1.2 Study Area Stratification

Stratifying the study area into smaller units can aid in understanding variations in the structure of the urban forest according to land use types (e.g. residential, commercial, etc.) or neighbourhoods. The study area was stratified by land use after the plots had been randomly distributed. If the distribution of land use categories changes in the future, this method of post-stratification will allow the municipality to revisit the sample plots and record the new land use types since plots are not dependent on a static land use distribution.

The study area was stratified into 6 land use categories. These categories were comprised of 10 substrata represented by the Municipal Property Assessment Corporation (MPAC) codes assigned to each property in the municipality. Each MPAC code, or substrata, was grouped into one of 6 generalized categories based on similarities in ownership and management type. See Appendix C for a complete description of each land use category and the corresponding MPAC codes. This list is drawn from the most recent iteration of MPAC codes, completed in 2012. Given that land use changes are likely to occur within each four year period, MPAC codes should be screened for every new sample inventory and adjusted to reflect approved developments since the previous update in order to provide the most accurate projected urban forest calculations by land use.

The vacant spaces (9 plots) agricultural lands (13 plots) and institutional lands (8 plots) represented the three smallest land use categories of the total study area. In order to produce statistically accurate results the USDA Forest Service recommends that a minimum of 15 to 20 plots fall within a distinct category. Consequently, the aforementioned categories were collapsed into one category, to create a total of six land use categories:

- Commercial/Industrial
- Natural Cover
- Open Space
- Residential
- Transportation & Utilities
- Agricultural, Institutional & Vacant

Categories were grouped together based on similarities in vegetation cover and management needs. See Appendix D for a generalized land use map depicting these six land use categories.

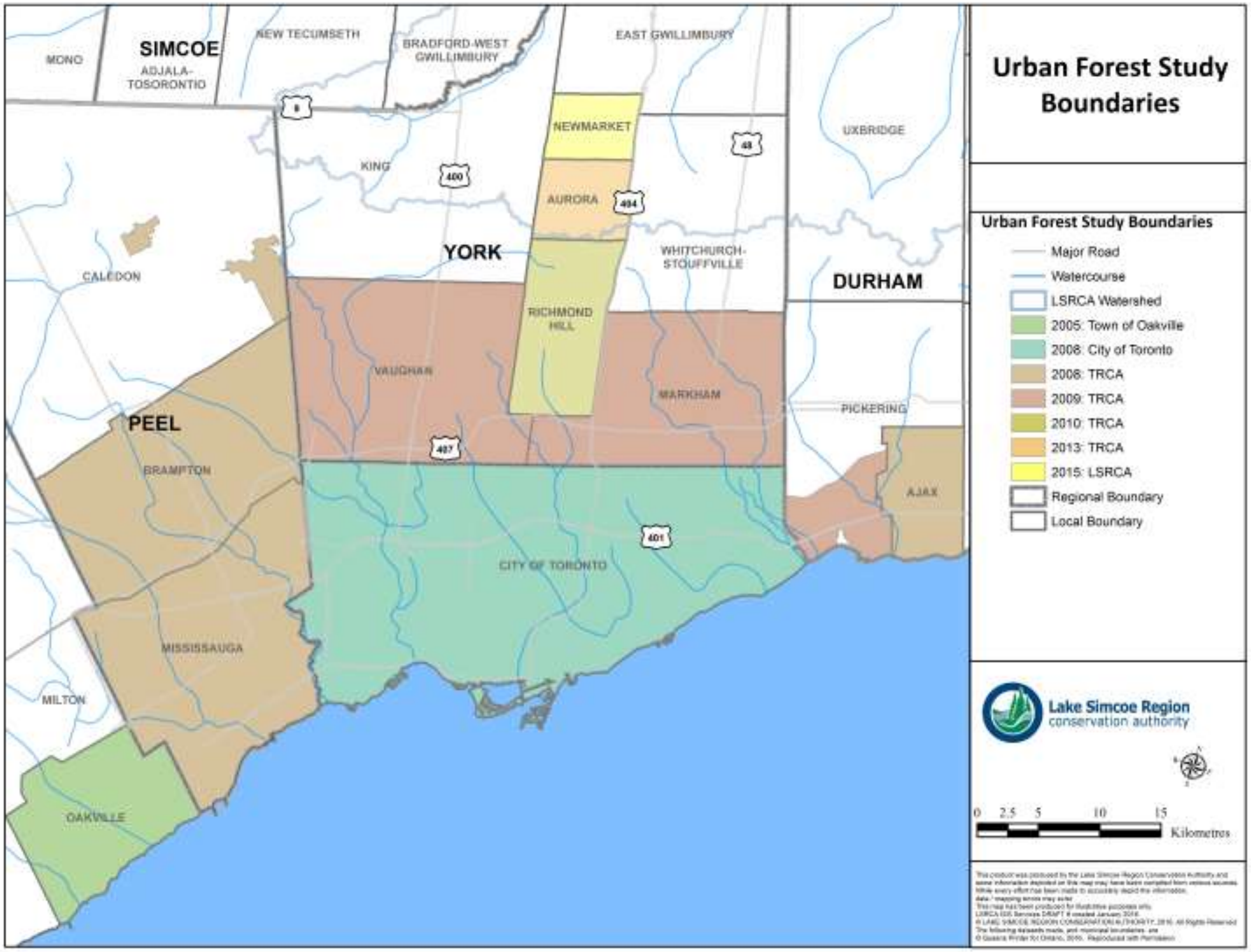

Figure 1: Municipalities in the Greater Toronto Area that have participated in urban forest studies

3.1.3 Landowner Contact

Permission to access plots located on private property was sought initially through written communication. Prior to entry, all property owners were mailed a request for access form in addition to a letter outlining the scope and duration of the study. The letter requested a response with either free access, or access with prior notice on a particular day. If no response was given, field staff requested permission to access the property via phone call or in person. In the event that permission was not granted, access was restricted due to physical barriers, or the site was deemed unsafe, field staff recorded measurements at the nearest alternate representative location.

3.1.4 Field Data Collection

Field data was collected by a staff of two people during the summer leaf-on season in 2015. At each sample plot field staff recorded the distance and direction from plot center to permanent reference objects using the range finder and mapping software. This exercise was carried out to make plot relocation easier for future re-measurements. Detailed vegetation information was recorded for each plot in accordance with i-Tree Eco data collection protocol. The following general plot data was recorded:

- Percent tree cover
- Percent shrub cover
- Percent plantable space
- Land use as observed in the field
- Percent of plot within each observed land use
- Percent ground cover of each:
    - Building
    - Cement
    - Tar-blacktop/asphalt
    - Soil
    - Rock
    - Duff/mulch
    - Herbaceous (exclusive of grass and shrubs)
    - Maintained grass
    - Wild/unmaintained grass
    - Water

For each shrub mass, the following data were recorded:

- Genus and, if possible, species
- Height
- Percent of shrub mass volume occupied by leaves
- Percent of total shrub area in the plot occupied by the shrub mass

For each tree with the centre of its stem in the plot and a minimum trunk diameter at breast height (1.4m) (DBH) of at least 3cm, the following data were recorded:

- Species
- Status (planted, naturally in-seeded, or unknown)
- Direction and distance from point centre
- Land use in which the tree is growing
- Number of stems
- diameter at breast height for each stem up to a maximum of 6 stems
- tree height
- height to top of live crown, if different from total height
- height to base of live crown
- crown width (average of two perpendicular measurements)
- percent canopy missing
- tree condition (based on percent of branch dieback in crown)
  - excellent (< 1 dieback)
  - good (1-10)
  - fair (11-25)
  - poor (26-50)
  - critical (51-75)
  - dying (76-99)
  - dead (100-no leaves)
- percent of area under tree canopy occupied by impervious ground surface
- percent of area under tree canopy occupied by shrub mass
- crown light exposure (number of the tree's sides out of a total of 5 that are exposed to direct sunlight)
- distance and direction from the building (for trees > 6m in height and located within 18.3m of a residential building)
- tree site (indicated whether the tree is a municipal managed street tree)

3.1.5 Data Analysis

The i-Tree Eco model used standardized field, air pollution-concentration and meteorological data for Newmarket to quantify urban forest structure and function. Five model components were utilized in this analysis:

1) Urban Forest Structure
   - Quantifies urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass) based on field data.
2) Biogenic Emissions
   - Quantifies hourly urban forest volatile organic compound (VOC) emissions (isoprene, monoterpenes, and other VOC emissions that contribute to O3 formation) based on field and meteorological data, and
   - O^3 and CO formation based on VOC emissions.
3) Carbon Storage and Annual Sequestration
   - Calculates total stored C, and gross and net C sequestered annually by the urban forest based on field data.

4) Air Pollution Removal
    - Quantifies the hourly dry deposition of O^3, SO^2, NO^2, CO, PM10[2], and PM2.5 by the urban forest and associated percent improvement in air quality throughout a year. Pollution removal is calculated based on local pollution and meteorological data.
5) Building Energy Effects
    - Estimates effects of trees on building energy use and consequent emissions of carbon from power plants.

For a detailed description of the i-Tree Eco model methodology see Appendix E.

3.2 Urban Tree Canopy Analysis

The Urban Tree Canopy (UTC) analysis was conducted by the Spatial Analysis Laboratory of the University of Vermont's Rubenstein School of Environment and Natural Resources, in consultation with the USDA Forest Service Northern Research Station. Advanced automated processing techniques using high-resolution 2012/13 colour infrared aerial imagery and ancillary datasets were used to map land cover for the entire town with such detail that single trees were detected (Figure 2). The following land cover categories were mapped:

- Tree canopy;
- Grass/Shrub;
- Bare Soil; Water;
- Buildings; Roads; and
- other paved.

Figure 2: Digitalized land cover mapping

Using the land cover data the following tree cover statistics were calculated:

- Existing tree canopy;

[2] PM10 data was not available for the weather station associated with the study area

- Impervious possible tree canopy; and
- Vegetated possible tree canopy (see Table 1 for a description of each metric).

Table 1: Description of tree canopy metrics used in Urban Tree Canopy (UTC) analysis.

Tree Canopy Metrics	Description
Existing Tree Canopy	The amount of tree canopy present when viewed from above using aerial or satellite imagery
Impervious possible tree canopy	Asphalt or concrete surfaces – excluding roads and buildings – that are theoretically available for the establishment of tree canopy
Vegetated possible tree canopy	Grass, bare soil or shrub area that is theoretically available for the establishment of tree canopy. This estimate does not consider land use preference.

Tree canopy metrics were summarized for each property in the municipality's parcel database. For each parcel both the absolute area and percent of existing and possible tree canopy were computed.

Existing and possible tree canopy metrics were summarized for the following geographic categories:
- Municipal Right of Way (ROW);
- Census unit;
- Dissemination Area;
- Municipal Ward; and
- Watershed.

3.3 Priority Planting Index

The technique developed by TRCA is used to identify priority planting areas based on census dissemination areas (DAs). DAs are a small but stable geographical unit at a neighbourhood level used to collect census data. The digital cover maps described in section 3.2 together with 2011 census data were used to produce an index that prioritizes tree-planting areas within dissemination areas in Newmarket. The index combines three criteria:

1. Population density (PD): The greater the population density, the greater the priority for tree planting.
2. Canopy green space (CG): Canopy green space is the proportion of total green space area (non-impervious areas) filled with tree canopies. The lower the value, the greater the priority for tree planting.
3. Tree canopy cover per capita (TPC): The lower the amount of tree canopy cover per person, the greater the priority for tree planting.

Each criterion above was standardized on a scale of 0 to 1, with 1 representing the maximum population density and minimum canopy green space and tree cover per capita. The standardized values were weighted to produce a combined score:

$$I = (PD * 40) + (CG * 30) + (TPC * 30)$$

Where I is the combined index score, PD is the standardized population density value, CG is the standardized canopy green space value, and TPC is the standardized tree cover per capita value. The combined score was standardized again and multiplied by 100 to produce the planting priority index. The tree planting priority index (PPI) ranks the dissemination with values from 100 (highest priority) to 0 (lowest priority).

3.4 i-Tree Forecast

The i-Tree Forecast computer model, created by the USDA Forest Service, Northern Research Station, was used to estimate future canopy cover under the following two scenarios: 1) maintain existing canopy cover; and 2) increase canopy to 40%. Both scenarios estimated future canopy cover using 5 different annual mortality rates, ranging from 2% annual mortality to 6% annual mortality. The actual mortality rate of trees in Newmarket is not known, but is assumed to fall within this range based on studies done in other municipalities with a similar climate and population density.

Tree measurements collected in the field for the i-Tree Eco analysis were utilized by the model to simulate future canopy cover. Projections for each tree were based on various tree characteristics including: species (growth rate, longevity, height at maturity); diameter at breast height (dbh); crown light exposure; and percent dieback in tree crown. Tree growth or annual increase in dbh was based on the number of frost free days (149), crown light exposure, dieback, growth rate classification and median height at maturity. Individual tree mortality was based on the percent dieback in the crown, dbh and average height at maturity for each tree. Average percent mortality was calculated for all trees measured. In anticipation of wide-spread and potentially complete ash species mortality as a result of emerald ash borer (*Agrilus planipennis*) infestation, a scenario in which 100% of existing ash trees were killed over a ten year period was also modeled. Under this scenario, a zero% rate of natural regeneration for ash species was assumed.

3.5 i-Tree Hydro

Hydro is a stand-alone application designed to simulate the effects of changes in tree and impervious cover characteristics within a defined watershed on stream flow and water quality. It was designed specifically to handle urban vegetation effects so urban natural resource managers and urban planners can quantify the impacts of changes in tree and impervious cover on local hydrology to aid in management and planning decisions. Hydro quantifies and illustrates hourly and total changes in stream flow and water quality. Data will be presented in tabular summaries as well as through graphs (hydrographs) that illustrate the changes between the base case (conditions as they are now) and an alternate case specified by the user. (Since the whole sub-watershed needs to be analyzed together, the data will be supplemented in fall 2016 as an additional appendix.)

4.0 Results

4.1 Urban Forest Distribution

The Urban Tree Canopy (UTC) analysis found that approximately 840ha of the Town is covered by tree canopy (termed existing TC), representing 24% of all land cover in Newmarket (Figure 3). Grass, herbaceous cover (including agricultural crops) and bare soil represents 29% of the municipal land cover, and impervious surfaces (roads, buildings, and other paved surfaced) cover 26% of the town.

The two add up to an additional 55% of the Town's land area that could theoretically be modified to accommodate additional tree canopy (combined possible TC). Specifically, 29% of the total land area is classified as vegetated possible TC the analysis did not consider social-economic and cultural expectations for land use. Therefore, agricultural lands have been classified as vegetated possible TC. Agricultural lands represent approximately 5% of the total land use area within the municipality.

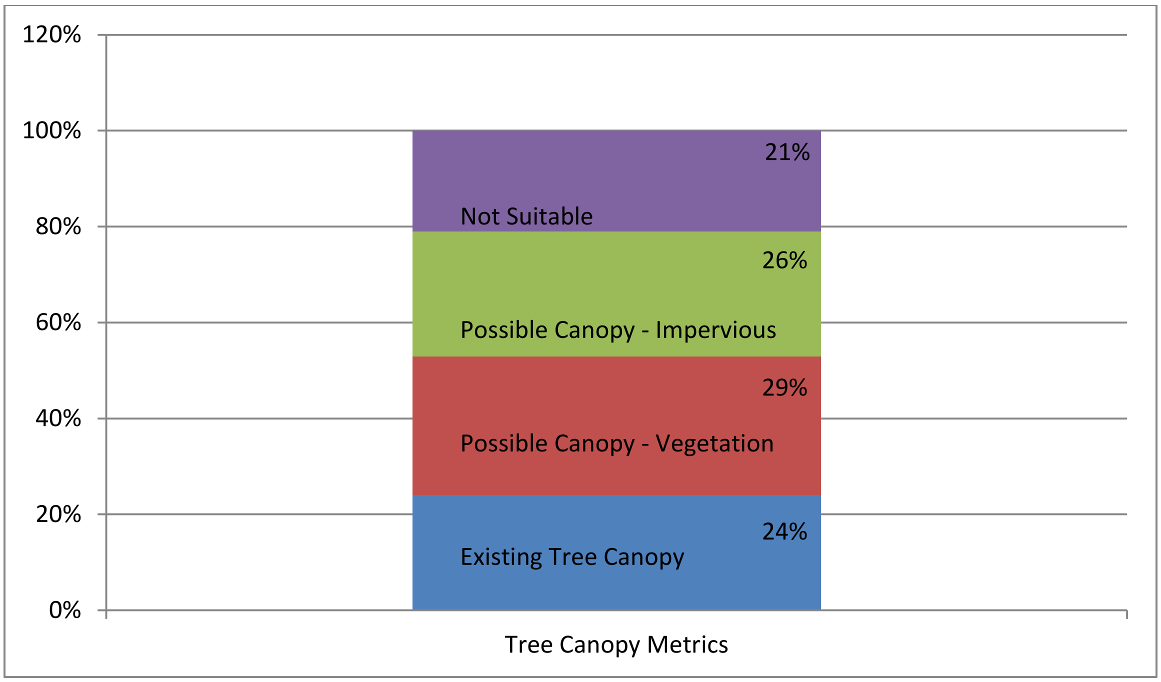

Figure 3: Tree canopy metrics for Newmarket

Total area (ha) of existing and possible TC within each land use is illustrated in figure 4. Table 2 presents TC metrics for each land use calculated as a percentage of all land in the town (%Town), and as a percentage of land area within the specified land use category (% Land Use). The *natural cover* land use category supports the highest existing TC by land use, with 53% tree cover (123ha). However, due to the relative size of this land use, tree canopy within the natural cover category represents only 3% of the Town's total land area. The greatest proportion of the existing TC is found within the *residential* category (260ha or 7% of towns total land area). Existing TC is lowest in the *Industrial and Commercial* category.

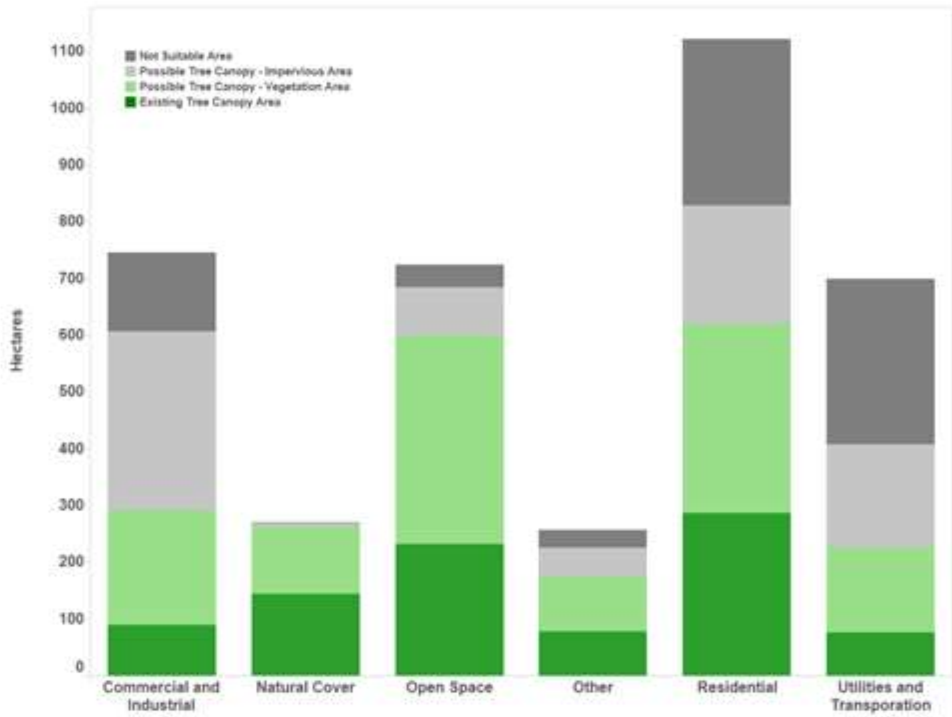

Figure 4: Tree Canopy metrics (existing or possible canopy) summarized by landuse for Newmarket

Table 2: Tree canopy metrics summarized by land use in Newmarket. For each land use category, TC metrics were calculated as a percent of all land cover in the municipality (Town), and as a percent of land cover within the specified land use category

Land Use	Existing Tree Canopy		Possible TC - Vegetation		Possible TC - Impervious	
	Town	Land Use	Town	Land Use	Town	Land Use
Residential	7%	27%	10%	29%	5%	18%
Natural Cover	3%	53%	3%	44%	0%	2%
Open Space	6%	32%	11%	50%	2%	2%
Commercial & Industrial	2%	11%	5%	28%	8%	43%
Utilities & Transportation	2%	10%	4%	22%	3%	24%
Other	2%	30%	3%	36%	1%	20%

The greatest opportunity to increase total municipal tree cover is theoretically found in the residential land use category. Approximately 560,400 ha of *residential* land (15% residential land use) (11% of the Town's total land area) are classified as possible TC. – Vegetation and Impervious. The results indicate that *Open Space* land use offers 13% possible tree canopy. However this characterization considers only physical requirements of tree planting and does not recognize social or economic expectations for each land use. As such, parcels on which active social activities are currently occurring (picnics, sports, other recreational activities) can be further excluded from this percentage.

Approximately 43% of the commercial and industrial land uses are classified as *Possible Impervious TC*. Though, establishing tree canopy in impervious surfaces is likely more challenging than doing so in pervious surfaces. However, an added benefit would be a reduction in heat transfer and reduce the volume of storm water runoff.

Tree canopy metrics have been generated for dissemination areas in Newmarket (Figures 5 and 6). High existing TC is indicated by dark green shading; high possible TC (both vegetated and impervious) is indicated by dark brown shading.

In areas where tree canopy has been removed, surface temperatures can be substantially higher than adjacent forested areas. The effect may be most pronounced in areas with extensive impervious surfaces, which absorb and hold thermal radiation from the sun. Analysis of recent thermal data (Landsat, July 18, 2013) illustrated this effect in Newmarket (Figures 7 and 8). A significant inverse relationship was found to exist between tree canopy and surface temperature providing evidence that trees help to reduce the urban heat island effect.

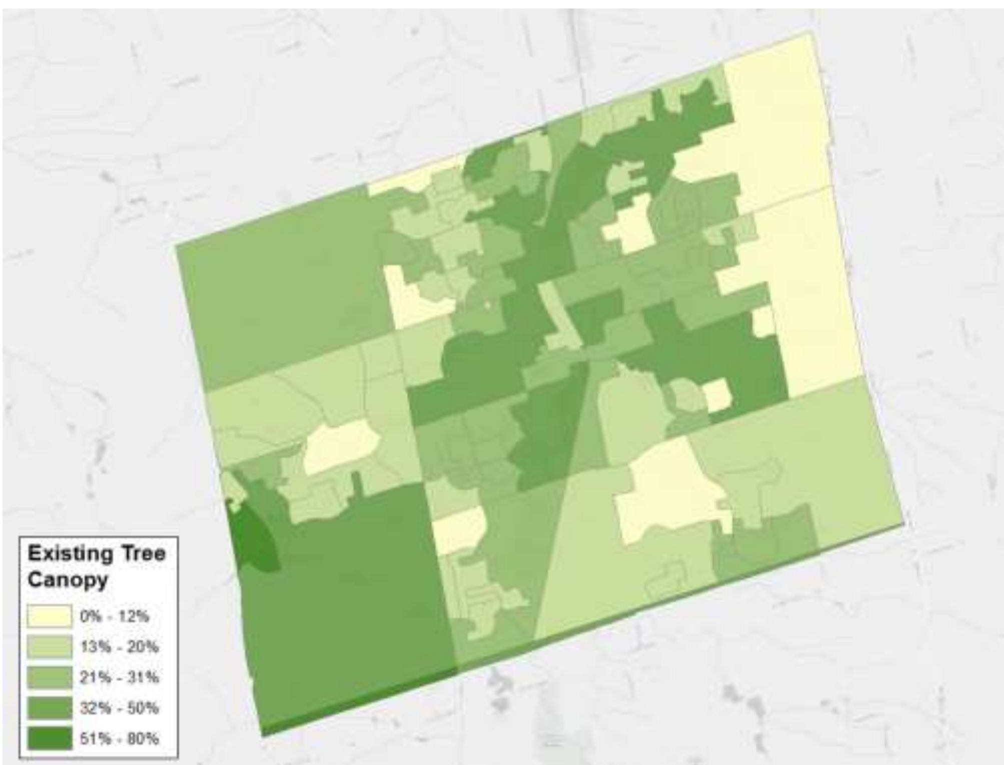

Figure 5: Existing tree canopy summarized by dissemination areas in Newmarket

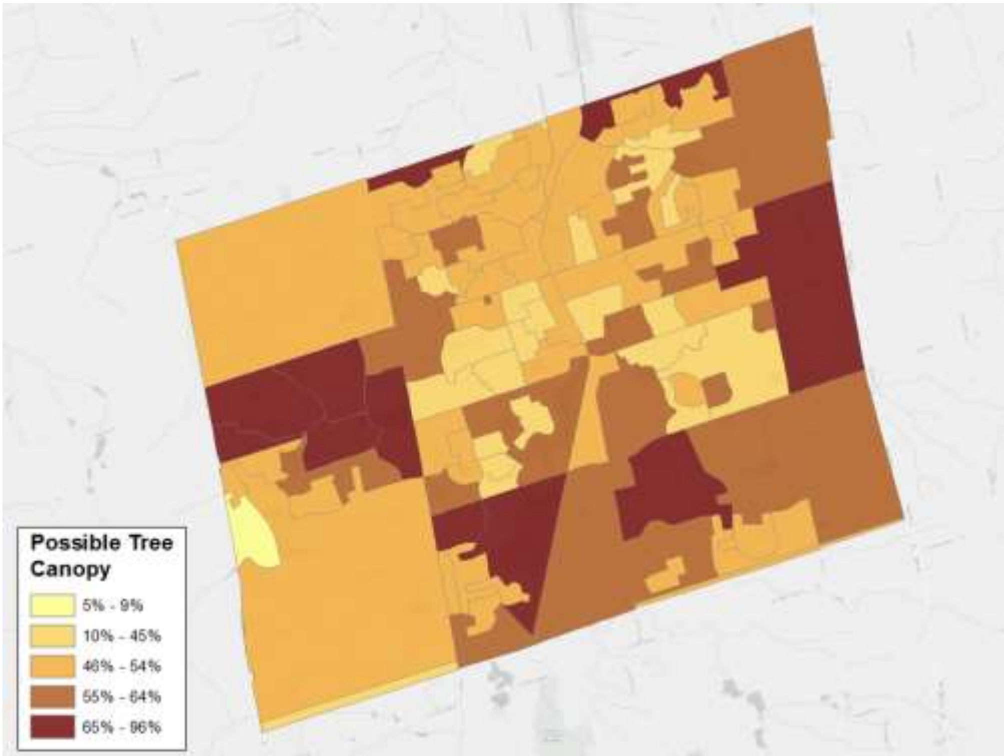

Figure 6: Possible tree canopy summarized by dissemination areas in Newmarket

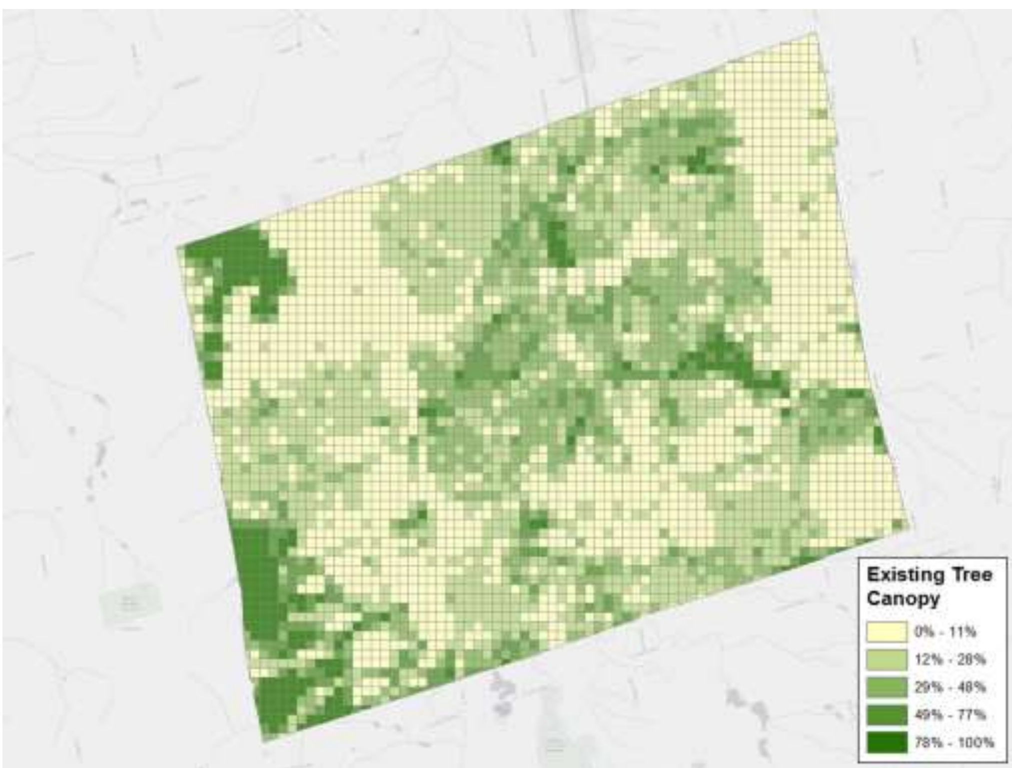

Figure 7: Existing tree canopy in Newmarket as assessed by urban tree canopy analysis

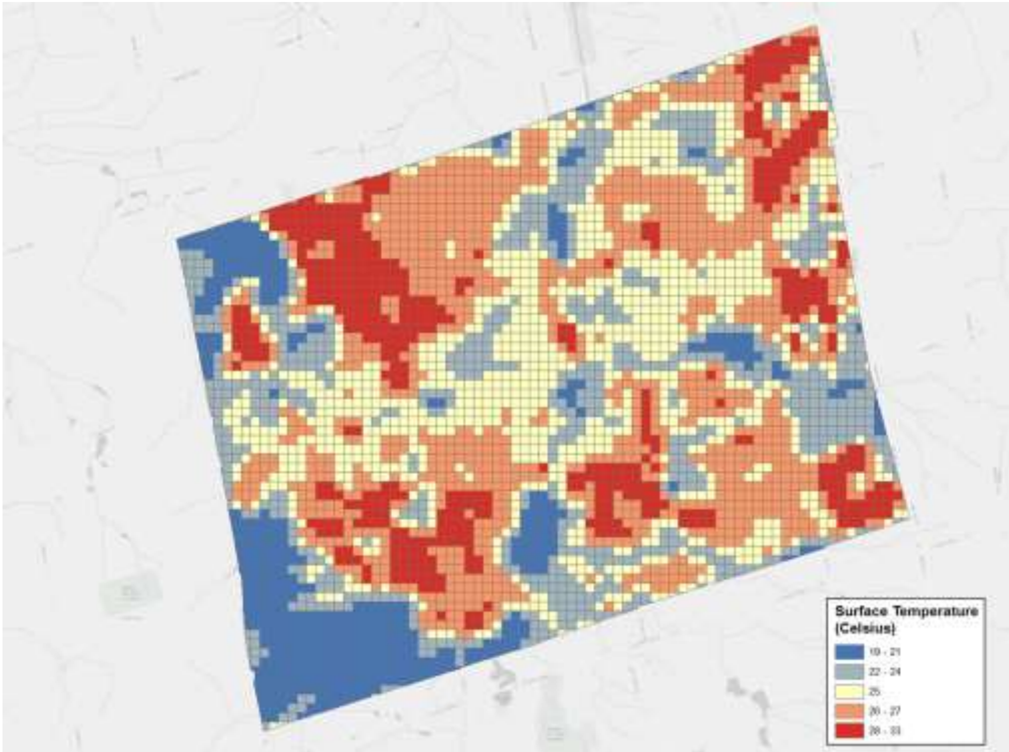

Figure 8: Surface temperatures (degree Celsius) in Newmarket derived from Landsat satellite imagery

4.2 Planting Priority Index

The priority planting index provides direction for tree planting and establishment by using key demographic and existing canopy parameters in its calculations. The index has been summarized at the scale of dissemination area (Figure 9). Each unit has been assigned a value between 0 (lowest priority) and 100 (highest priority). Units with a higher human population density and a lower tree cover per capita have received a higher index value, as they highlight need for added canopy cover. Residential areas located through the municipality as high priority (shown in red), as these areas support a high population density but have a low relative tree canopy. Consequently, the ecosystem services provided by the urban forest are not currently distributed equitably across all neighbourhoods.

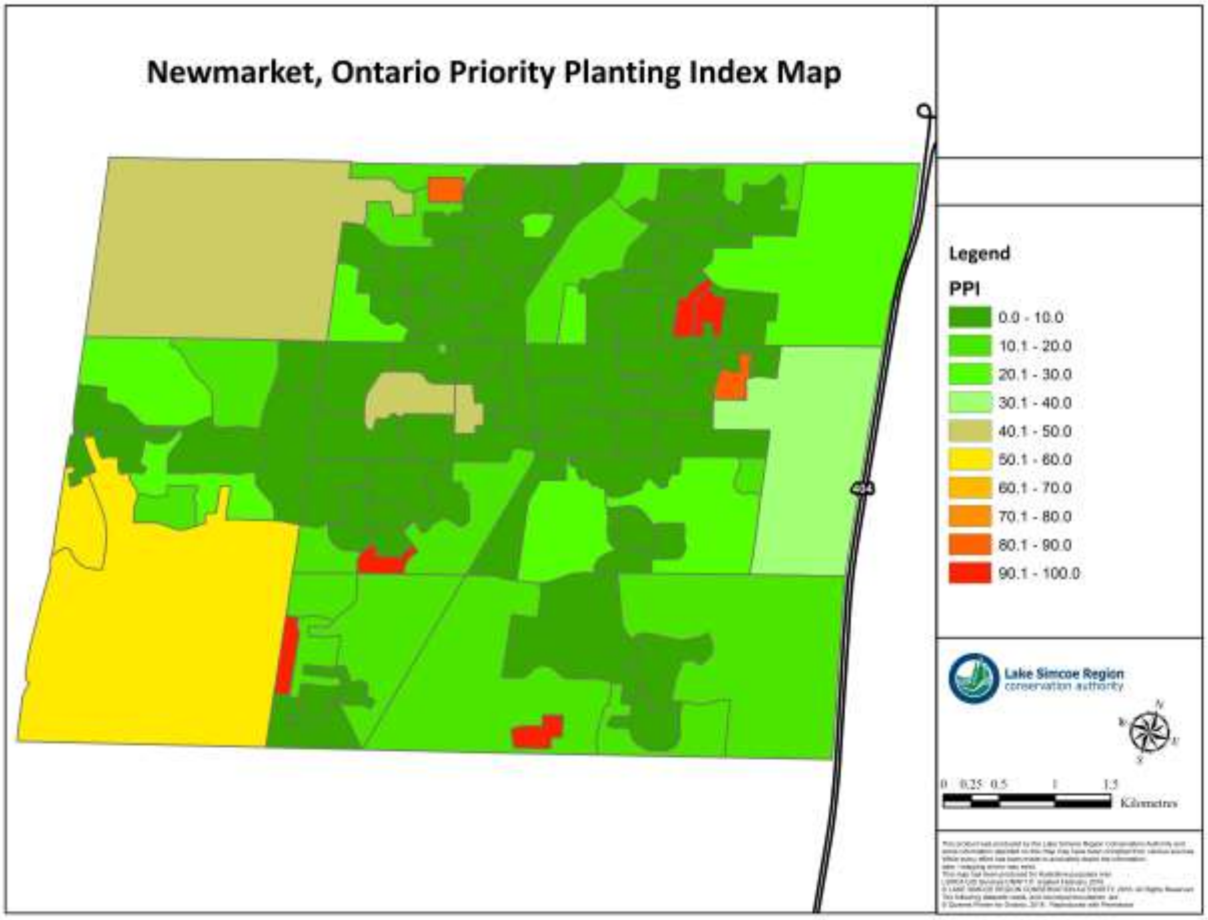

Figure 9: Priority Planting Index summarized by dissemination areas in Newmarket

4.3 Urban Forest Structure

Tree Density:

The i-Tree Eco model determined that there are approximately 294,755 trees in Newmarket (with an acceptable standard error of ±38,345). Average tree density in Newmarket is 77 trees/ha, with the highest in *Natural Cover* (294.1 trees/ha) land use areas, followed by open space (117.7 tree/ha) and *Residential* (86.6 trees/ha). In the *Commercial/Industrial* (3.8 trees/ha) and *Transportation & Utilities* (39.9 trees/ha) land use categories, tree density is lower than the overall mean for the Town (Figure 10).

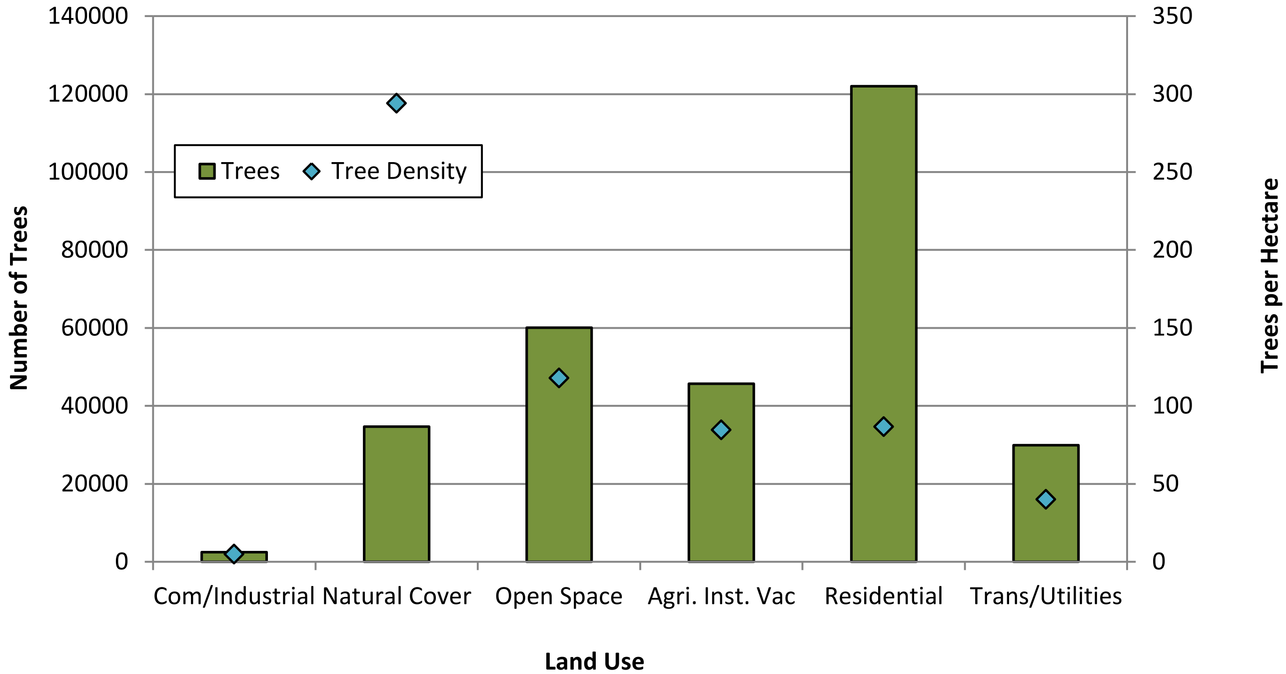

Figure 10: Total number of trees and tree density (trees per hectare) summarized by land use in Newmarket

Leaf Area:

Leaf area can be defined as the total surface area of leaves present on trees. Average leaf area density (including both trees and shrubs) defined as leaf area per hectare in Newmarket is approximately 13,285 m^2/ha with a total leaf area of 51 km^2 across the municipality. Leaf area varies between land uses and is concentrated in the natural cover category which represents 3.06% of the total land use in Newmarket. The lowest leaf area density 100m^2/ha is in the commercial/industrial land use category which accounts for 13.5% (Figure 11) of the total area of Newmarket.

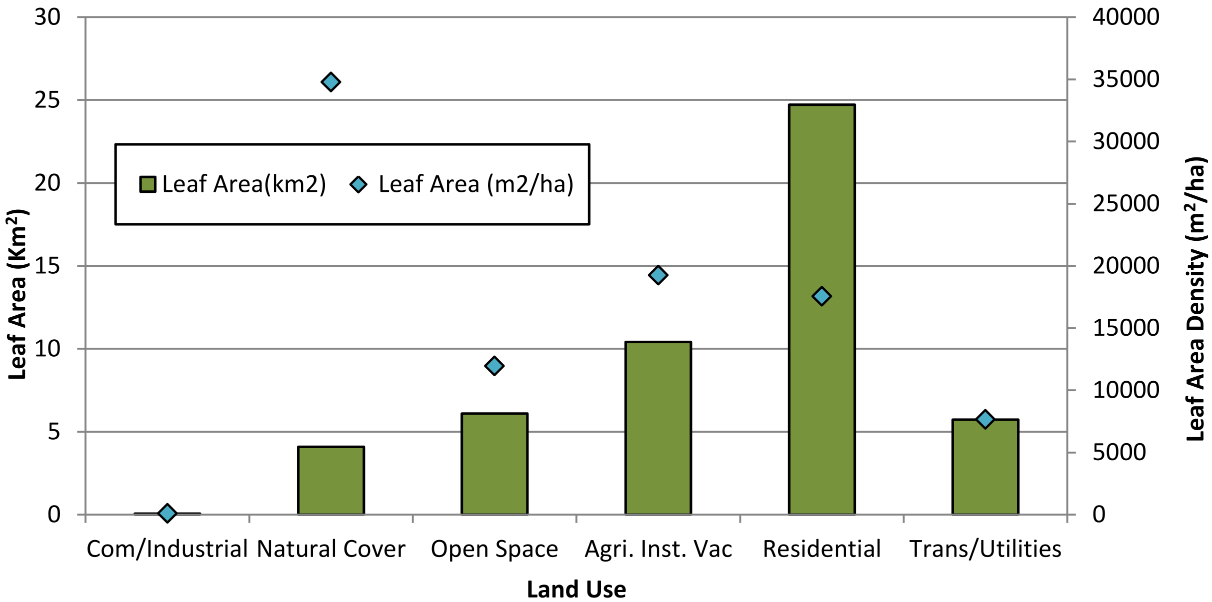

Figure 11: Leaf area (km²) and leaf area density (m²/ha) by land use in Newmarket

Tree Species Dominance:

Tree species dominance can be expressed either as a percent of total leaf area or as a percent of the total number of stems (Figure 12). When the latter method is used, species that maintain a small growth form and also grow in high densities, such as eastern white cedar, tend to dominate total species composition. In contrast, species composition expressed as a percent of total leaf area captures the relative contribution made by each species to the canopy layer as well as to the provision of ecosystem services (as ecosystem services are generally a function of leaf area). With respect to total leaf area, the dominant tree species in Newmarket are Norway maple (*Acer platanoides*), with 13.9% of total leaf area, black walnut (*Juglans nigra*, 10.2%), and Norway spruce (*Picea abies,*10.2%). i-Tree Eco also presents this through importance value, a combination of leaf area and total stems value. Figure 12 suggests the importance value of Norway maple significantly higher than the rest; this is an effect of its larger leaf area. Black walnut is second in the importance value category for the same reason.

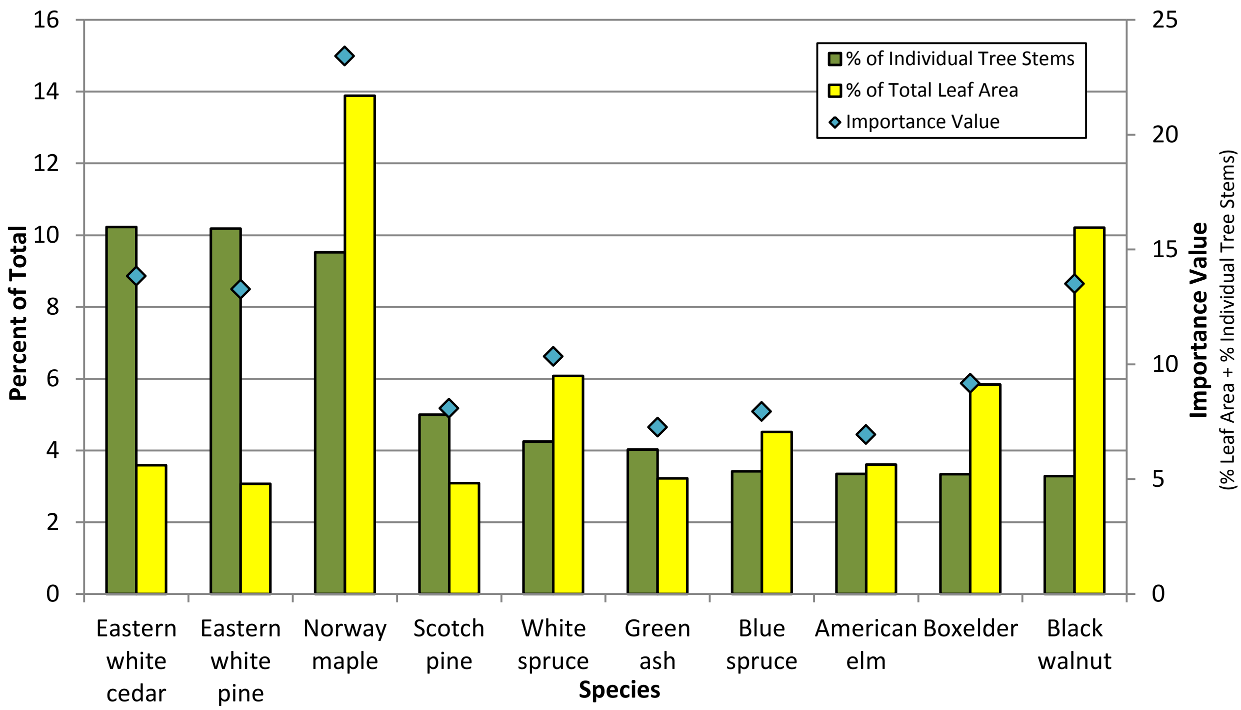

Figure 12: Top 10 tree species in Newmarket expressed as a percent of total stems, percent of total leaf area and the combined importance value.

With respect to the total number of individual tree stems, the most common tree species are eastern white cedar (*Thuja occidentalis*, 10.5%), eastern white pine (*Pinus strobus*, 10%) and Norway maple (*Acer platanoides*, 9.75%). Species dominance by land use is illustrated in Table 3. The most common genera in Newmarket are Maple (*Acer spp*., 25% of total leaf area), Spruce (*Picea spp.,* 19% of total leaf area) and Pine (*Pinus spp*., 11% of total leaf area).

A total of 75 tree and shrub species have been identified across all sample plots. Species richness is highest in the residential land use (57 species); this can likely be attributed to the number of exotic horticultural species found in residential yards and gardens. Thus, high species richness should not necessarily be viewed as an indication of ecosystem health. Rather, it may simply indicate an abundance of exotic species. Urban forests often have a species richness that is higher than surrounding rural landscapes. In Newmarket, 65% of the tree species identified are native to Ontario.

Table 3: Dominant tree species by percent of total leaf area and percent of total stems within land uses in Newmarket. Estimates for the commercial + industrial and institutional + utilities & transportation land use categories are associated with high standard error.

Land Use	Percent of Total Stems		Percent of Total Leaf Area	
	Common Name	Percent	Common Name	Percent
Commercial/Industrial	Eastern white cedar	40%	Eastern white cedar	58%
	Common lilac	20%	Common lilac	21%
	Russian olive tree	20%	Russian olive tree	21%
Natural Cover	Green ash	16%	Green ash	10%
	White pine	12%	Scots pine	8%
	Norway maple	9%	Norway maple	8%
Open Space	Eastern white pine	29%	Black walnut	21%
	Eastern white cedar	16%	Eastern white cedar	12%
	Trembling aspen	9%	Balsam poplar	11%
Agri./Inst./Vac.	Eastern white pine	16%	Norway spruce	24%
	Norway maple	9%	Sugar maple	10%
	White spruce	9%	Manitoba maple	9%
Residential	Eastern white cedar	10%	Norway maple	15%
	Scots pine	10%	Black walnut	15%
	Norway maple	9%	White spruce	8%
Trans/Utilities	Norway maple	27%	Norway maple	34%
	Blue spruce	7%	Blue spruce	10%
	White spruce	7%	Juniper	6%

Table 4 presents the percent of stems that have been planted (as opposed to natural regeneration/establishment) for the most common tree species in Newmarket. Many of the common tree species in Newmarket are high in abundance due to planting efforts. From the 20 total blue spruce and 26 white spruce sampled; 100% of the blue spruce was planted and 89% of the white spruce was planted. 55% of the Eastern white pine is planted and 53% of the Norway maple is planted. The data for the neighbouring Town of Aurora are quite different, as most of the dominant species are due to natural regeneration. This contrast is likely due to the large proportion of Aurora falling within the Oak Ridges Moraine. The intensive landscaping and the location of Newmarket being mostly north of the Oak Ridges Moraine has led to most of the trees being landscaped plantings.

Common shrubs in Newmarket include Eastern white cedar[3] (<3.5 cm dbh), and Staghorn sumac (*Rhus typhina*) comprising 15 and 10% of the total shrub leaf area, respectively. Table 5 presents the most common shrub species for each land use in the study area.

[3] Please see Appendix E for a detailed differentiation of shrubs and trees used in the data collection protocol

Table 4: Percent of stems planted (versus natural regeneration) for common tree species in Newmarket, where "n" equals number of trees sampled.

Common Name	Scientific Name	Percent planted	N
Blue spruce	*Picea pungens*	100	20
White spruce	*Picea glauca*	88.5	26
Scotch pine	*Pinus sylvestris*	71.4	42
Eastern white pine	*Pinus strobus*	54.2	72
Norway maple	*Acer platanoides*	53.8	65
Austrian pine	*Pinus nigra*	52.9	17
American elm	*Ulmus americana*	51.85	27
Eastern white cedar	*Thuja occidentalis*	43.2	74
Black walnut	*Juglans nigra*	38.9	18
Red pine	*Pinus resinosa*	38.1	21
White birch	*Betula papyrifera*	36	25
Norway spruce	*Picea abies*	31.6	19
Manitoba maple	*Acer negundo*	10.53	19
Green ash	*Fraxinus pennsylvanica*	9.5	42
Trembling aspen	*Populus tremuloides*	0	19

Table 5: Dominant shrub[4] species by percent of shrub area within land uses in Newmarket.

Land Use	Percent of Total Stems		Percent of Total Leaf Area	
	Common Name	Per cent	Common Name	Per cent
Commercial/Industrial	Northern White Cedar	40%	Northern White cedar	79%
	Common Lilac	20%	Common lilac	21%
	Russian olive tree	20%	Russian olive tree	
Natural Cover	Green ash	16%	Green ash	10%
	White pine	12%	Scotch pine	8%
	Norway maple	9%	Norway maple	8%
Open Space	Eastern White pine	29%	Black walnut	21%
	Northern white cedar	16%	Northern White cedar	12%
	Trembling aspen	9%	Balsam poplar	11%
Agri./Inst./Vac.	Eastern White pine	16%	Norway spruce	24%
	Norway maple	9%	Sugar maple	10%
	White spruce	9%	Manitoba maple	9%
Residential	Northern White cedar	10%	Norway maple	15%
	Scotch pine	10%	Black walnut	15%
	Norway maple	9%	White spruce	8%
Trans/Utilities	Norway maple	27%	Norway maple	34%
	Blue spruce	7%	Blue spruce	10%
	White spruce	7%	Juniper	6%

[4] i-Tree Eco protocol defines all plants below the DBH of 3 cm as shrub

Pest Susceptibility:

Pest susceptibility was calculated for the following insects/diseases: Asian long-horned beetle (*Anoplophora glabripennis*), emerald ash borer (*Agrilus planipennis*), gypsy moth (*Lymantria dispar*), and Dutch elm disease (*Ophiostoma spp*.) (Figure 13). Estimates represent the maximum potential pest damage expressed as a percent of all live trees susceptible in Newmarket. Approximately 29% of Newmarket's live tree populations (live stems) are susceptible to Asian long-horned beetle. This equates to a potential loss in structural value of approximately $109,273,215. Gypsy moth is a threat to 26% of the population with a potential loss in structural value of $56,033,072. Emerald ash borer is a threat to 5% of the live tree population, representing a loss of $13,630,638 in structural value. Although some elm species have shown varying degrees of resistance, Dutch elm disease could destroy the remaining elm population, representing 2% of the live tree population, valued at $8,354,122.

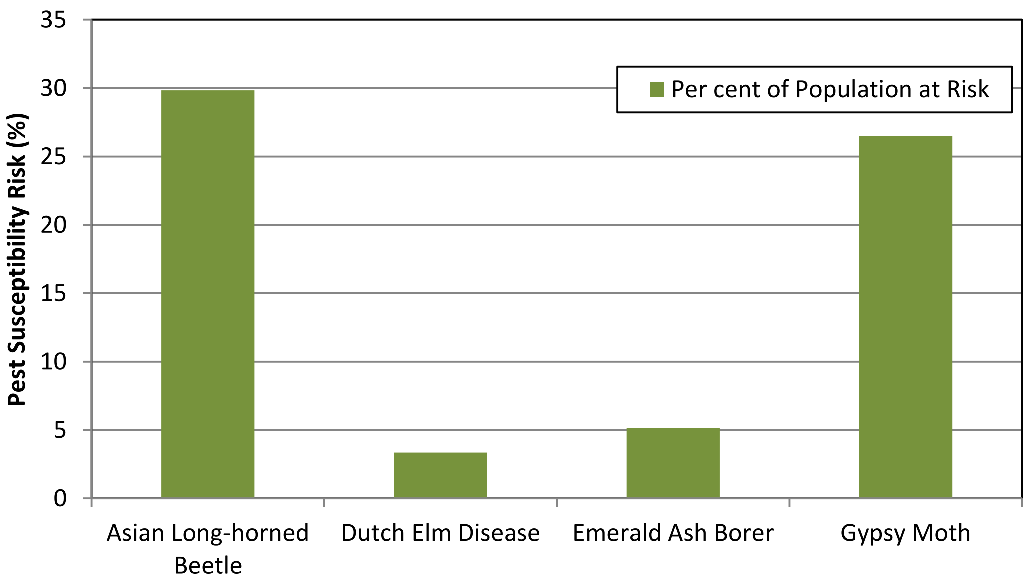

Figure 13: Percent of the tree population in Newmarket that is susceptible to Asian long-horned beetle, emerald ash borer, gypsy moth, and Dutch elm disease, and potential loss in associated structural value of host trees.

Diameter Distribution:

All trees measured have been grouped into size classes based on DBH; diameter classes increase in 7.6cm increments. Approximately 12% of all trees in Newmarket fall within the smallest diameter class (<7.6cm) and 37% of all trees are below 15.2 cm DBH.

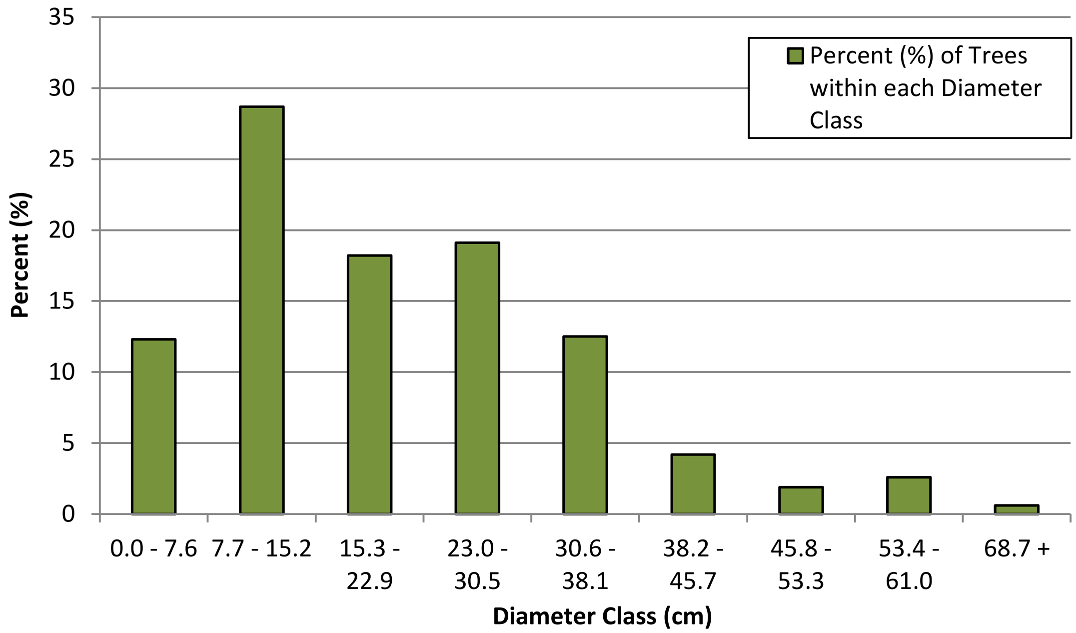

Figure 14: Diameter class distribution of trees in Newmarket.

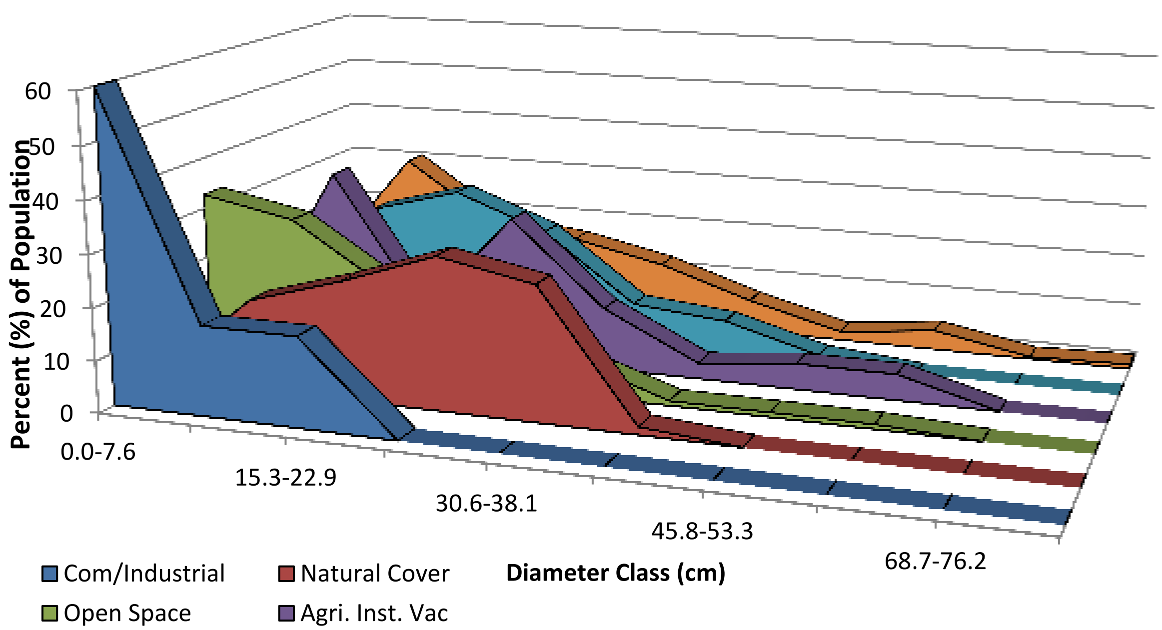

Figure 15: Diameter class distribution of trees by land use class in Newmarket.

All trees measured were assigned a condition rating in the field based on the proportion of dieback in the crown. The crown condition ratings range from excellent (<1% dieback) to dead (100% dieback).

Approximately 66% of all trees in Newmarket were classified within the excellent condition rating (Figure 16). Condition ratings do not incorporate stem defects and root damage.

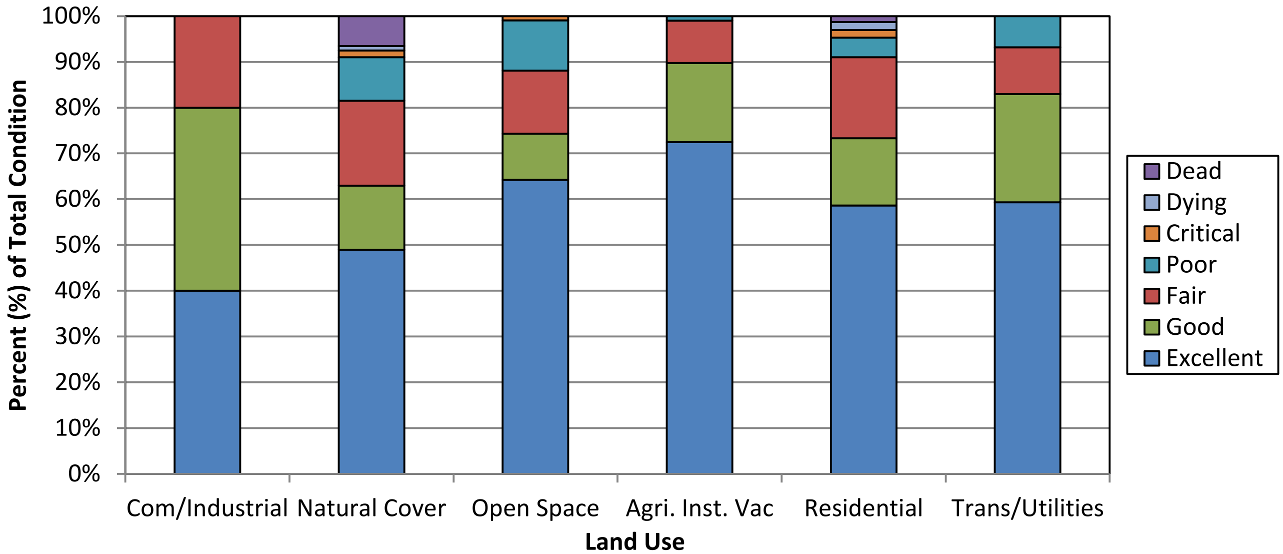

Figure 16: Average tree condition by land use in Newmarket.

The estimated structural value of all trees in Newmarket in 2015 is approximately $277 million. This value does not include the ecological or societal value of the forest; it represents an estimate of tree replacement cost determined by the cost of tree removal, stump grinding and replacement tree and/or compensation due to tree owners for tree loss. There is a positive relationship between the structural value of an urban forest and the number and size of healthy trees. As trees increase in size the replacement costs for removal, stump grinding and replacement increase thereby increasing the value as the tree grows in size.

4.4. i-Tree Forecast

The i-Tree Forecast model simulations provide an estimate of the level of annual planting required to meet multiple canopy cover targets within the next 50 years. The models emulated the growth of Newmarket's urban forest based on existing conditions as quantified by the i-Tree Eco analysis. Simulations are based on existing urban forest characteristics, including species growth rates and current tree health conducted by USDA -FS. The results are summarized into two scenarios: number of trees planted annually or established through natural regeneration in order to maintain existing canopy cover (currently 22% as estimated by i-Tree Eco and UTC) and number of trees planted annually in order to increase the existing canopy cover to 40%. In addition the anticipated impact of the emerald ash borer beetle has been included in these scenarios by assuming 100% mortality of all ash species over the next ten years, described in table 6 as "Total Ash Kill".

With an annual mortality rate of 4%, approximately 29,200 trees will need to be planted to maintain the existing canopy cover over a 50 year period (Table 6). If the total ash population of Newmarket is lost the number of trees required for annual planting drops to 28,000. Under a 4% annual mortality scenario, approximately 47,000 trees must be planted or established through natural regeneration annually across the municipality to reach a 35% canopy cover target over the next 50 years; when the loss of all ash species is factored into this scenario the number of trees required drops to 46,000 annually. Results assume that mortality rates and maintenance practices are held constant over time. Interestingly, the number of plantings required to maintain the canopy cover is lower for *ash kill* scenario compared to the *no ash kill* scenario. This is due to the higher combined growth rates of the projected new plantings compared to ash, the combination leads to faster canopy growth requiring less planting. In other words most other trees grow faster than Ash Trees and therefore will increase canopy cover faster than Ash would have.

Table 6: Estimated amount of tree planting required in Newmarket to: 1) maintain exiting canopy cover of 22%; and 2) increase canopy cover to 40% over a 50 year period, given 5 possible annual mortality rates.

Annual Mortality Rate	Annual tree planting to maintain 22% cover		Annual tree planting to increase to 35% cover	
	No ash kill	Total ash kill (10%/yr)	No ash kill	Total ash kill (10%/yr)
2%	11,000	11,000	24,500	25,000
3%	20,000	20,000	36,000	36,000
4%	29,200	28,000	47,000	46,000
5%	37,500	35,000	59,000	56,500
6%	47,000	42,000	73,000	67,000

4.5 Hydrologic Effects of the Urban Forest

i-Tree Eco calculates stormwater runoff avoided by the canopy by intercepting the rainfall. Norway maple avoids the highest amount of run off (29,849.88 m^3/yr) and provides an estimated annual value of $69,392 in stormwater and flood control management. Black walnuts avoid 21,965m^3/yr and Norway spruce a total of; 17,794 m^3/yr. The two provide a cost savings of $51,062 and $41,367 respectively. Residential land use avoids the highest amount of surface run off; 104,097 m^3/yr for a total value of $241,995. Commercial/Industrial land avoids the least run off; 169 m^3/yr a value of $392.

4.6 Urban Forest Function

4.6.1 Annual Pollution Removal

The i-Tree Eco model quantified pollution removal by trees and shrubs in Newmarket. Pollution removal is greatest for ozone (O_3), followed by Nitrogen dioxide (NO_2), and particulate matter less than 2.5 microns ($PM_{2.5}$), (Figure 17). Sulphur dioxide and carbon monoxide are also removed from the environment; however the amounts are significantly lower than the other pollutants. PM_{10} is not recorded by the weather department therefore PM10 removal numbers are not available.

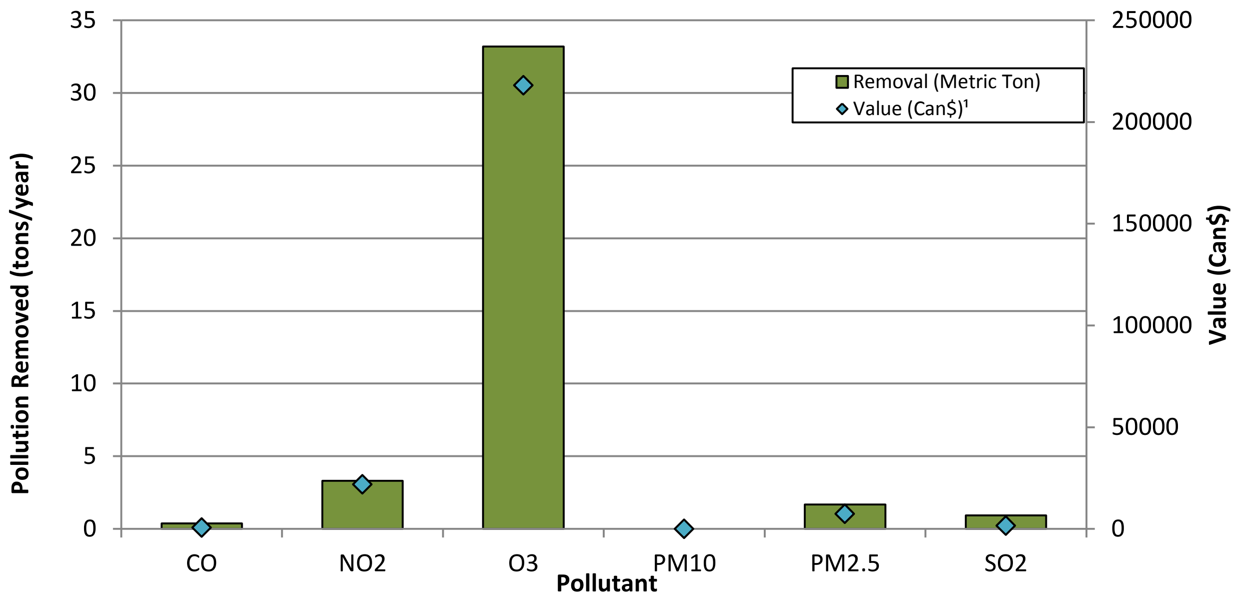

Figure 17: Annual pollution removal by trees and shrubs and associated removal value.

Newmarket trees and shrubs remove 40 tonnes of air pollution (CO, NO_2, O_3, $PM_{2.5}$, SO_2) per year with an associated removal value of $249,118 (based on estimated Canadian national median externality costs associated with pollutants)[5]. Average annual pollution removed per tree generally increases with tree size (figure 18).

[5] Murray, F.J.; Marsh L.; Bradford, P.A. 1994.New York state energy plan, vol. II: issue reports. Albany, NY: New York State Energy Office. An externality is a side effect of an economic transaction whose damages or benefits are not taken into account in the price of the transaction. Water pollution from industries is an example of a negative externality. Values were adjusted to Canadian dollars with a conversion rate of 0.8 US dollars per Canadian dollar.

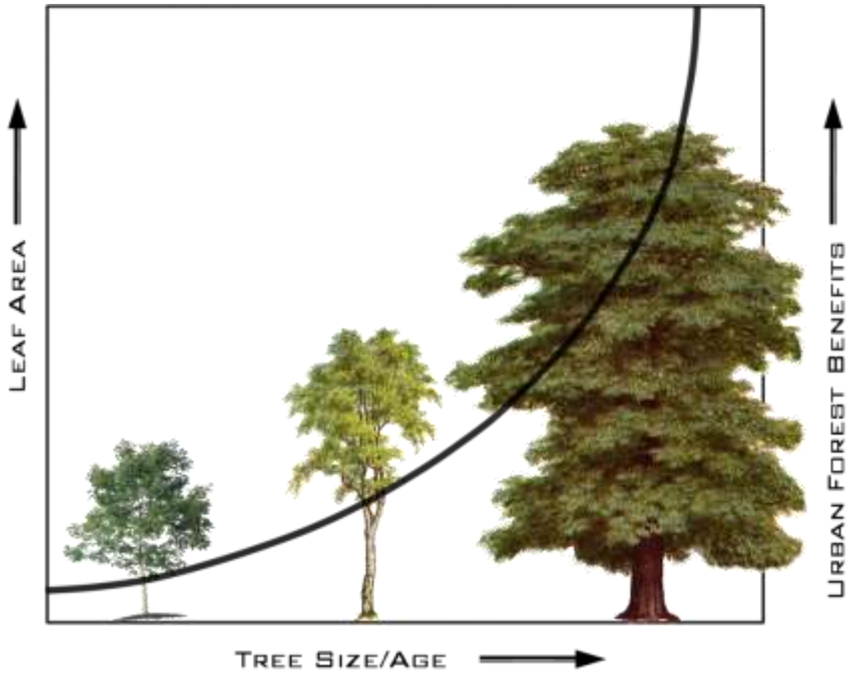

Figure 18: Urban forest benefits are directly proportional to tree size/age (graphical represenation)

4.6.2 Carbon Storage and Sequestration

According to the estimates produced by the i-Tree Eco model, gross carbon sequestration by trees in Newmarket is approximately 1,558 tonnes of carbon per year. Net carbon sequestration in Newmarket is approximately 1,273.8 tonnes per year based on carbon loss due to tree mortality and decomposition

Trees in Newmarket are estimated to store 35,345 tonnes of carbon. Of all the species sampled, Norway maples store the most carbon at 5,097 tonnes (approximately 14% of total carbon stored) and annually sequester the greatest net amount of carbon, 218.7 tonnes (approximately 17% of new carbon sequestered). This is mainly due to the dominance of this species in Newmarket's urban forest.

Figure 19 illustrates total carbon storage and total annual carbon sequestration distributed by diameter class. This graph should be viewed in the context of the diameter class distribution of the entire tree population (Figure 14). For example, trees greater than 68.6cm DBH represent less than 1% of the total tree population in Newmarket, yet these trees store approximately 7% of the total volume of carbon. In contrast the smallest trees (2.5 to 15.2cm DBH) represent approximately 40% of the tree population but store less than 4% of the total volume of carbon. When the results are standardized to illustrate average *per tree storage capacity,* individual large trees are shown to store significantly larger volumes of carbon than individual small trees (Figure 19).

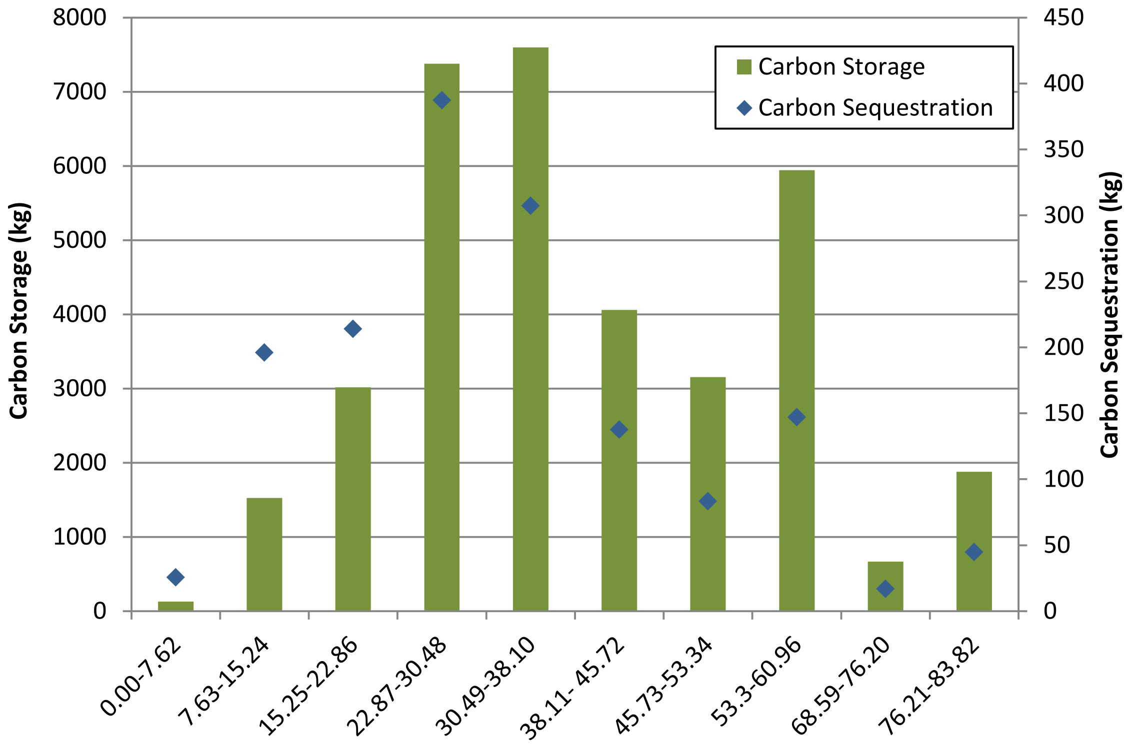

Figure 19: Total carbon storage and sequestration by diameter class

Average sequestration rates are also positively correlated with tree size. For example, the average tree in diameter class 7.7 – 15.2cm stored 18 kg of carbon and sequestered 2.1 kg of carbon annually, while the average tree in diameter class 38.2 – 45.7cm stored 328 kg of carbon and sequestered 11.2 kg of carbon annually. Similarly an older tree with a faster growth rate (i.e. Silver maple) will sequester more carbon as it utilizes carbon for growth. This increase in size results from storing carbon in its above and below ground biomass. However, the stored carbon will be released back into the atmosphere after the death of the tree through decomposition, combustion or stored in soil.

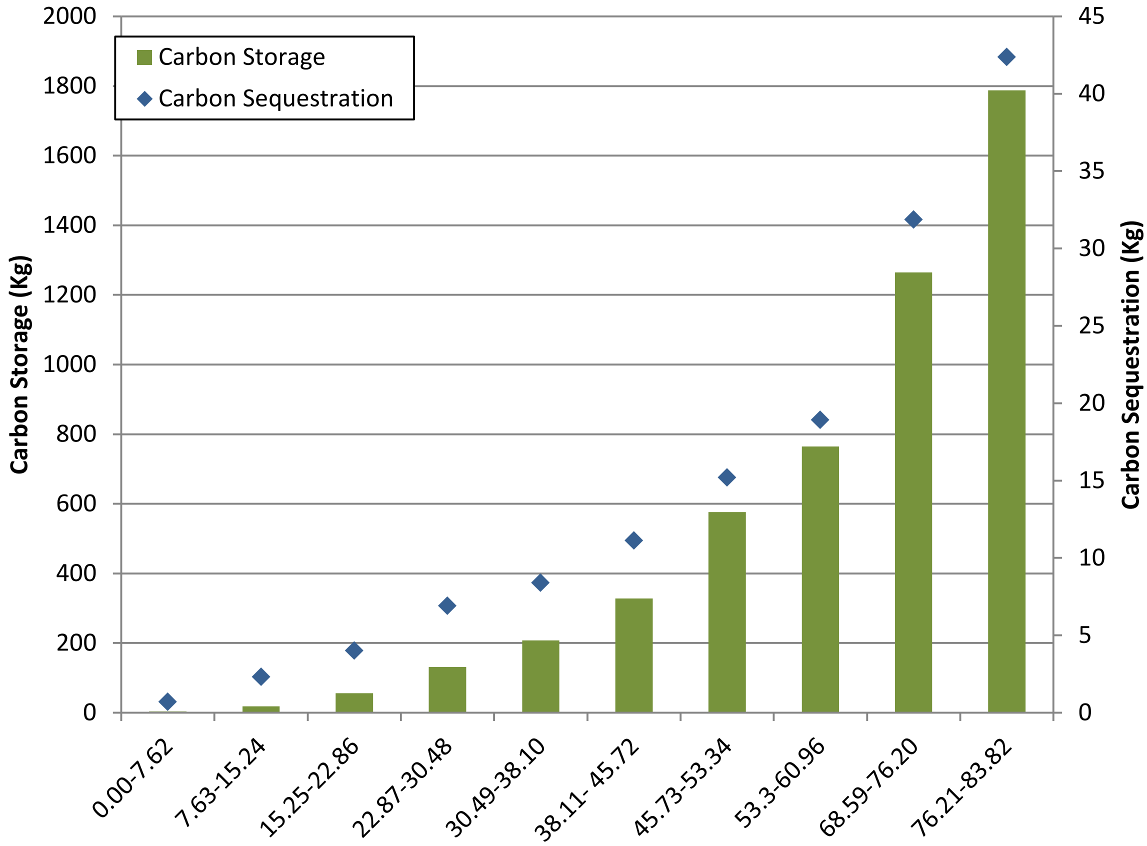

Figure 20: Average per tree carbon sequestration and carbon storage by diameter class

4.6.3 Residential Energy Effects

The i-Tree Eco model estimates the effects of trees that are more than 6.1m in height and within 18.3m of a residential building on energy use as a result of shading, windbreak effects, and local micro-climate amelioration. Estimates are based on field measurements of tree distance and direction of residential buildings. Annually, trees adjacent to residential buildings in Newmarket are estimated to reduce energy consumption by approximately 23,914 Million British thermal units (MBTU) for natural gas use and 1,127 megawatt-hours (MWH) for electricity use based on energy costs in GTA (Table 7).

Table 7: Annual energy savings and carbon avoided due to trees near residential buildings.

Energy Units	Heating	Cooling	Total
Natural Gas (Million British Thermal Units)	23,914	n/a	23,914
Electricity (Megawatt-hour)	204	923	1,127

Based on average energy costs, trees in Newmarket are estimated to reduce energy costs for residential buildings by $334,533 annually (Table 8). Trees also provide an additional $35,371 per year by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 457 tonnes of carbon emissions).

Table 8: Annual financial savings (Canadian $) in residential energy expenditures during heating and cooling seasons.

Energy Units	Heating	Cooling	Total
Natural Gas (Million British Thermal Units)	$250,008	n/a	$250,008
Electricity (Megawatt-hour)	$15,300	$69,225	$84,525

5.0 Discussion

This section offers a discussion of the results and presents recommendations for strategic management; these recommendations are listed at the end of each relevant section and summarized in Section 6.0. Implementation will be dependent on available resources and be subject to annual budget approval.

5.1 Urban Forest Structure

Discussion and recommendations pertain to three aspects of urban forest structure: distribution, species composition, and size. Benefits attributed to the urban forest, as listed in section 1.0, are largely influenced by these structural elements.

5.1.1 Existing and Possible Urban Forest Distribution

Newmarket's urban forest covers approximately 24% of the total land area. Total leaf area in the study area is approximately 55 km^2, with a leaf area density of 76 trees/ha.

In addition to the existing 24% canopy approximately 55% of the target area has been identified as *'possible tree canopy'*. These results have been produced from a spatial data set that can be further refined to address social and economic land use considerations. For Example, agricultural areas and sports fields have been categorized as possible areas for tree establishment; however tree planting in these areas may be socially undesirable in the context of food production and recreation. By refining this data the municipality can generate a precise estimate of plantable space that is physically, socially and economically feasible. In turn, the refined digital cover maps can be used to generate realistic urban forest targets that consider existing and possible canopy cover.

The process of prioritizing tree planting and establishment efforts should consider a range of biophysical and social factors related to the need for tree planting as well as the suitability of sites. Criteria can be developed so that decision-makers can effectively prioritize sites and optimize the urban forest in a strategic manner. With respect to a need for tree planting, variables to consider may include urban heat island mitigation, stormwater management, localized air pollution, household income, human health, and natural system integrity; the number of variables included will be dependent on the range of tool and spatial datasets available. With respect to the suitability of sites for tree planting, variables to consider may include ownership type, land use designation, soil conditions, biodiversity, natural heritage features and cost. For a detailed example of criteria-driven prioritization process please see the methodology developed by Locke *et al*. 2010.

Planting and establishment activities should also be considered within areas of existing cover. A successful strategy for increasing the ecosystem service provided by the urban forest should include an under-planting program, which will not only increase leaf area density in the short-term but will also ensure that aging trees are gradually replaced by a younger generation. Succession planning will be particularly important in areas that support a high proportion of ash trees that are likely to be killed *en masse* by the emerald ash borer (EAB). Although succession planning alone cannot mitigate the full impacts of EAB due to the speed at which the insect is projected to move through the municipality, it can ensure that replacement trees are established before full ash canopy loss. Municipal staff are already actively engaged in emerald ash borer mitigation activities, including succession planning and applying treatments to ash trees located along streets and boulevards. Tree removals are taking place where treatment is insufficient and where public safety is a concern. The Town has also developed two nursery sites specifically for the cultivation of replacement trees for boulevards and parks.

Increasing native shrub cover under canopied areas also represents an opportunity to increase total leaf area. Shrub cover that is established around mature trees can discourage trampling, compaction of root zones, and damage from mowers or other yard equipment. Shrubs can also add attractive visual elements to the landscape. Many of the benefits provided by the urban forest, such as microclimate amelioration and sequestration of gaseous pollutants, are directly related to leaf-atmospheric processes (e.g., interception, transpiration) (McPherson, 2003). It follows that an increase in the provision of these benefits can be best achieved by increasing total leaf area density.

Distribution of the urban forest is also an important social justice consideration. Ultimately the protection of trees equates to the protection of ecosystem services that are essential to the health of both humans and wildlife (e.g. clean air, cooler summer temperatures). The services provided by the urban forest are an asset that belong to the entire community, and must be managed in a manner that ensures equal access by all residents. For example, housing market inequalities may lead to uneven distribution of urban reforestation efforts, resulting in a bias toward owner-occupiers. In Milwaukee, Wisconsin, an urban reforestation program offered both homeowners and renters the opportunity to obtain a free tree. However, the vast majority of trees planted in this program were done so on owner-occupied land, suggesting that renters were less interested to participate in tree planting efforts around their houses (Perkins *et al.*, 2004). Residents in higher density and newer housing areas may also receive fewer benefits from the urban forest as trees in these neighbourhoods tend to be smaller and less abundant. Urban forest management plans that seek to address such inequalities can more effectively contribute to community sustainability.

Recommendation 1: Refine the results of the urban tree canopy (UTC) analysis to develop an urban forest cover target based on existing and possible tree canopy.

Recommendation 2: Develop decision making criteria that prioritizes municipal tree planting and establishment efforts to improve the distribution of functional ecosystem services including air pollution removal and avoidance, urban heat island mitigation and storm water management and planting success.

Recommendation 3: Increase leaf area in canopied areas by planting suitable tree and shrub species under existing tree canopy cover. Planting efforts should continue to be focused in areas of the municipality that currently support a high proportion of ash species.

5.1.2 Tree Species Effects

The most common genera in Newmarket by total leaf area are Maple (*Acer* spp., 29%), Walnuts (*Juglans* spp., 9.9%), Pine (*Pinus* spp., 11%) and Spruce (*Picea* spp., 19%). Together, these four genera represent 69% of the total leaf area. These native genera (which contain some non-native species) are found across land use categories, as they are able to thrive in sheltered natural areas as well as high-traffic urban zones. A high relative abundance of maple species in particular is typical to the forests of this eco-region; however, the lack of diversity among genera is a potential threat to the sustainability of the urban forest. Species diversity is a crucial element of ecological resiliency and the capacity of an ecosystem to rejuvenate from major disturbances. Dominance by a single tree species or genus will increase the possibility of large-scale tree mortality in the event of pest outbreaks that are species-specific (Sanders, 1978). Thus, an urban forest that is not sufficiently diverse is at risk of widespread canopy loss. For example, the spread of Dutch elm disease (*Ophiostoma* spp.) virtually eliminated American elm from the urban landscape during the twentieth century. Unfortunately, when the elms were replaced – largely by ash and maple – the guiding principle that influenced replanting was once again informed by visual uniformity rather than ecological resiliency.

Risk associated with a lack of species diversity is currently exemplified by the emerald ash borer infestation. Ash species (*Fraxinus americana, F. pennsylvanica*, *F. nigra*) are distributed across all land uses in Newmarket, reflecting the ability of these species to thrive in both natural areas and high traffic urban environments where soil quality is poor. Unfortunately, Newmarket is now at risk of losing all ash species in the municipality, which represents a significant portion of the urban forest (5% of the tree population). Since emerald ash borer has been present on the landscape for several years now, it is possible that this number already represents a reduction in the ash population from an earlier, healthier state. i-Tree ECO condition class distribution also shows 34% of green ash to be in a fair, poor, critical, dying or dead condition bracket. This is the highest for all species sampled in Newmarket. The condition class distribution for green ash further supports the upcoming risk of losing ash species from the Newmarket urban forest. Asian long-horned beetle is another cause for concern, as it targets a range of hardwood species that comprise approximately 28% of the tree population, excluding the multiple species of maples which account for 29% of the total leaf area.

In order to avoid future canopy loss, Santamour (1990) recommends that an urban forest contain no more than 10% of any single species, no more than 20% of any single genus, and no more than 30% of any single family. However, the “10-20-30” approach has been criticized for its inability to account for potential damage by multi-host pests, such as the Asian long-horned beetle (Raupp *et al.*, 2006), which impacts maple, poplar, willow and elm species. To address this concern, Lacan and McBride (2008) created the Pest Vulnerability Matrix (PVM), which provides a rapid analysis and graphic display of the interaction between urban tree species diversity and the susceptibility of the urban forest to insects and diseases. The model predicts how the introduction of certain tree species, or a new pest species, will affect the overall vulnerability of the urban forest. Consideration must be given to multi-host pests;

thus, vulnerable species assemblages should also be accounted for when designing diversification programs.[6]

The dominant tree species in the study area, Norway maple (*Acer platanoides*), represents 14% of the total leaf area. Norway maple has been favoured in the GTA for landscaping and streetscaping projects because it is tolerant of urban conditions and it produces a desirable growth form. However, the Ontario Invasive Plant Council (OIPC) has listed this prolific seed producer as invasive because it is known to spread into natural areas and threaten sensitive native vegetation.

Future planting of known invasive plants must be avoided, particularly at sites adjacent to natural areas, where they would cause maximum damage. Control measures vary between species but generally require a long-term commitment to rigorous site management and the application of bio-controls where appropriate. Municipal strategies for the management and restoration of infested areas will benefit from collaboration and partnership with LSRCA, the Regional Municipality of York and adjacent municipalities. An Invasive Plant Management Strategy framework for Ontario Municipalities was developed by the Ontario Invasive Plant Council in the spring of 2015 to facilitate avoiding and managing invasive species.

Residential property owners and tenants in Newmarket can play an important role in preventing the spread of invasive species. Horticultural species that escape from residential gardens are a common cause of invasions in natural areas. By purchasing and planting only native or non-invasive exotic plant species in yards and gardens the incidents of future invasions may be greatly reduced. In addition, the horticultural industry can play a significant role by phasing out the sale of highly invasive species, such as Norway maple and winged euonymus (*Euonymus alatus*) and offering as replacements similar native plants, such as red maple (*Acer rubrum*) and nannyberry (*Viburnum lentago*)[7]. Targeted outreach for residents surrounding the natural system should be provided by the municipality via stewardship and education programs.

The use of high quality native planting stock grown from locally adapted seed sources is strongly encouraged in all municipal planting projects. Genetic variability within a species facilitates the survival of that species by increasing the likelihood that some individuals will be adapted to withstand a major stress or disturbance event. A reliance on clones in the urban forest will have the opposite effect and will increase the risk of catastrophic loss of leaf area and tree cover in the event of a pest or disease outbreak.

In an effort to simplify the planting process, municipalities may sometimes rely on stock lists of pre-approved tree species for planting projects and draw upon this list in a somewhat arbitrary manner. This may result in a lack of species diversity, trees that are poorly suited to their growing environments, or

[6] For detailed methodology, please see Lacan and McBride (2008). The PVM tool can be obtained by contacting the authors.
[7] The Ontario Invasive Plant Council (OIPC), TRCA and CVC have coordinated a Horticultural Outreach Program called *Grow Me Instead* with the following objectives: to work with the nursery and landscape industry to phase-out the sale of highly invasive horticultural plants and phase-in the provision of non-invasive alternatives, including native species; and to promote the sale, use and production of native plant species within the horticultural and landscape industry.

trees that do not offer the optimal ecological services in a certain area. A more context-sensitive approach is likely advantageous. For example, Kirnbauer *et al*. (2009) developed a prototype decision support system (PDSS) that would allow managers to plan tree planting according to numerous small-scale variables, and select trees that are appropriate for local conditions.

Recommendation 4: Establish a diverse tree population in which no species represents more than 5% of the tree population, no genus represents more than 10% of the tree population, and no family represents more than 20% of the intensively managed tree population both municipal-wide and at the neighbourhood level.

Recommendation 5: Utilize the Pest Vulnerability Matrix and a context-sensitive approach during species selection for municipal tree and shrub planting.

Recommendation 6: Utilize native planting stock grown from locally adapted seed sources in both intensively and extensively managed areas and phase out the sale of highly invasive species.

Recommendation 7: Educate residents regarding the threat of invasive horticultural species.

5.1.3 Tree Size Effects

The proportion of very large trees (>61cm) is low, approximately 1%. The overall current diameter class distribution of trees in Newmarket is a fairly even spread with 78% of the trees below 30.5cm. However in the future this might be significantly different based on various factors. Most notably, the natural growth patterns and the forms of dominant species, will strongly influence average tree size. For example, eastern white cedar is the dominant species with respect to the total number of stems. This species typically maintains a comparatively medium-sized form at maturity, but its abundant use as a small-stature hedgerow tree in residential areas strongly influences the population dynamic. 70% of eastern white cedars are below 30cm which means a major part of the younger Newmarket trees population will not progress into the large tree category due to the natural form of the eastern white cedar. Larger trees provide more benefits.

The dominant species in terms of leaf area is Norway maple, which maintains a fairly large form at maturity. The current population of Newmarket has a very small percentage of younger Norway maples (18% below the 15.2 cm DBH). Therefore it is plausible that a major portion of the younger tree population of Newmarket will not grow into a very large form hampering the total leaf area of the town. In addition Black walnut and Silver maple make up 97% of trees with a DBH higher than 61 cm. The current young population of the two species (below 15.2cm DBH) is 30 and 20% respectively further indicating that the majority of the mature large sized trees are not dominating the smaller DBH categories. Looking at the current mid-size trees, 44% of the Sugar maples are in the range of 15.3-53.7cm and less than 1%are below 15.2cm. The distribution shows that sugar maples will soon be a part of the mature tree population in Newmarket and will not be a major part of the younger population. Although this does not conclude to the fact that Newmarket will not have any larger trees in the future, it does provide a glimpse into what the future mature trees of Newmarket might be (i.e. Freemani maple, honey locust, tree lilac etc.)

As urban trees increase in size, their environmental, social and economic benefits increase as well. By virtue of their increased stature and leaf area, large trees provide much greater energy savings, air and water quality improvements, runoff reduction, visual impact, increase in property values, and carbon sequestration.

Due to the highly modified and intensively managed nature of the urban forest, there is no appropriate historic/pre-settlement age-class distribution for which to strive. In other words, the intensively managed areas of the urban forest will maintain a very different diameter or age-class distribution than that observed in extensively managed woodlands. Typically, woodlands maintain an inverse j-shaped curve that reflects the abundance of small trees in the understory as a result of natural regeneration. This pattern was observed in the diameter class distribution in the *open space + natural cover* land uses. However, natural regeneration occurs infrequently in the intensively managed urban forest. Consequently, active management is needed in order to facilitate regeneration. In areas of the municipality where mature trees are dominant, managers should plan for future succession by planting replacement trees well in advance of mature tree decline and removal.

Richards (1983) proposed the primary age diversity model, which suggests a diameter class distribution designed to ensure continuous canopy cover over time. The City of Davis, California, modified this model slightly to produce the following guidelines: 40% of municipal trees less than 15.2cm DBH, 30% between 15.3 and 30.5cm, 20% between 30.6 and 61cm, and 10% greater than 61cm. The results of the i-Tree Eco analysis revealed the following diameter class distribution in Newmarket: approximately 41% of municipal trees were less than 15.3cm DBH, 37% were between 15.3 and 30.5cm, 21% were between 30.6 and 61cm, and less than 1% were greater than 61cm (Figure 20). According to these guidelines the proportion of trees in Newmarket is fairly ideal other than the very large tree category; however it will neither maintain this trend nor synchronize with the ideal model unless DBH distribution and species composition is considered in the future planting plans.

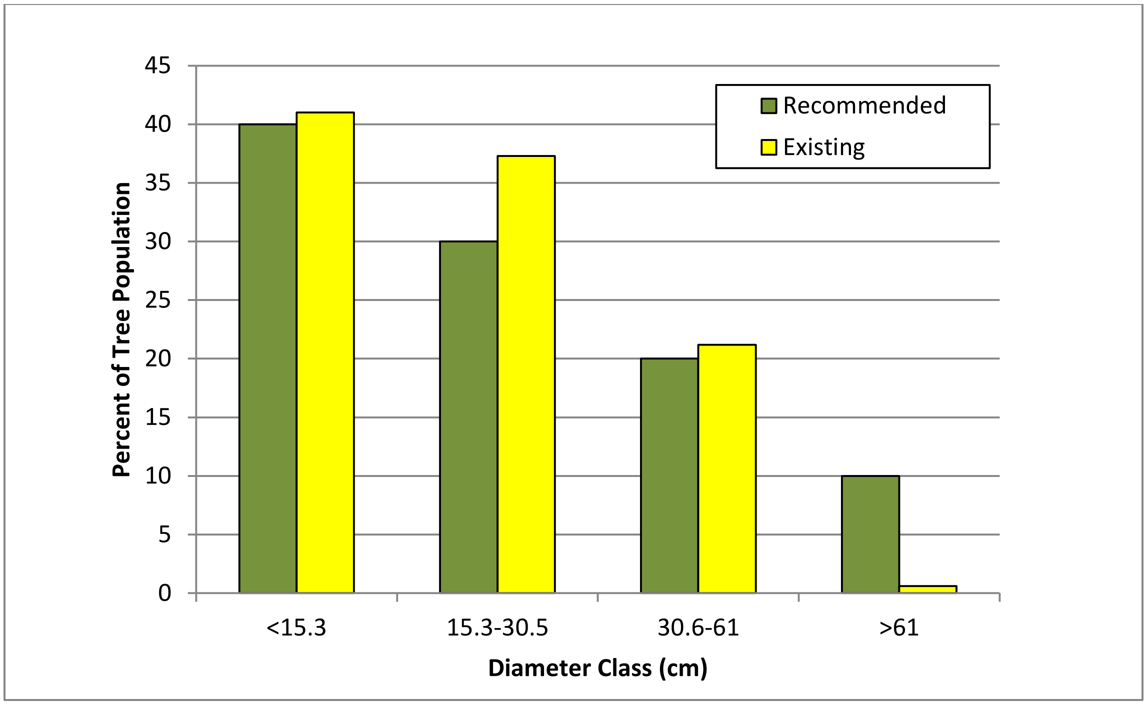

Figure 21: Recommended diameter class distribution and actual diameter class distribution in Newmarket.

The planning process can address the protection of mature large-stature trees that are outside of the natural heritage system by preventing tree cutting prior to development application approval or incorporating existing mature large-stature trees into development plans. This will be particularly important for the preservation of trees in agricultural lands designated for residential or commercial development.

Recognizing that tree size will naturally vary by species, it is important to understand the physiological requirements of different species and incorporate this understanding into planting schemes in order to ensure that each newly planted tree reaches its full size potential. For example, anticipating conflicts with power lines, sidewalks, and underground utilities and selecting appropriate species accordingly will reduce premature mortality. Soil loss and compaction under pavement and in construction sites tends to increase tree mortality and reduce tree vigor, thereby exacerbating susceptibility to pests and diseases. To achieve a desirable age-class structure, it is necessary to take a proactive approach to urban design by providing adequate tree habitat in the initial stages of urban planning. By increasing soil volume in tree habitat, improving soil moisture and fertility and maintaining a healthy soil profile, the longevity of urban trees can be significantly extended. Adopting the right tree in the right space planting approach and training parks and forestry staff on these fundamentals will help support the maintenance of an ideal DBH distribution.

When properly integrated into urban design, trees can deliver multiple engineering benefits including increased pavement life and a reduction in stormwater runoff. A balance between grey and green infrastructure must be sought in order to create a healthy urban environment. Interdepartmental collaboration will be critical to achieving success in this regard, as it will be necessary to foster common knowledge, methods, and goals related to the optimal integration of trees into the urban environment.

The Green Streets Program implemented by the City of Portland, Oregon, offers an example of sustainable streetscape design. The Green Street design was first created for the purpose of stormwater management and has since evolved into an integrated application that provides multiple benefits, such as greenspace and habitat connectivity, enhancement of the bicycle and pedestrian environment and neighbourhood livability. The Town of Markham has developed a Streetscape Design Guidelines Manual to ensure that adequate replacement and increased numbers of new tree plantings occur in a sustainable manner. The manual provides specifications and required design features for applications for Site Plan and Subdivision as well as town boulevard tree planting. Minimum soil volumes standards for Newmarket can be drawn from this manual as well as the City of Toronto's Green Development Standard; the suggested minimum is $15m^3$ of high quality soil per tree if in a shared planter, and a minimum volume of $30\ m^3$ of soil per tree if located in a single planter. In softscape areas (e.g. lawns, open space) a minimum of $30m^3$ of high quality, non-compacted, well-drained soil per tree is suggested. York Region has streetscape designs and street tree preservation and planting guideline as well. In addition to planting and preservation plans, the guidelines also consider significant factors such as spacing, diversity and stock. [8]

Technologies such as subsurface cells (e.g. Silva cell) will further enhance growing conditions and can be incorporated into urban design. To minimize costs, tree habitat construction activities can be incorporated into planned capital works projects and other infrastructure maintenance where possible. An evaluation of the budget requirements for the use of such technologies can be completed during the development of a strategic urban forest management plan.

Recommendation 8: Evaluate and develop strategic steps to protect and increase the proportion of large, mature trees in the urban forest. This can be achieved using a range of tools including Official Plan policy, by-law enforcement and public education. Where tree preservation cannot be achieved, Official Plan policy can be considered that will require compensation for the loss of mature trees and associated ecosystem services.

Recommendation 9: Develop municipal guidelines and regulations for sustainable streetscape and subdivision design that ensure adequate soil quality and quantity for tree establishment and eliminate conflict between natural and grey infrastructure.

Recommendation 10: Explore the application and viability of subsurface cells and other enhanced rooting environment techniques for street trees and other heavily used areas such as school grounds. Utilizing these technologies at selected test-sites in the short-term may provide a cost effective means

[8] York Region Street Tree Preservation and Planting Design Guidelines: http://www.york.ca/wps/wcm/connect/yorkpublic/07c48829-5332-4123-9b65-29d3fa69a23d/Street+Tree+Preservation+and+Planting+Design+Guidelines.pdf?MOD=AJPERES

of integrating these systems into the municipal budget. If successful the application of such technologies should be budgeted.

Recommendation 11: In areas of the municipality where mature trees are dominant, managers should plan for future succession by planting replacement trees well in advance of mature tree decline and removal in order to attain and maintain the ideal urban forest size distribution.

5.2 Urban Forest Function

The following is a discussion of the services (benefits) that have been quantified by the i-Tree Eco analysis. Urban forest benefits will increase in Newmarket as a result of the implementation of the previous recommendations for urban forest distribution, composition and size. However, several additional recommendations are provided here to address needs and opportunities.

5.2.1 Effect on Air Quality

Trees and shrubs in Newmarket remove 40 tonnes of air pollution (CO, NO_2, O_3, $PM_{2.5}$, SO_2) per year with an associated removal value of $249,118 (based on estimated national median externality costs associated with pollutants).

A study by Pollution Probe suggests that climate change (coupled with the urban heat island effect) could further exacerbate the degree of health effects associated with air pollution (Chiotti *et al*., 2002). For example, the frequency of air masses that bring hot, humid and smoggy conditions are projected to increase from the current level of 5% of summer days to 23-39% by 2080 (Wilner et al, 1993). This means that the Greater Golden Horseshoe will likely experience more frequent, more severe and possibly longer smog episodes in the future. Thus, by mitigating the human health risks associated with air pollution, as well as mitigating both the causes and effects of climate change, Newmarket's urban forest plays an essential role in community wellness, particularly for those more vulnerable members of the population.

i-Tree Eco results reveal that large diameter trees remove more pollution on a per tree basis than small diameter trees. Similarly, trees were found to remove greater volumes of pollution than shrubs. In both instances, pollution removal capacity was a direct function of leaf area. Planting species that require little maintenance, that are well adapted to local conditions and that have long life spans will offset emissions of air pollutants from maintenance and removal activities required for these species. In addition, Nowak *et al.* (2002) suggested that in areas with high levels of ground-based emissions (e.g., highways), tree and shrub cover located adjacent to the highway, with minimal overhead canopy, will allow pollutants to disperse upwards while increasing removal immediately adjacent to the source.

Trees and shrubs emit biogenic volatile organic compounds (VOCs), including isoprene and monoterpenes. These compounds are natural chemicals that make up essential oils, resins and other plant products (Kramer and Kozlowski, 1979). VOCs emissions by trees can contribute to the formation of ground level ozone and carbon monoxide. However, this process is temperature dependent. Given that trees generally lower air temperature, the net result is often still positive with respect to the effects of trees on air quality.

5.2.2 Climate Change Mitigation

Trees can mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tree cells and by reducing carbon dioxide emissions from fossil-fuel based power plants through energy use reductions in buildings. In Newmarket, trees store approximately 35,350 tons of carbon annually and sequester approximately 1,560 tonnes of carbon annually. The amount of carbon stored and sequestered per hectare in Newmarket is relatively high for a low tree density (76.60 trees/ha). Based on previous urban forest studies the Town of Newmarket has the lowest tree density by comparison with other southern Ontario cities, however, its carbon storage capacity matches municipalities like City of Brampton with 40% higher tree density. This high productivity of Newmarket's urban forest is likely due to the comparatively well distributed size of the trees and their relative condition. (Table 9). Therefore it's vital that future size distribution and protection of natural cover be one of the prime criteria in selecting future planting locations and species.

The urban forest can also influence CO_2 levels by reducing the demand for heating and cooling in residential buildings, thereby decreasing carbon emissions by power plants. In Newmarket, the annual demand for heating and cooling was reduced by approximately 23,914 MBTU and 1,127 MWH, respectively, with an associated annual financial savings of approximately $334,533. As a result of this reduced demand for heating and cooling, the production of 457 tonnes of carbon emissions were avoided annually (associated annual savings of $35,371)

Table 9: Tree density, carbon storage and annual carbon sequestration by urban forests in Canadian cities that have completed an i-Tree Eco analysis.

City	Tree Density (trees/ha)	Carbon Storage (tonnes/ha)	Carbon Sequestration (tonnes/ha/yr)
Newmarket, ON	76.5	9.1	0.4
Aurora, ON	395.5	20.8	0.8
Richmond Hill, ON	250.9	16.2	0.7
Vaughan, ON	182.6	13.1	0.5
Markham, ON	148.3	10.8	0.4
Pickering, ON	354.4	22.1	0.9
Oakville, ON	192.9	13.4	0.6
London, ON	185.5	15.3	0.5
Toronto, ON	160.4	17.4	0.7
Brampton, ON	134.3	6.5	0.3

Proper species selection and tree placement can have significant impact on potential energy savings. For example, conifer species planted along the south facing wall of a building will block the heat from the winter sun and will increase the need for daytime heating. In contrast, a large deciduous tree planted at the south and west sides of a house will shade buildings during hot summer months and, after leaves have dropped, will allow solar heat to reach homes in the winter. Public education and outreach will be required to communicate these benefits and to provide direction for strategic planting around buildings to enhance energy savings. A tree benefit estimator based on the size and location of the tree in proximity to a resident's home was designed by Dr. Andrew Millward of Ryerson University, the program is available on the website for LEAF[9], a York region NGO. Maximizing energy savings will not only yield financial savings but will assist in efforts to mitigate climate change.

Nowak and Crane (2002) argued that carbon released through tree management activities must be accounted for when calculating the net effect of urban forestry on atmospheric carbon dioxide. Tree care practices often release carbon into the atmosphere as a result of fossil fuel emissions from maintenance equipment. In order to compensate for the carbon emissions associated with planting, establishment, pruning, and tree removal, trees planted in the urban landscape must live for a minimum amount of time. If trees succumb to early mortality, sustaining the tree population will lead to net emissions of carbon throughout the life cycle of that population (Nowak and Crane, 2002). This observation further highlights the importance of selecting low maintenance, well-adapted and resilient species, as well as proper planting sites, with the goal of maximizing tree health and longevity. A reduction in emissions associated with urban forest maintenance will also have a positive impact on local carbon levels and contribute to a healthier and more livable community.

Recommendation 12: Develop tree planting and maintenance programs designed to increase tree health and longevity.

Recommendation 13: Increase over all tree density in the town by planting in priority areas using the Planting Priority Index

Recommendation 14: Reduce energy consumption and associated carbon emissions in private sector by providing direction, assistance and incentives to residents and businesses for strategic tree planting and establishment around buildings and private properties.

Recommendation 15: Develop public education and outreach to communicate benefits and to provide direction and incentive to property owners for strategic planting around buildings to enhance energy savings.

5.2.3 Heat Island Mitigation

With the Town of Newmarket's Community Energy Plan[10] gaining momentum, the need for urban heat island mitigation (UHI) becomes paramount. The urban heat island effect occurs in urban and suburban areas where surface temperatures are significantly warmer than nearby rural areas. As cities replace natural land cover with pavement, buildings and other grey infrastructure, urban surface temperatures increase due to the high heat absorption and retention properties of the impervious materials. Higher surface temperature can then lead to higher air temperatures as the heat retained in impervious

[9] For more details on the benefit estimator visit www.yourleaf.org/estimator
[10] Details about Newmarket's Community Energy Plan can be found on the town website

materials is slowly emitted. Typically, UHI intensity is greatest at the urban center with a large temperature gradient at the urban-rural edge (NRCan, 2009).

Research has shown that by increasing the amount of urban vegetation, UHI effects can be mitigated (Rosenzweig *et al.*, 2006; Solecki *et al*., 2005). Specifically, the shade generated by tree canopies can reduce the amount of solar radiation transmitted to underlying surfaces. Consequently, increased canopy cover lessens UHI effect by reducing heat transfer from these surfaces to the surrounding air. Furthermore, evapotranspiration by urban vegetation can result in peak summer temperature reductions of 1 - 5°C in urban areas (EPA, 2013). According to Simpson (1998), every 1 % increase in canopy cover results in a maximum mid-day air temperature reduction of 0.04 to 0.2°C.

Natural Resources Canada (NRCan) recently evaluated the potential to characterize and map UHI in the GTA using remote sensing data (NRCan, 2009). The research utilized both satellite imagery and in-situ air and surface temperature measurements. Although the study was not designed to directly evaluate the influence of urban trees and shrubs on UHI, the results are relevant to urban forest management. On a GTA-wide scale, suburban land use was found to have distinctly higher thermal admittance properties. A direct relationship was observed between urbanization and substantial increases in surface temperatures in extreme heat event conditions, which can have a direct impact on human, and wildlife mortality and morbidity.

Effective heat island mitigation strategies should incorporate both “green” technology (e.g. green roofs) and natural infrastructure (e.g. urban forest). Installing green roofs in high density areas can also be an effective way of adding greenspace to areas with low planting potential at street level. Establishing trees and other forms of greenspace in hot-spots identified in the thermal mapping exercise can reduce surface temperatures and the formation of VOCs and ground level ozone, which will in turn have direct public health benefits.

Recommendation 16: Explore and develop green infrastructure (i.e. green roofs, bioswales) in order to provide urban heat island mitigation, surface water run-off, etc.

5.3 Growing a Sustainable Urban Forest

The preceding discussion of results offered a number of recommendations related to the urban forest distribution, species composition and tree size. This section outlines the prerequisites for their implementation in four operational themes: tree preservation and protection, stewardship and education, urban landscape ecology, and adaptive urban forest management.

5.3.1 Tree Preservation and Protection

The protection and stewardship of existing trees is the most effective means of achieving greater tree cover and leaf area. Trees that grow to reach a large mature size provide the highest benefit-cost ratio with respect to the provision of ecosystem services. Newmarket’s woodlot by-law (No. 2007-71) affords protection to urban trees in woodlots within the municipality. A tree protection by-law, potentially consisting of greater conservation measures, was under development at the time of report writing. York Region’s Forest Conservation By-law prohibits and regulates the destruction or injuring of trees in areas designated by the by-law, it also provides that a lower-tier municipality i.e. Newmarket may pass on part or all of its power to the upper tier municipality.

Increased funding will be required to implement future management plan actions and address the threats posed by EAB. Possible revenue streams for additional staff and resources include funds gained from compensation for development applications, by-law infractions and tree removal permits. The generation of subsequent funding for operations (i.e. tree planting and management) can be determined through the development of a strategic management plan.

The most critical time for tree care, including watering, mulching, and pruning, is in the first three to five years following planting. Without this care, tree mortality will be high during the early stages of tree establishment and few trees will survive to reach their full size potential. Effective tree protection in newer residential developments will be of critical importance to ensuring that young trees become fully established. In addition, protection of root zones during construction activities can partially safeguard trees against root damage caused by soil compaction or trenching. Typically, a tree protection barrier includes, as a minimum, the area within the drip line of the tree. However, protection to the drip line is rarely sufficient for large mature trees, as tree roots commonly extend two to three times the distance of the drip line.

Recommendation 17: Encourage the protection of privately owned natural heritage features through by-laws, outreach and incentives.

5.3.2 Stewardship and Education

The majority of Newmarket's urban forest is located on private property. Thus, the residents and businesses of Newmarket are the most influential stewards of the Town's urban forest and their cooperation is essential to achieving all future urban forest targets. Recognizing that the lack of tree care is a significant threat to tree health and that municipal resources are finite, it is clear that the public must share the responsibility for tree care and preservation. While by-laws designed to prevent the damage and destruction of trees can serve as a critical safety net, it is ultimately a strong collective stewardship ethic that will ensure the growth and long-term health of the urban forest on both public and private property. For example, tenants and property owners can reduce the mortality of public trees planted in residential boulevards and along commercial rights-of-way by providing regular care and maintenance, such as watering and mulching, particularly to newly planted trees.

Newmarket can further explore means of building on existing partnerships to increase participation in stewardship activities. Additionally, the municipality is advised to conduct an assessment of opportunities to pursue new partnerships. Potential connections may be found with agencies such as LSRCA, LEAF and the Regional Municipality of York, who share common objectives, but may be pursuing them through different means. Public health departments are also working to improve community health and would more readily meet this objective if urban forest cover were enhanced in the municipality. Community groups with an interest in ecology or natural history also present potential partnership opportunities. Similar synergies likely exist with public and private schools interested in promoting children's health.

The Town should also establish partnerships to facilitate green infrastructure and tree establishment on commercial and industrial lands. Promoting these activities will improve tree canopy in commercial and industrial areas, improve the matrix influence, beautify employment lands, and facilitate corporate team building and leadership development. This will lead to the mitigation of urban heat island effect, energy consumption and pollution in the industrial areas. A program like this will not only strengthen the joint public-private mandate of urban forest stewardship, but also help to raise private companies' environmental profiles.

Municipal staff must also be equipped with the expertise necessary to effectively manage Newmarket's natural and grey infrastructure in an integrated manner. Objectives for each form of infrastructure should be made compatible at all scales and valued equally. Unintentional damage to trees may be prevented through a more comprehensive understanding and appreciation of acceptable root protection zones during construction activities. A municipal staff training program can therefore be developed and implemented for all relevant employees. This will facilitate a harmonization of approaches to urban forest assets and mitigate the "silo" effect of municipal departments operating independently and employing incongruent methods to manage complementary resources.

Together with the Region, LSRCA and the surrounding area municipalities, Newmarket is also advised to continue their participation in the York Region Urban Foresters Forum. This working group can liaise with stakeholders in urban forest management and establish new partnerships. Stakeholders include those who are directly involved in urban forestry as well as those whose activities indirectly affect or are affected by the urban forest, such as municipal parks, operations and planning departments, transportation and health departments and school boards. The working group organized information sharing sessions for stakeholders to share the results of this urban forest study and to gain consensus on future targets and objectives established in management plans.

Recommendation 18: Research and pursue new partnerships and opportunities with local agencies to enhance urban forest stewardship in Newmarket.

Recommendation 19: Work in partnership with local agencies i.e. LEAF to pursue the development of an urban forest communication plan that guides the dissemination of key messages around private tree maintenance and care to residents with trees and shrubs.

Recommendation 20: Explore the development and implementation of a municipal staff training program to enhance awareness of tree health and maintenance requirements generally, and of proper tree protection practices to be used during construction activities more specifically.

5.3.3 Biodiversity Management and Urban Landscape Ecology

Newmarket's tree preservation, protection, replacement and enhancement policy contains numerous measures aimed at protecting natural areas and environmental features during the development process and for their value on the urban landscape. Many of these vulnerable natural features are included in provincial legislation pertaining to the Oak Ridges Moraine and Greenbelt, and intersect with developed areas across a variable urban matrix.

Enhancing connectivity within the natural system will increase ecological function and adaptive capacity of the entire urban and peri-urban landscape. When weather conditions are favourable many migratory birds are able to fly over the municipality without stopping; however, in inclement conditions most will seek canopy cover in which to refuel, rest and find refuge. For these thousands of birds, the more trees there are distributed across the municipality, the better. In contrast, most summer or breeding species, especially ground-dwelling bird and amphibian species, find few options for nesting and local movement in the intensively managed urban forest. Similarly, habitat is often unsuitable for understory plants (e.g. wildflowers and ferns) within intensively managed urban areas as seeds do not germinate or plants are removed during regular maintenance. Therefore, most local movement of flora and fauna species will occur within established natural systems (the extensively managed urban forest), where there may also be competition with non-native invasive species.

While one should not expect the urban forest in Newmarket to provide habitat for all species, it is reasonable to expect that the urban forest will assist in increasing the rate of breeding success of some, particularly canopy-dwellers, by providing them with additional resources. For example, the placement of trees adjacent to the natural system can provide resources (foraging areas and refuge from predators) near their nest location that can increase the survival rate of young birds. Many urban areas, notably commercial and industrial, can be inhospitable to migratory birds and other species. Increasing leaf area and canopy cover in the commercial and industrial land uses will provide a more positive matrix influence on the adjacent natural system, and increase the quality of habitat patches and the adaptive capacity of the species that inhabit them.

In urbanized watersheds the provision of a range of ecosystem services is essential to the health of community members. These services (e.g. heat island mitigation and air pollution removal) extend well beyond the provision of species habitat; many of such services are provided by the intensively managed urban forest located outside of the natural system. Furthermore, these services can be provided by new combinations of biotic and abiotic elements that have never been observed, a phenomenon now referred to as *novel ecosystems* (Hobbs et al., 2006). For this reason it will be advantageous to collaboratively explore the development of targets for ecosystem services as part of a comprehensive approach to management at a broad, cross-jurisdictional landscape scale.

Research is now emerging that can guide the development of such targets. For example, Perrings et al. (2011) state that biodiversity and ecological function targets must be based on the ecosystem services they support, that the spatial and temporal characteristics of targets reflect the processes involved and that interdependencies between ecosystem services be reflected in targets. They further suggest that where such interdependent targets exist, coordinated implementation across departments and agencies is necessary. It follows that a deeper understanding is needed of the connection between ecological function and the ensuing ecosystem services; this will better enable managers to cultivate the functions in a manner that provides desired services.

Recommendation 21: Explore and develop targets that achieve a comprehensive distribution of ecosystem services and improve overall landscape function.

5.3.4 Adaptive Urban Forest Management

Newmarket's urban forest is facing an uncertain future due to threats from climate change, invasive species and the effects of human encroachment. In order to manage for uncertainty and increase the adaptive capacity of the urban landscape, ecological resilience must be built into the urban forest (both the intensively and extensively managed components). A key strategy for building both resilience and adaptive capacity is to increase diversity at all scales, as discussed in Section 5.1.2. Careful monitoring of the urban forest resource will also facilitate adaptive management.

Newmarket is encouraged to use their existing comprehensive tree inventory to develop a comprehensive monitoring program that tracks trends in tree establishment and mortality, and more generally evaluates the distribution and structure of the urban forest over the next 20 years. The tools of analysis utilized for this study should form the basis of this program. Monitoring intervals can be determined in the context of funding and resource availability.

The full impact of current and future climate change on Newmarket's urban forest is uncertain. Extreme high temperatures and increased drought in the growing season may reduce tree growth, although these negative impacts may be offset by the positive growth effects from rising atmospheric CO_2 levels (see for example, Saxe *et al*., 1998). The impacts of climate change are species specific, therefore, species with larger genetic variability are likely more adaptable to a variety of climate conditions and as a result may be more successful (Colombo *et al*., 1998). Given the likelihood of increased summer temperature and drought under future climate change scenarios, the selection of hardy native species that are heat and drought tolerant is advised, especially at locations with harsh growing environments. A general trend towards northward migration of tree species is also being observed and projected for the future (see for example, Colombo *et al*., 1998), so it may be advantageous to select native species that are currently at or near the northern limit of their range (e.g., Kentucky coffee-tree (*Gymnocladus dioicus*), and tulip tree (*Liriodendron tulipifera*)).

The potential impacts of climate change on trees in Ontario are part of an emerging field of forestry research, but there is a lack of research on the potential effects of southern Ontario's urban trees. Research partnerships with local academic institutions can therefore be developed to further research goals and fill gaps in knowledge. Long-term monitoring programs will also be essential in order to evaluate the growth and survival of the urban tree population.

Native tree and shrub species under stress from climate change may also become more susceptible to introduced pests or may be out-competed by hardy generalist invasive plants. Controlling emerging invasive species is therefore more critical under future climate change scenarios. Managers must identify and address common pathways of introduction (i.e. dispersal by hikers, pets, yard waste, etc.), as an important step in the invasive species management strategy (please see Section 5.1.2).

It is now likely that the vast majority of ash trees in Newmarket (5 % of the urban forest) will be eliminated by the EAB infestation that is moving across southern Ontario. There is a need to collect and store high quality seeds from native ash species before this component of the tree population is lost. Preserving seed from a wide range of healthy ash specimens in the local population will prevent the possible loss of native ash species and facilitate reintroduction once adequate environmental control measures for EAB are developed or trees resistant to the insect are bred and introduced (NRCan, 2010). Newmarket can consider working with the Region, TRCA, LSRCA, the Ministry of Natural Resources and Forestry (MNRF) and the National Tree Seed Centre of Natural Resources Canada (NRCan) to implement a seed collection program for native ash species; the municipality should also participate in other EAB research opportunities as they arise i.e. biological controls and insecticides.

Adaptive management practices will be critical to protecting the ecosystem services provided by the urban forest. Many of these services will become more valuable under future climate scenarios, including shading and space cooling, soil aeration and stabilization and interception of storm water. Urban forests will play a major role in our ability to adapt to future climate change (please see Sections 5.1.5 and 5.1.6 for examples of how the urban forest can contribute to climate change and UHI mitigation).

Recommendation 22: Using the towns exiting tree inventory, monitor tree health the distribution, structure and function of the urban forest using the methods employed in this baseline study. A potential monitoring scenario may consist of a cover mapping assessment (UTC) at a five year interval and a field-based assessment (i-Tree Eco) at a ten year interval.

Recommendation 23: Support research partnerships that pursue the study of climate change and its impacts on the urban forest and that evaluate the potential for planting more hardy and southern species in select locations.

Recommendation 24: Develop an open map community urban forest monitoring system that allows public data input and updates

Recommendation 25: Develop an Invasive species management guideline/plan for Ash seed collection.

5.4 Urban Forest Management Plan

Urban forest management plans are becoming more common as urban populations expand and municipalities embrace the value urban forests represent for their residents. An urban forest management plan is the principal planning and operational tool through which the urban forest can be protected and enhanced. A management plan can set priorities and comprehensively address a wide range of management themes including: maintenance and pruning; strategic planting and establishment; stewardship and outreach; risk assessment and response; and long-term monitoring. Urban forest management plans should set scheduled intervals at which this work takes place. Five year intervals for pruning are standard and allow for forestry workers to conduct inspections and risk assessments. Additional stakeholder consultation will be a critical component of management plan development in order to determine the appropriate sequencing of actions within the context of existing resources and municipal goals. The successful development of urban forest management plans accounts for the influences of local conditions, attitudes and resources to create a plan that meets local needs.

The Region provided to area municipalities the *Urban Forest Management Planning Toolkit*. The toolkit is intended to aid each area municipality in the development of a Strategic Urban Forest Management Plan and outlines the key components of a comprehensive plan, as well as supporting technical reference materials and templates.

Kenney *et al.* (2011) have developed a comprehensive list of criteria and performance indicators for sustainable urban forest management (See Appendix F for complete list, with highlighted sections pertaining to Newmarket's current situation). This list was derived from the work of Clark *et al.* (1997) and can be used to assess the progress towards urban forest sustainability. Newmarket is advised to use the criteria and indicators to inform the creation of the recommended management plan, monitor implementation and assess the progress made toward urban forest sustainability.

Recommendation 26: Develop and implement an urban forest management plan for Newmarket. When developing an urban forest management plan include a clear implementation plan and associated costs.

6.0 Summary of Recommendations

Recommendation 1: Refine the results of the urban tree canopy (UTC) analysis to develop an urban forest cover target based on existing and possible tree canopy.

Recommendation 2: Develop decision making criteria that prioritizes municipal tree planting and establishment efforts to improve the distribution of functional ecosystem services including air pollution removal and avoidance, urban heat island mitigation and storm water management and planting success.

Recommendation 3: Increase leaf area in canopied areas by planting suitable tree and shrub species under existing tree canopy cover. Planting efforts should continue to be focused in areas of the municipality that currently support a high proportion of ash species.

Recommendation 4: Establish a diverse tree population in which no species represents more than 5% of the tree population, no genus represents more than 10% of the tree population, and no family represents more than 20% of the intensively managed tree population both municipal-wide and at the neighbourhood level.

Recommendation 5: Utilize the Pest Vulnerability Matrix and a context-sensitive approach during species selection for municipal tree and shrub planting.

Recommendation 6: Utilize native planting stock grown from locally adapted seed sources in both intensively and extensively managed areas and phase out the sale of highly invasive species.

Recommendation 7: Educate residents regarding the threat of invasive horticultural species.

Recommendation 8: Evaluate and develop strategic steps to protect and increase the proportion of large, mature trees in the urban forest. This can be achieved using a range of tools including Official Plan policy, by-law enforcement and public education. Where tree preservation cannot be achieved, Official Plan policy can be considered that will require compensation for the loss of mature trees and associated ecosystem services.

Recommendation 9: Develop municipal guidelines and regulations for sustainable streetscape and subdivision design that ensure adequate soil quality and quantity for tree establishment and eliminate conflict between natural and grey infrastructure.

Recommendation 10: Explore the application and viability of subsurface cells and other enhanced rooting environment techniques for street trees and other heavily used areas such as school grounds. Utilizing these technologies at selected test-sites in the short-term may provide a cost effective means of integrating these systems into the municipal budget. If successful the application of such technologies should be budgeted.

Recommendation 11: In areas of the municipality where mature trees are dominant, managers should plan for future succession by planting replacement trees well in advance of mature tree decline and removal in order to attain and maintain the ideal urban forest size distribution.

Recommendation 12: Develop tree planting and maintenance programs designed to increase tree health and longevity.

Recommendation 13: Increase over all tree density in the town by planting in priority areas using the Planting Priority Index

Recommendation 14: Reduce energy consumption and associated carbon emissions in private sector by providing direction, assistance and incentives to residents and businesses for strategic tree planting and establishment around buildings and private properties.

Recommendation 15: Develop public education and outreach to communicate benefits and to provide direction for strategic planting around buildings to enhance energy savings.

Recommendation 16: Explore and develop green infrastructure (i.e. green roofs, bioswales) in order to provide urban heat island mitigation, surface water run-off, etc.

Recommendation 17: Encourage the protection of privately owned natural heritage features through by-laws, outreach and incentives.

Recommendation 18: Research and pursue new partnerships and opportunities with local agencies to enhance urban forest stewardship in Newmarket.

Recommendation 19: Work in partnership with local agencies i.e. LEAF to pursue the development of an urban forest communication plan that guides the dissemination of key messages around private tree maintenance and care to residents with trees and shrubs.

Recommendation 20: Explore the development and implementation of a municipal staff training program to enhance awareness of tree health and maintenance requirements generally, and of proper tree protection practices to be used during construction activities more specifically.

Recommendation 21: Explore and develop targets that achieve a comprehensive distribution of ecosystem services and improve overall landscape function.

Recommendation 22: Using the towns exiting tree inventory, monitor tree health the distribution, structure and function of the urban forest using the methods employed in this baseline study. A potential monitoring scenario may consist of a cover mapping assessment (UTC) at a five year interval and a field-based assessment (i-Tree Eco) at a ten year interval.

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Recommendation 25: Develop Invasive species management guideline/plan for Ash seed collection.

Recommendation 26: Develop and implement an urban forest management plan for Newmarket. When developing an urban forest management plan include a clear implementation plan and associated costs.

References

Ares, A., Neill, A.R., and K.J. Puettmann. 2010. Understory abundance, species diversity and functional attribute response to thinning in coniferous stands. Forest Ecology and Management 260: 1104-1113.

Brook, R.D., Brook, J.R., Urch, B., Vincent, R., Rajagopalan, S. and F. Silverman. 2002. Inhalation of fine particulate air pollution and ozone causes acute arterial vasoconstriction in healthy adults. American Heart Association, Circulation, April, pp. 1534-1536.

Burnett, R.T., Smith-Doiron, M., Steib, D., Cakmak, S. and J.R. Brook. 1999. Effects of particulate and gaseous air pollution on cardiorespiratory hospitalization. Archives of Environmental Health, 54, 2, pp. 130-139.

Chiotti, Q., Morton, I., Ogilvie, K., Maarouf, A., and M. Kelleher. 2002. Towards and adaptation plan: climate change and health in the Niagara region. A Pollution Probe Report. 50 pp.

Clark, J.R., Methany, N. P., Cross, G. and V. Wake. 1997. A model of urban forest sustainability. Journal of Arboriculture 23(1): 17-30.

Colombo, S.J., M.L. Cherry, C. Graham, S. Greifenhagen, R.S. McAlpine, C.S. Papadopol, W.C. Parker, T. Scarr, M.T. Ter-Mikaelian and M.D. Flannigan. 1998. The impacts of climate change on Ontario's forests. Forest research information paper No. 143. Ontario Forest Research Institute.

EPA. 2012. Health effects of ozone in the general population. U.S. Environmental Protection Agency. http://www.epa.gov/o3healthtraining/population.html.

EPA. 2013. Heat island effect: trees and vegetation. U.S. Environmental Protection Agency. http://www.epa.gov/heatisld/mitigation/trees.htm.

Girão, L.C., Lopes, A.V., Tabarelli, M., and E.M. Bruna. 2007. Changes in tree reproductive traits reduce functional diversity in a fragmented Atlantic forest landscape. PLoS ONE 2(9): e908.

Hobbs, R. J., Arico, S., Aronson, J., Baron, J. S., Cramer, V. A., Epstein, P. R., Ewel, J., Klink, C, Lugo, A., Ojima, D., Norton, D., and D. M. Richardson. 2006. Novel ecosystems: Theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography*, (15).

Kenney, W.A., van Wassenaer, P.J.E. and A.L. Satel. 2011. Criteria and Indicators for Strategic Urban Forest Planning and Management. Arboriculture & Urban Forestry 37(3): 108-117.

Kirnbauer, M.C., Kenney, W.A., Churchill, C.J., and B.W. Baetz. 2009. A prototype decision support system for sustainable urban tree planting programs. Urban Forestry & Urban Greening 8: 3-19.

Kramer, P.J., and T.T. Kozlowski. 1979. Physiology of woody plants. Academic Press, New York.

Lacan, I. and J.R. McBride. 2008. Pest vulnerability matrix: A graphic model for assessing the interaction between tree species diversity and urban forest susceptibility to insects and disease. Urban Forestry & Urban Greening 7:291-300.

Locke, D.H., Grove, J.M., Lu, J.W.T., Troy, A., O'Neil-Dunne, J.P.M., and B.D. Beck. 2010. Prioritizing preferable locations for increasing urban tree canopy in New York City. Cities and the Environment, 3(1).

McPherson, E.G. 2003. A benefit-cost analysis of ten street tree species in Modesto, California, U.S. Journal of Arboriculture, 29(1): 1-8.

Nowak, D.J. Crane, D.E., Stevens, J.C., and M. Ibarra. 2002. Brooklyn's urban forest. USDA Forest Service, Northeastern Research Station. General Technical Report NE-290.

Nowak. D., R. Hoehn, and D.Crane. 2007. Oxygen Production by Urban Trees in the United States. *Arboriculture & Urban Forestry* 33(3):220–226

NRCan. 2009. Thermal Remote Sensing of Urban Heat Islands: Greater Toronto Area. Natural Resources Canada.

NRCan. 2010. National Tree Seed Centre: Ash Seed Collection for Genetic Conservation. Natural Resources Canada. Retrieved from: http://cfs.nrcan.gc.ca/publications?id=34522

Oliver, C. D, and B.C. Larson. 1996. Forest stand dynamics. New York, NY: Wiley.

Nowak, D.J. and D.E. Crane. 2002. Carbon storage and sequestration by urban trees in the USA. Environ. Poll. 116(3):381-389.

Perkins, H.A., Heynen, N., Wilson, J., 2004. Inequitable access to urban reforestation: the impact of urban political economy on housing tenure and urban forests. Cities 21 (4): 291–299.

Perrings , C., Naeem, S., Ahrestani, F., Bunker, D.E., Burkill, P., Canziani, G., Elmqvist, T., Ferrati, R., Fuhrman, J., Jaksic, F., Kawabata, Z., Kinzig, A., Mace, G.M., Milano, F., Monney, H., Prieur-Richard, A.H., Tschirhart, J., and W. Weisser. 2011. Ecosystem services, targets, and indicators for the conservation and sustainable use of biodiversity. Frontiers in Ecology and the Environment 9: 512–520

Perry, J., and M.D. LeVan. 2003. Air Purification in Closed Environments: Overview of Spacecraft Systems. *U.S. Army Natick Soldier Center.* http://nsc.natick.army.mil/jocotas/ColPro_Papers/Perry-LeVan.pdf (accessed July 25, 2014).

Raupp. M.J., Cumming, A.B., and E.C. Raupp. 2006. Street tree diversity in eastern North America and its potential for tree loss to exotic borers. Arboriculture and Urban Forestry 32(6): 297-304.

Richards, N. A. 1983. Diversity and stability in a street tree population. Urban Ecology 7.

Rosenzweig, C., Solecki, W., Parshall, L., Gaffin, S., Lynn, B., Goldberg, R., Cox, J., and S. Hodges. 2006. Mitigating New York City's heat island with urban forestry, living roofs, and light surfaces. A report to the New York State Energy Research and Development Authority.

Sanders, R.A. 1978. Managing for species diversity in cityowned trees. In Urban Forester's Notebook. General Technical Report NE 49 of the USDA Forest Service, S. Little (Ed.), Northeastern Forest Experiment Station, Broomall, PA.

Santamour, F. 1990. Trees for urban planting: diversity, uniformity and common sense. In: METRIA, Proceedings of the Seventh Confederation of Metropolitan Tree Improvement Alliance. The Morton Arboretum, Lisle, IL, pp 57–65.

Saxe, H., Ellsworth, D.S., and J. Heath. 1998. Tansley Review No. 98: Tree and forest functioning in an enriched CO2 atmosphere. New Phytologist 139(3): 395-436.

Schmitt, D. and R. Suffling. 2006. Managing eastern North American woodlots in a cultural context. Landscape and Urban Planning 78: 457-464.

Simpson, J.R. 1998. Urban forest impacts on regional cooling and heating energy use: Sacramento County case study. Journal of Arboriculture 24(4):201-214.

Solecki, W.D., C. Rosenzweig, L. Parshall, G. Pope, M. Clark, J. Cox, and M. Wiencke, 2005. Mitigation of the heat island effect in urban New Jersey. Global Environ. Change B Environ. Hazards 6:30-49, doi:10.1016/j.hazards.2004.12.00.

Statistics Canada. 2012. Aurora, Ontario (Code 3519046) and York, Ontario (Code 3519) (table). Census Profile. 2011 Census. Statistics Canada Catalogue no. 98-316-XWE. Ottawa. Released October 24, 2012. http://www12.statcan.gc.ca/census-recensement/2011/dp-pd/prof/index.cfm?Lang=E (accessed October 1, 2013).

Steib, D.M., Judek, S. and R.T. Burnett. 2002. Meta-analysis of time-series studies of air pollution and mortality: effects of gases and particles and the influence of cause of death, age and season. Journal of the Air and Waste Management Association, 52, pp. 470-484.

Appendix A: Literature Review

Note: The literature review has not been completed specifically for the Town of Newmarket study, it is a shared review in a number of recent urban forest studies within the GTA.

Urban Forest Structure

Multiple definitions of urban forest structure exist. Rowntree (1984) defines urban forest structure as the spatial arrangement of vegetation in relation to other objects within urban areas, while Sanders (1984) describes structure as the static assemblage of plant materials above, on, and below the ground surface within an urban area or its zone of influence. Generally, all such definitions refer to characteristics such as species composition, spatial distribution of vegetative cover, and tree size and condition.

Urban forest structure can be influenced by a number of variables. McBride and Jacobs (1986) suggest that the structure of an urban forest can be tied directly to pre-settlement forest composition. Nowak and Crane (2002) observed a direct relationship between pre-settlement forest cover and the extent of urban forest canopy in American cities, recording the highest tree cover in cities developed in naturally forested areas (34.4%), followed by grasslands (17.8%), and deserts (9.3%).14 Sanders (1984) argues that urban vegetation patterns and their expected variations can be determined by the following three factors: urban morphology; the natural environment or natural processes that influence vegetation establishment, growth, competition, and decline; and human management systems. Nowak (1993) identifies four general forces that can alter urban forest structure: direct anthropogenic, e.g. planting and removals; indirect anthropogenic, e.g. war, economic depression; natural direct, e.g. storms, fire; and natural indirect, e.g. large earthquakes. Although forest managers have little control over indirect forces, proper planning will facilitate control over the direct forces of structural change. In the Greater Toronto Area population density and parcel size were not found to be related to the amount of vegetation cover (Conway and Hackworth, 2007), suggesting that other factors, such as land use policy, are influencing conditions on the ground.

Various socio-economic influences on urban forest structure are also recognized. A direct correlation between neighbourhood wealth and the extent and diversity of urban vegetation cover has been observed (Iverson and Cook, 2000; Martin *et al.*, 2004; Heynen and Lindsay, 2003; Hope *et al.*, 2003). Education (Heynen and Lindsay, 2003), household age composition (Fung and Sui, 2000), occupancy rates (Heynen *et al.*, 2006), and the distribution of long- versus short-term residency in neighbourhoods (Perkins *et al.*, 2004) have also been identified as determinants of the structure of urban vegetation.

Fraser and Kenney (2000) found that the landscape traditions unique to various cultural groups in the City of Toronto directly affected preferences for urban forest structure. For example, the Mediterranean community, having developed in a small-scale agrarian culture, demonstrated a preference for fruit trees and vegetable gardens. Chinese-Canadians expressed the greatest desire for treeless landscapes, while people of British descent responded the most positively to shade trees and naturalized parks. These cultural differences are largely consistent with the traditional use of trees in British, Mediterranean and Chinese landscaping, and appear to be maintained among North American immigrant populations (Fraser and Kenney, 2000).

Compositional differences in forest structure will directly influence the environmental services provided. For example, Beckett *et al.* (2000a) found that conifer species captured more particulate matter than deciduous species when location and placement were controlled. The greater particulate capture was attributed to the finer, more complex structure of conifer species.]

Furthermore, structural properties of leaf and bark surfaces have been found to affect the capacity for particulate capture (Beckett *et al.*, 2000b). Rough, hairy leaf surfaces more effectively captured particles than smooth, waxy leaf surfaces. An understanding of the various attributes of different species can enhance the management capacity to direct urban forest structure to provide certain desired functions, such as particulate removal or stormwater interception.

Urban Forest Function

The urban forest provides numerous valuable ecosystem services. A general discussion of the relevant services is offered here.

Air Quality

Urban air pollution negatively impacts human health. Exposure to common transport-related air pollutants, such as particulate matter (PM2.5 and PM10), ozone (O3), sulphur dioxide (SO2), nitrogen dioxide (NO2), and carbon monoxide (CO), has been linked to various health problems, including: inflammation of the respiratory tract; exacerbated allergic reactions in asthmatics; adverse outcomes in pregnancy; and increased mortality risk due to heart attack, cardiopulmonary and respiratory complications (Kuna-Dibbert and Krzyzanowski, 2005). These risks are not equally distributed across the population. Rather, children and elderly persons with pre-existing chronic disease have shown increased susceptibility to the adverse effects of exposure to air pollutants.

By significantly reducing the amount of airborne pollutants, trees can mitigate the potential health problems associated with poor air quality. Trees reduce the amount of airborne particulate matter by intercepting and storing large airborne particulate matter on outer leaf, branch, and bark surfaces (Nowak et al., 2006). In addition, trees improve air quality by binding or dissolving water-soluble pollutants onto moist leaf surfaces. Other gaseous air pollutants, such as carbon monoxide and sulphur dioxide, are removed primarily by gas exchange through the leaf stomata (Smith, 1990).

Ground level ozone (O3) is not emitted directly but is created by chemical reactions between oxides of nitrogen and volatile organic compounds (VOCs) in sunlight. Although trees are a source of VOC emissions, the net effect of tree cover on the landscape is usually positive with respect to O3 formation, resulting in reductions in ground level ozone (Cardelino and Chameides, 1990; Taha, 1996). Because VOC emissions are temperature-dependent and trees have been found to lower air temperatures, increased tree cover can lower overall VOC emissions and, subsequently reduce ozone levels in urban areas (Nowak and Dwyer, 2007). Furthermore, increasing tree cover over parking lots can reduce VOC emissions by shading parked cars and thereby reducing evaporative emissions (Scott et al., 1999). Thus, urban trees, particularly species that emit low levels of VOCs, can contribute to the reduction of urban O3 levels (Nowak et al., 2000). It should be noted that VOC emissions do vary by species, air temperature and other environmental factors (Guenther et al., 1994).

Carbon Dioxide Reduction and Energy Conservation

Urban forests also play a role in climate change mitigation by reducing atmospheric carbon dioxide (CO2) concentrations. This is achieved by sequestering and storing carbon as woody biomass, reducing GHG emissions by conserving energy used for space heating and cooling, or displacing GHG emissions by using urban tree residue as bio-energy fuel. Trees reduce atmospheric CO2 levels through photosynthesis and subsequent carbon sequestration in woody tissue. During photosynthesis, atmospheric CO2 enters the leaf through surface pores, combines with water, and is converted into cellulose, sugars, and other materials in a chemical reaction catalyzed by sunlight. Most of these materials then become fixed as wood, while a small portion are respired back as CO2 or are utilized in the production of leaves that are eventually shed by the tree (Larcher 1980). Nowak (1994) found that the net annual carbon sequestration by trees in Chicago equaled the amount of carbon emitted from transportation in one week in the Chicago area. This trend is similar to the national rate of carbon sequestration in urban trees (Nowak and Crane, 2002). Furthermore, the amount of carbon emitted by the U.S. population over a 5.5 month period was equal to the estimated amount of carbon stored by urban trees in the United States (Nowak and Crane, 2002).

Trees that are adjacent to buildings can reduce the demand for heating and air conditioning through their moderating influence on solar insolation and wind speed. Additionally, trees moderate climate by transpiring water from their leaves, a process that has a cooling effect on the atmosphere, and by shading surfaces that would otherwise absorb and slowly re-emit heat. Thus, the effective placement of a tree or shrub can lower building temperatures. Simpson and McPherson (1999) report that by planting two large trees on the west side of a house, and one large tree on the east side of a house, homeowners can reduce their annual air conditioning costs by up to 30%. Potential greenhouse gas (GHG) emission reductions from urban forestry are likely to be greatest in regions with large numbers of air-conditioned buildings and long cooling seasons. However, in colder regions where energy demands are high during winter months, trees that are properly placed to create windbreaks can also substantially decrease heating requirements and can produce savings of up to 25% on winter heating costs (Heisler, 1986). This reduction in demand for heating and cooling in turn reduces the emissions associated with fossil fuel combustion (Simpson and McPherson, 2000).

Utilizing urban tree biomass as feedstock for bio-power plants eliminates GHGs that would have been emitted by combusting fossil fuels. The most common way to convert tree biomass to energy is by burning wood fuel to produce heat that powers turbines. However, the cost effectiveness of utilizing removed city trees as a bio-energy feedstock has not yet been well-researched. According to the California Climate Action Registry (2008) there can be costs associated with initial processing at the removal site, transporting to a transfer station, processing facility, or bio-energy facility, storing in open piles, and handling, usually through a combination of automatic conveyors and driver-operated front-end loaders. Research is also underway to develop more efficient processes for converting wood into fuels such as ethanol, bio-oil, and syngas (Zerbe 2006).

Stormwater Management

When stormwater hits impervious surfaces, the water is heated and various pollutants, including lawn fertilizers and oils on roadways, are picked up by the runoff. Water quality problems then arise when large volumes of polluted stormwater flow into receiving waters, posing threats to temperature sensitive species and providing suitable conditions for algal blooms and nutrient imbalances (Kollin, 2006). Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and moderating the onset of peak flows. The urban canopy also filters pollutants that eventually flow to receiving waters. Once runoff is infiltrated into soils, plants and microbes can naturally filter and break down many common pollutants found in stormwater.

Tree roots also increase the rate at which rainfall infiltrates soil as well as the capacity of soil to store water, thereby reducing overland flow. Transpiration through tree leaves then reduces soil moisture, increasing the soil's capacity to store future rainfall. By increasing infiltration rates, urban vegetation also limits the frequency of sewer overflow events by reducing runoff volumes and by delaying stormwater discharges. It is worth noting that trees' ability to perform this work is hampered by heavily compacted soil, which may be too dense for large amounts of water to easily infiltrate and which may adversely affect tree health. Nevertheless, tree canopies can reduce soil erosion by diminishing the impact of rainfall on barren surfaces.

The trees and woody shrubs that comprise urban riparian buffers also improve water quality through filtration of sediment and contaminants, vegetative uptake of soluble nutrients, and infiltration of overland runoff from surrounding fields and hillslopes. Removal of over half the phosphorus, nitrogen and sediment inputs is typically achieved within the first 15 m of buffer width (Osborne and Kovacic, 1993; Castelle *et al*., 1994). Woody riparian vegetation also stabilizes banks and moderates stream temperature by providing shade, which provides favourable habitat for aquatic life.

Land use change associated with urbanization can negatively impact hydrologic processes. A summary of recent literature provided by Endreny (2005) concludes that conversion to urban cover results in the following: a reduction in stormwater interception as a consequence of the loss of tree and vegetative cover; a decrease in infiltration as a consequence of soil compaction and an increase in impervious cover; and, a decrease in evaporation due to reduced soil water volumes. The result is an increase in peak runoff magnitude from precipitation events, which can scour and destabilize many urban channels (Riley, 1998). Although many models have been created to examine the effects of land use change on urban hydrology, i-Tree Hydro, created by the USDA Forest Service, is the only model designed to explicitly examine tree effects on stormwater.

Social Benefits

Although more difficult to quantify, the urban forest provides a variety of important social benefits that bear on other important local issues, such as health care costs and economic productivity. For example, urban trees have been linked with reduced neighborhood crime levels. Kuo and Sullivan (2001) found that apartment buildings with high levels of greenery witnessed 52% fewer crimes than those without trees. This phenomenon is likely due to a combination of factors, including a positive effect by trees on neighbourhood property values, greater community involvement, and higher levels of pedestrian traffic. Some credit has also been given to the positive psychological effect of trees and natural features on human behaviours, and the general contributions of trees to overall community well-being (Jackson 2003).

Research has also shown that the urban forest has demonstrably positive effects on the physical and mental health of urban residents. Hospital patients were found to recover from major surgery more quickly and with fewer complications when provided with a view of trees (Ulrich, 1984). Trees and urban parks also improve mental health and over all well-being by conveying a sense of calm, relieving stress, and facilitating relaxation and outdoor activity. For example, Maas *et al*. (2009) found that residents reported better personal health and stronger social bonds in areas where there was access to green space within one kilometer of the home. Access to natural settings has also been linked to the improvement of children's mental health and academic performance (Roe and Aspinall, 2011), lower weight and BMI in children and teens (Wolch *et al*., 2011), and increased longevity in seniors (Takano *et al*., 2002). The presence of trees can contribute to a generally more attractive living environment and contribute to residents' quality of life (White *et al*., 2013). For example, trees effectively reduce noise levels by absorbing unwanted sound (Aylor, 1972; Cook, 1978).

Traffic and Pedestrian Safety

Research suggests that trees may also improve driving safety. Drivers seeing natural roadside views demonstrated lower levels of stress and frustration compared to those viewing all-built settings (Parsons *et al*. 1998). A study conducted by Mok *et al*. (2006) found a 46% decrease in crash rates across urban arterial and highway sites after landscape improvements were installed. Similarily, research conducted by Naderi (2003) found that placing trees and planters in urban arterial roadsides reduced mid-block crashes by 5% to 20%.

Economic Benefits

A healthy urban forest is a municipal capital investment that will appreciate in value over time. As urban forests grow, their environmental, social and economic benefits increase. The process of valuation of the goods and services provided by the urban forest and surrounding natural system is currently receiving considerable attention across all fields of conservation. A comprehensive assessment of this area of research is beyond the scope of this review; therefore, only a few key examples of this research are offered here.

DeGroot *et al.* (2002) proposed a framework for the valuation of ecosystem functions, goods and services that is based on the synthesis of complex ecological structures and processes into a more limited number of ecosystem functions that provide ecosystem goods and services valued by humans. This framework can be used at various scales; for example, to calculate the natural capital assets within TRCA jurisdiction, a watershed, or an individual site.

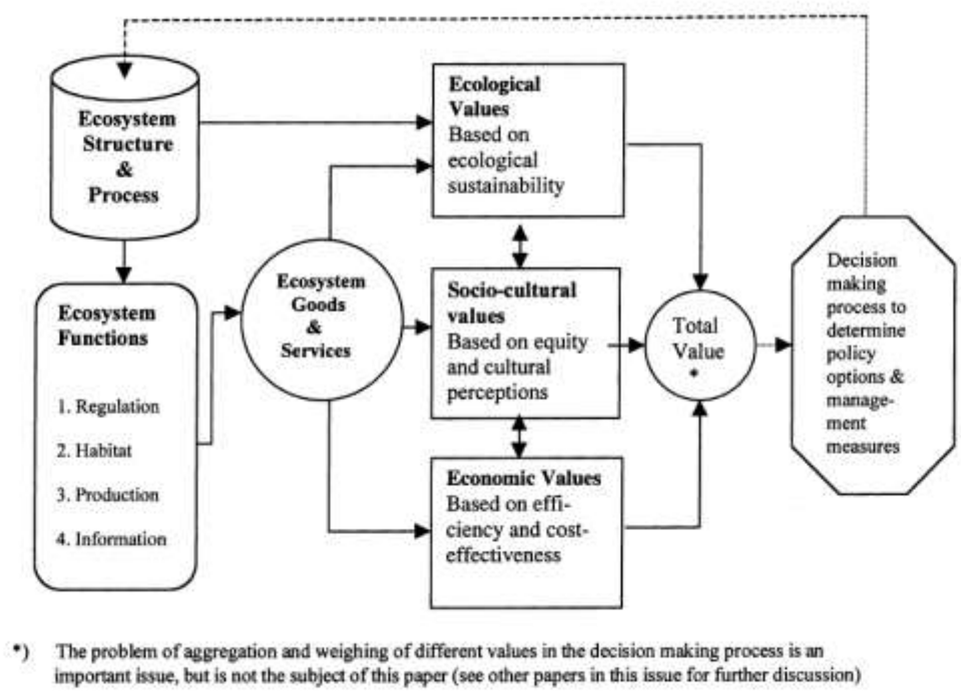


Figure 1: Framework for integrated assessment and valuation of ecosystem functions, goods and services (DeGroot *et al.*, 2002)

The Pembina Institute and Credit Valley Conservation (2009) estimated the value of ecosystem goods and services in the Credit River Watershed using a benefit transfer methodology that focused on the non-market value of ecosystem services; this non-market value was derived from a “willingness to pay” approach.The report found that the value of the natural capital provided by the urban forest in the watershed was estimated at $18.7 million annually. This estimate included the value of the following services: climate regulation; gas regulation; water supply; pollination; recreation; and amenity and cultural.

There are numerous challenges associated with ecological valuation. For example, many ecosystem services are difficult to measure directly (e.g. gas exchange) and therefore require the use of surrogates or indicators (Cuperus *et al.*, 1996; Bond and Pompe, 2003). Other services require a more qualitative approach to discern value, such as various social and cultural benefits. Furthermore, in the absence of local jurisdictional data, the best matching default values and parameters must be selected in order to calculate the value of ecosystem services. Consequently, values derived are often generalized for a large geographic area and are not site-specific. Thus, this field of research is still rapidly evolving in an effort to address these challenges.

A direct economic benefit of urban vegetation is observed in the relationship between tree cover and property value. Both residential tree cover and proximity to green space have been associated with higher property values in residential neighborhoods (Dombrow *et al*., 2000; Anderson and Cordell, 1988). The Center for Urban Forest Research (2005) estimates that properties with trees are valued 5 to 15% higher than comparable properties without trees. Sander *et al*. (2010) found that mere proximity to neighbourhood trees in Minnesota was linked to higher home sale values, with the highest value reported in local neighbourhoods with over 40% tree cover. Furthermore, research shows that shoppers in well-landscaped business districts were willing to pay more for both parking and goods and services (Wolf, 1999).

Urban tree cover can also increase the longevity of grey infrastructure, thereby reducing the frequency of costly repairs. McPherson and Muchnick (2005) have demonstrated that tree shade is correlated with reduced pavement fatigue, cracking, rutting, shoving, and other distress. Consequently, infrastructure maintenance costs can be reduced by increasing tree cover over asphalt. For example, repaving could be deferred ten years on a well-shaded street and potentially 25 years on a heavily shaded street.

An emerging valuation scheme in which urban forestry has begun to receive attention is the global carbon market. While carbon accounting through carbon offset programs has become a relatively well established protocol, in the past such programs generally operated outside the realm of urban forestry. In 2008 the California Climate Action Registry released the *Urban Forest Project Reporting Protocol Version 1.0*; this protocol was subsequently updated and rereleased as version 1.1 in March 2010. The Protocol provides guidance to account for and report greenhouse gas emission reductions associated with a planned set of tree planting and maintenance activities to permanently increase carbon storage in trees (Climate Action Reserve, 2010). This protocol is applicable to urban forest GHG projects undertaken by municipalities, educational campuses and Utilities. Only projects operating within the United States are eligible at the time of release of this report.

Wildlife Habitat

Urban zones have a somewhat complex relationship with wildlife. As rural ecosystems are replaced with urban and suburban development, wildlife diversity decreases, with urban-tolerant species dominating the landscape and sensitive species disappearing. Environmental factors such as noise and forest fragmentation disrupt the natural behaviour of many wildlife species, making urban areas unsuitable as habitat (Dowling *et al*., 2011; Tremblay and St. Clair, 2011). Construction activities destroy habitat and result in animals abandoning the area - eliminating these species both from the site and from adjacent areas (Schaefer 1996).

However, close proximity between urban development and natural habitat does not always translate into whole scale disappearances of wildlife. As human development at the margins of urban zones pushes further into intact forests, human-wildlife interactions increase, with potentially negative outcomes on both sides. As natural habitat shrinks and resources are more limited, wildlife may venture into urban areas seeking food, potentially causing conflicts and safety concerns, especially with large animals such as deer or bears (DeStefano and DeGraaf, 2003).

In York Region and southern Ontario as a whole, few large and connected woodlands remain to serve as habitat for native resident and migratory fauna species. Consequently, the urban forest now plays an increasingly important role in biodiversity conservation and habitat provision for these species. Preventing encroachment and maintaining connectivity of intact forest tracts are vital to the management of these remnant forests.

Sustainable Urban Forest Management

The structure and function of an urban forest will be influenced by a myriad of physical, biological, socioeconomic, cultural, and political factors; these factors are directly interconnected and cannot be viewed in isolation (Zipperer, 2008; Clark *et al.* 1997; Carreiro and Zipperer, 2008; Perkins *et al.*, 2004; Picket *et al.*, 1997). Moreover, these factors and the manner in which they interact with one another must be taken into account when making management decisions. A growing body of research suggests that in order to successfully incorporate these diverse factors into management plans a holistic *ecosystem-based approach* to urban forest management is required (Zipperer, 2008; Carreiro and Zipperer, 2008; Elmendorf and Luloff, 1999).

The ecosystem-based approach found formal acceptance at the Earth Summit in Rio (1992), where it became the primary framework for action under the Convention on Biological Diversity. It is based on the application of appropriate scientific methodologies focused on levels of biological organization, which encompass the essential structures, processes, functions and interactions among organisms and their environment. The following themes are central to this approach: ecological rather than jurisdictional boundaries; ecological integrity; interagency and intermunicipal cooperation; humanity in nature; and environmental justice (Elmendorf and Luloff, 1999). To achieve an ecosystem-based approach to urban forest management Zipperer (2008) argues that consideration must be given to the broader context in which a management site occurs, as the site will affect and be effected by adjacent land uses and surrounding ecological processes. Ames and Dewald (2003) state that assembling a diverse base of expertise with multiple viewpoints into partnerships to address the management of a city’s urban forest is integral to an ecosystem-based approach, as these partnerships can inform the creation and implementation of plans at the outset, thereby avoiding costly problems during and after project completion. Unfortunately, as Ordóñez and Duinker (2013) discovered, many Canadian municipalities with strategic urban forest management plans had very limited public consultation and placed inadequate emphasis on elements crucial to an ecosystem-based approach, including climate change, community stewardship, and connectivity.

Urban forest managers typically alter the structure of the forest through single-tree management on public land only. However, this need not be a barrier to the use of a holistic ecosystem based management approach. Using the theory of vegetation dynamics developed by Pickett *et al*. (1987a,b), Zipperer (2008) demonstrates how managers may take a holistic approach through single-tree management. Three major drivers and explanatory categories for successional change are presented: site availability; species availability; and species performance (Figure 1). A non-exhaustive list of the factors that affect each these three variables is provided. By considering this hierarchy of factors in the management decisions made at the single-tree level, managers can better understand and direct urban forest change at a landscape level.

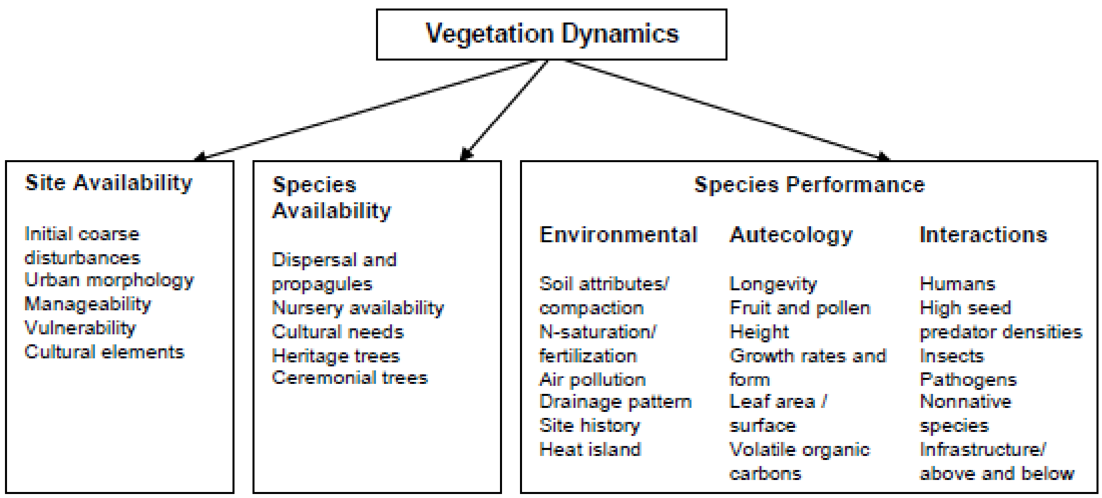


Figure 2: Theory of vegetation dynamics modified for application of ecosystem management in urban landscapes by incorporating elements of the urban ecosystem in the management-decision process (Zipperer, 2008).

In light of two observations, 1) urban environments are extremely heterogeneous in space and dynamic in time, and 2) areas containing urban trees and forest patches are often geographically fragmented, Wu (2008) argues that an urban forest may be most appropriately treated as a landscape that consists of a variety of changing and interacting patches of different shape, size, and history. Essentially, an urban forest is a dynamic patch mosaic system. The *urban landscape ecology approach* has been proposed by Wu (2008) in response to a growing awareness of the importance of considering spatial heterogeneity and its ecological consequences for understanding system processes. This approach emphasizes the diversity and interactions of the biological and socioeconomic components of the city. Spatial pattern of these elements and their ecological consequences from the scale of small patches to that of the entire urban landscape, and to the regional context in which the city resides (Pickett *et al.*, 1997; Zipperer *et al.*, 2000; Luck and Wu, 2002; Wu and David, 2002; Wu, 2008).

When pursuing an urban landscape ecology approach, urban forest managers should ideally consider a planning schematic that can modify tree planting projects according to the requirements of a variety of planting contexts rather than relying on a stock list of approved tree species. This will enable managers to properly assess and characterize different urban zones, thus enhancing the ability of planting projects to be contextually appropriate and to realize specific socio-cultural, economic, or environmental goals (Pickett *et al*., 2011). For example, while the selection of native species may be preferable in some scenarios, there may be instances in which non-native species are more suited to harsher growing environments and thus capable of delivering greater benefits. However, the use of non-native species must also account for their potential invasiveness and any detrimental influence they may exert on the urban landscape and its surroundings.

Progress must be assessed relative to defined standards if sustainability is the ultimate landscape management goal. Recognizing this need, Clark *et al.* (1997) have developed a model of sustainability that provides a list of criteria and associated indicators for the evaluation of the following critical elements of urban forest management: the vegetation resource; community framework; and resource management approaches. Kenney *et al.* (2011) revised this model further to produce a more detailed set of criteria and measurable indicators. This revised model has been used in the Urban Forest Strategic Management Plan for the Town of Oakville to assess the Town's progress towards sustainability. Carreiro and Zipperer (2008) argue that the construction of urban sustainability indices and the valuation of ecosystem services will be critical, particularly in the short-term, for preventing undesirable trajectories and gauging the efficacy of collective actions aimed at creating more ecologically sound cities.

Threats to the Urban Forest

Climate Change

Human activities occurring in the industrialized era, such as fossil fuel combustion, agricultural practices, land use change and deforestation, have released large quantities of heat trapping greenhouse gases into the atmosphere over a short period of time. As a consequence, the rising atmospheric greenhouse gas concentrations have been correlated with increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising sea levels (IPCC, 2007). Such climatic changes have had, and will continue to have, disastrous outcomes for the global biosphere.

Climate change is projected to impact the forests of Ontario by altering the frequency, intensity, duration, and timing of fire, drought, and insect and pathogen outbreaks (Dale *et al.*, 2001). In many areas, higher temperatures will alter moisture regimes and lead to increased drought stress for trees in urban settings; urban heat island effects are likely to magnify these stresses (Arnfield, 2003). An incremental increase in temperature during the growing season could increase evaporative demand, triggering drought stress (Dale *et al.*, 2001). In the Great Lakes basin soil moisture may decrease by as much as 30% in the summer and fall (de Loë and Berg, 2006). In areas where drought is not observed, rising levels of carbon dioxide may lead to increased water-use efficiency in trees, and consequently increased tree growth. Higher temperatures may also increase rates of photosynthesis and extend the growing season (Zhou *et al.*, 2001).

Extreme precipitation events in Southern Ontario are projected to increase in both frequency and intensity under future climate change scenarios (Hengeveld and Whitewood, 2005). Consequently, increased branch failure caused by ice storms and high winds will lead to higher rates of tree mortality. Some degree of damage may be mitigated by proper routine maintenance and preferential selection of tree species that can withstand disturbance. Furthermore, erosion associated with flooding following heavy rain and rapid snow melt will expose roots to pathogenic fungi and will weaken tree stability.

Warmer annual temperatures will provide less control over many insect populations, many of which are kept at low levels by cold winter temperatures (Volney and Fleming, 2000). The seasonal development of many insects such as the spruce budworm (*Choristoneura spp*) or forest tent caterpillar (*Malacosoma disstria*) will likely be accelerated and extended as climate change continues (Fleming and Volney, 1995; Cerezke and Volney, 1995). Stress caused by drought, heat and air pollution will, in turn, increase the susceptibility of urban trees to such insect pest outbreaks.

Changes in species composition in the urban forest may also be observed as a consequence of altered climatic conditions. For example, certain generalist species that tolerate a wide range of conditions and have several means of reproduction, such as poplar species, may prevail over those species that have narrow ecological tolerances (Thompson *et al.*, 1998). Drought tolerant species will likely possess a greater adaptive capacity, while populations of structurally weak species that are susceptible to ice damage may decline. In addition, northward migration of species as a result of shifting population ranges will create opportunities for increased planting of Carolinian species, while a loss of species at the southern edge of their present natural range may also be observed. For example, research suggests that species found in the oak-hickory forests of the central United States may migrate into what is currently the Great Lakes-St. Lawrence forest (Colombo *et al.*, 1998). However, differing migration rates and the reactions of individual species to new environmental conditions (e.g. modified soil moisture levels) could result in new species mixes for which inadequate forest management experience exists.

Malcolm *et al.* (2008) modeled current and future tree species distribution in the Credit River Watershed under projected climate change scenarios. The results showed a clear north – south pattern in potential tree community change, understood as a temperature analog perspective. Thus, under a moderate warming scenario the habitat conditions observed in the south of the watershed could be expected to shift into the north of the watershed. More specifically, under an A2 emissions scenario tree communities in the watershed would likely approximate those of Kentucky or northern Georgia in 2095 (depending on the model used). However, the authors state that it is unlikely that these tree species will achieve the rates of northward migration necessary to accompany the rapidly shifting habitat conditions. Rather, the more probable outcome for the Credit River Watershed will be decreased species diversity, lower forest biomass, and a “weedier” (early successional) set of taxa.

The uncertainty associated with climate change highlights the need for decisions that emphasize ecological processes, rather than those based solely on structure and composition (Harris *et al.*, 2006). Millar *et al.* (2007) note that attempts to use historical ecosystem conditions as management targets may lead to the development of forests that are ill adapted to current conditions and more susceptible to undesirable changes. Thus, new management options must be considered.

Urbanization and Development Pressure

Population growth and the ensuing urbanization have transformed natural landscapes throughout the world and have contributed to the current crisis of biodiversity loss, habitat destruction, and deterioration of ecosystem services (Wu, 2008). The global urban population is growing three times faster than the rural population (Nilsson *et al.*, 1999). This trend is consistent with growth patterns in Canada. As of 2006, 80% of Canadian citizens lived in urban areas (Statistics Canada, 2008). The ecological footprints of growing Canadian cities are also increasing in size due to the demands for resources and the regional impacts of waste and emissions on soil, air, and water.

In southern Ontario, agriculture and urbanization have triggered the conversion of presettlement forest cover to isolated forest patches and prompted the loss of ecosystem services. Fragmentation and encroaching human development have been shown to cause alterations to plant communities, invasions of non-native flora and fauna, soil compaction or erosion, and damage from unauthorized recreational use (McWilliam *et al.*, 2010; Ranta *et al.*, 2013). Other types of encroachment, caused by light, sound, and other factors, are difficult to quantify and have yet to be studied in depth. A study by McWilliam *et al*. (2013) of several southern Ontario municipalities found that few had proper policy mechanisms to effectively deter or curb urban forest encroachment and that better cooperative planning strategies are needed.

If urban planning efforts fail to adequately include greenspace conservation, a community may see increased public costs for social and ecosystem services, increased public costs for disaster remediation, decreased community image and morale, lower property values, and increased public anxiety (Wilkinson, 1991). A failure to incorporate greenspace conservation and urban forest management into community development early on will only amplify the complexities and costs of later efforts as land values increase concurrently with competition for land purchase (Elmendorh and Luloff, 1999).

A study by Berland (2012) examined the long-term impacts of urbanization on tree canopy cover in the Twin Cities Area of Minnesota. The majority of land use change in the study entailed the conversion of agricultural land to urbanized land, with a significant decrease in tree canopy cover observed following the conversion. However, an overall increase in tree canopy cover was observed over time as trees planted during development reached maturity. Despite the improvement in overall tree canopy cover, this is not synonymous with an improvement in overall ecosystem services, as the canopy cover was still embedded in a highly urbanized matrix and the measurements cannot account for the nuanced outputs of ecosystem functions.

Air Pollution

Air pollution contributes directly to urban forest degradation by inducing changes in tree condition, tree physiology, and biogeochemical cycling and by lowering tree resistance to insects and disease (Percy, 2002). Matyssek *et al.* (1992) found premature leaf discoloration and abscission in European white birch (*Betula pendula)* that were exposed to relatively low concentrations of ozone during the growing season. In addition, susceptibility to drought may also be increased by ozone and other gaseous pollutants. Evidence also suggests that air pollution can predispose some tree species to low temperature injury by reducing frost hardiness (Chappelka and Freer-Smith, 1995).

Air pollutants can have a more subtle effect on tree health by inducing changes to the reproductive success of particular genotypes or species. For example, acidic precipitation was shown to negatively affect the germination of pollen of a variety of species (Van Ryn *et al.*, 1986). Similarly, Scholz *et al.* (1985) and O'Connor *et al.* (1987) found that pollen germination in some species could be inhibited by sulphur dioxide.

Urban Forest Pests and Disease

Exotic insect pests pose a serious threat to the health of urban forests as no natural controls have developed to regulate these non-native species. Consequently, infestations commonly result in a substantial loss of canopy cover and associated ecosystem services, an increase in municipal maintenance and removal costs, a loss of species diversity, and a shift to earlier age class distribution. Two exotic insect pests are of particular concern in this region: the emerald ash borer (*Agrilus planipennis*) and the Asian long-horned beetle (*Anoplophora glabripennis*).

The emerald ash borer (EAB) is an invasive beetle from Asia that attacks and kills all species of ash (genus: *Fraxinus*). The larvae tunnel beneath the bark and feed on the cambium, disrupting the flow of water and nutrients within the tree. The beetle was first identified in Michigan in 2002 and quickly became well established throughout much of Essex County and Chatham-Kent. The beetle is now established across TRCA's jurisdiction. Ash species are very common in many urban forests of southern Ontario as they are tolerant of harsh urban conditions. The loss of existing ash trees will therefore translate to a significant loss of total canopy cover and associated services, and significant costs to municipalities and homeowners when dead trees must be removed. Some evidence exists that ash trees have been regenerating in natural forests during the period of infestation but the dramatic losses of mature ash trees have resulted in a depleted seed bank (Kashian and Witter, 2011).

The Asian long-horned beetle (ALHB) is also an invasive beetle, native to eastern Asia. This exotic beetle attacks multiple hardwood species native to Canada. In particular, maple species (genus: *Acer*), which comprise significant portions of urban forests in Canada, are a preferred host tree. The beetle also attacks the following genera: horsechestnut (*Aesculus spp*), elm (*Ulmus spp*), birch (*Betula spp*), poplar (*Populus spp*), willow (*Salix spp*), mountain-ash (*Sorbus spp)* and common hackberry (*Celtic occidentalis*). The ALHB's presence in Canada was first detected in 2003 in an industrial area on the Toronto – Vaughan boundary, prompting the Canadian Food Inspection Agency to launch an aggressive effort to contain the infestation. The area has been regulated to prevent further spread and ALHB was declared to have been eradicated from the GTA. Despite this apparent success, an ALHB infestation was discovered in Mississauga in 2013 and is believed to be the result of a recent re-introduction of the pest – further proof that ongoing vigilance against urban forest pests is required.

Non-native Invasive Plant Species

Non-native invasive plants are aggressive and opportunistic species whose introduction or spread can dominate natural areas, potentially threatening the environment, economy, and society, including human health. Such species reproduce abundantly and subsequently displace native vegetation, impede the natural regeneration of forest tree species, modify habitat, sometimes hybridize with native species, and ultimately threaten biodiversity (Simberloff *et al.*, 1997). The agricultural and urban areas of temperate regions are among the most invaded biomes in the world (Lonsdale, 1999). Particularly persistent non-native invasive species in the Greater Toronto Area include common and glossy buckthorn (*Rhamnus cathartica, R. frangula*), dog-strangling vine / swallowwart (*Cynanchum louiseae [Vincetoxicum nigram], C. rossicum*), garlic mustard (*Alliara petiolata*), and Norway maple (*Acer platanoides*).

Non-native invasive plant species have few natural controls that prevent establishment. For example, Jogesh *et al.* (2008) found that several highly invasive non-native plants common in the Ottawa region were more resistant to generalist herbivores, suggesting that these plants possess resistance traits to which native North American herbivores are poorly pre-adapted. Similarly, Cappuccino and Carpenter (2005) determined that nine common invasive plants found in Ontario, New York and Massachusetts experienced, on average, 96% less damage due to herbivory than non-invasive plant species.

In response to the serious threat to local biodiversity posed by non-native invasive plants, coordinated efforts for early detection and rapid response are now underway at the municipal, provincial, and federal scale. The prevention of new introductions will be vital to the success of these efforts, but some municipalities continue to plant Norway maple despite evidence of its invasiveness. Within the urban forest many invasive species are horticultural plants that have escaped from residential gardens into adjacent natural systems. Thus, a preference for planting non-invasive native species in urban gardens and yards will play an important role in invasive species management programs. Education of homeowners about plant invasiveness would also bolster efforts to control the establishment and spread of invasive plant species.

Additional Urban Forest Stressors

Urban forests are exposed to a host of additional biotic and abiotic stressors. Often multiple stressors combine to reduce a tree's vigour and increase vulnerability to additional problems. Moisture deficiency or excess are extremely common causes of urban tree decline. Soil saturation due to flooding or over-watering can decrease oxygen availability and lead to root suffocation (Iowa State University, 2008). Numerous factors may lead to soil-moisture-related drought stress, including restricted soil volumes, reduced rainfall infiltration, and soil compaction. Moisture stress can limit tree growth and reduce survival through direct and indirect effects on an array of physiological processes including photosynthesis (Cregg, 1995), respiration, protein synthesis, and secondary carbohydrate metabolism (Kramer, 1987). Furthermore, reduced tree vigour caused by moisture stress may predispose trees to additional health problems including insect infestation (Mattson and Haack, 1987), thereby creating favourable conditions for the spread of invasive pests such as Emerald Ash Borer. The urban heat island effect – whereby mean temperatures in urban cores are about 1-2 degrees Celsius higher or more than in nearby rural areas – can exacerbate tree stress and soil moisture loss. Soil temperatures can likewise be several degrees in higher in urban zones compared to rural soils (Pickett *et al.*, 2011). Chemical injury caused by exposure to herbicides, insecticides, fungicides, and de-icing salts is also a common cause of urban tree decline (Fluckiger and Braun, 1981).

References

Ames, B. and S. Dewald. 2003. Working proactively with developers to preserve urban trees. Cities 20:95–100.

Anderson, L.M. and H.K. Cordell. 1988. Residential property values improved by landscaping with trees. Southern Journal of Applied Forestry 9: 162-166.

Arnfield, A.J. 2003. Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. International Journal of Climatology 23:1-26.

Aylor, D.E. 1972. Noise reduction by vegetation and ground. Journal of Acoust. Soc. Am. 51(1):197-205.

Beckett, P.K., Freer-Smith, P.H., and G. Taylor. 2000a. Particulate pollution capture by urban trees: Effect of species and windspeed. Global Change Biology 6(8): 995-1003.

Beckett, P.K., 2000b. Effective tree species for local air quality management. Journal of Arboriculture 26(1): 12-19.

Berland, A. 2012. Long-term urbanization effects on tree canopy cover along an urban-rural gradient. Urban Ecosystems 15: 721-738.

Bonds, M.H. and J. Pompe. 2003. Calculating wetland mitigation banking credits; adjusting for function and location. *Natural Resources Journal* 43(4): 961-977.

California Climate Action Registry. 2008. Urban Forest Project Reporting Protocol. Version 1.0.

Cappuccino, N. and D. Carpenter. 2005. Invasive exotic plants suffer less herbivory than non invasive exotic plants. Biology Letters v.1 (4): 435–438.

Cardelino,C.A. and W.L. Chameides. 1990. Natural hydrocarbons, urbanization, and urban ozone. Journal of Geophysical Research 95(D9):13,971-13,979.

Carreiro, M.M. and W.C. Zipperer. 2008. Urban forestry and the eco-city: Today and tomorrow. In Ecology, Planning, and Management of Urban Forests: International Perspectives. M.M. Carreiro *et al.* (eds). Springer.

Castelle, A.J., A.W. Johnson, and C. Conolly. 1994. Wetlands and Stream Buffer Size Requirements: A Review. Journal of Environmental Quality 23: 878-882.

Cerezke, H.F. and W.J.A Volney. 1995. Forest insect pests in the Northwest region. In *Forest Insect Pests in Canada* (J.A. Armstrong and W.G.H. Ives, ed.). Canadian Forest Service, Science and Sustainable Development Directorate, Ottawa.

Chappelka, A.H., and P.H. Freer-Smith. 1995. Predisposition of trees by air pollutants to low temperatures and moisture stress. Environ. Pollut. 87: 105.117.

Clark, J.R., Methany, N. P., Cross, G. and V. Wake. 1997. A model of urban forest sustainability. Journal of Arboriculture 23(1): 17-30.

Climate Action Reserve. 2010. http://www.climateactionreserve.org/.

Colombo, S.J., M.L. Cherry, C. Graham, S. Greifenhagen, R.S. McAlpine, C.S. Papadopol, W.C. Parker, T. Scarr, M.T. Ter-Mikaelian and M.D. Flannigan. 1998. The impacts of climate change on Ontario's forests. Forest research information paper No. 143. Ontario Forest Research Institute.

Conway, T.M., and J. Hackworth. 2007. Urban pattern and land cover variation. The Canadian Geographer 51 (1): 43–57.

Cook, D.L. 1978. Trees, solid barriers, and combinations: Alternatives for noise control. In *Proceedings of the National Urban Forestry Conference* (G. Hopkins, ed.) SUNY College of Environmental Science and Forestry, Syracuse, NY, pp:330-339.

Cregg, B.M. 1995. Plant moisture stress of green ash trees in contrasting urban sites. J. Arboric. 2:271–276.

Cuperus, R., K.J. Canters, and A.A.G Piepers. Ecological compensation of the impacts of a road. Preliminary method for the A50 road link. Ecological Engineering Volume 7(4): 327-349.

Dale, V.H., Joyce, L.A., McNulty, S., Neilson, R.P., Ayres, M.P., Flannigan, M.D., Hanson, P.J., Irland, L.C., Lugo, A.E., Peterson, C.J., Simberloff, D., Swanson, F. J., Stocks, B.J., and M. Wotton. 2001. Climate change and forest disturbances. BioScience. 51(9): 723-734.

De Groot, R.S., M.A. Wilson, and R.M.J. Boumans. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41: 393–408.

De Loë R. and A.A Berg. 2006. Mainstreaming climate change in drinking water source protection in planning in Ontario. White paper prepared for the Canadian Water Resources Association and Pollution Probe. 42 Pages.

DeStefano, S. and R.M. DeGraaf. 2003. Exploring the ecology of suburban wildlife. Frontiers in Ecology and the Environment 1(2): 95-101.

Dombrow, J. M. R. and C.F. Sirmans. 2000. The market value of mature trees in single-family housing markets. The Appraisal Journal 68: 39-43.

Dowling, J.L., Luther, D.A., and P.P. Marra. 2011. Comparative effects of urban development and anthropogenic noise on bird songs. Behavioral Ecology 23(1): 201-209.

Elmendorf, W.F. and A.E. Luloff. 1999. Using ecosystem-based and traditional land-use planning to conserve greenspace. Journal of Arboriculture 25(5):264-273.

Endreny, T.A., 2005. Land Use and Land Cover Effects on Runoff Processes: Urban and Suburban Development. In: Encyclopedia of Hydrological Sciences, M.G. Anderson (Editor). Wiley, Chichester, United Kingdom, pp. 1775-1804.

Fleming, R.A. and W.J.A.Volney. 1995. Effects of climate change on insect defoliator population processes in Canada's boreal forest: some plausible scenarios. Water, Air, Soil Poll. 82: 445-454.

Fluckiger, W., and S. Braun. 1981. Perspectives of reducing the deleterious effect of de-icing salt upon vegetation. Plant Soil. 63:527529.

Fraser, E.D.G, and W.A. Kenney. 2000. Cultural background and landscape history as factors affecting perceptions of the urban forest. Journal of Arboriculture 26(2):106-113.

Fung, T., Sui, W., 2000. Environmental quality and its changes, an analysis using NDVI. International Journal of Remote Sensing 21, 1011–1024.

Guenther, A., Zimmerman, P., and M Wildermuth. 1994. Natural volatile organic compound emission rate estimates for U.S. woodland landscapes. Atmos. Environ. 28(6):1197-1210.

Harris, J. A., R. J. Hobbs, E. Higgs, and J. Aronson. 2006. Ecological restoration and global climate change. Restoration Ecology 14:170–176.

Heisler, G.M. 1986. Energy savings with trees. Journal of Arboriculture 12(5):113-125.

Hengeveld, H. and B. Whitewood. 2005. Understanding climate change — 2005; Environment Canada, Meteorological Service of Canada, 57 p.

Heynen, N.C., and G. Lindsay. 2003. Correlates of urban forest canopy cover: implications for local public works. Public Works Management and Policy 8 (1), 33–47.

Heynen, N., Perkins, H.A., and P. Roy. 2006. The political ecology of uneven green space: the impact of political economy on race and ethnicity in producing environmental inequality in Milwaukee. Urban Affairs Review 42 (1): 3–25.

Hope, D., Gies, C., Zhu, W., Fagab, W.F., Redman, C.L., Grimm, N.B., Nelson, A.L., Martin, C., and A Kinzig. 2003. Socioeconomics drive urban plant diversity. Proceedings of the National Academy of Science 100 (15), 8788–8792.

IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Iowa State University. 2008. Understanding decline in trees. Extension file: Forestry 2, Pest Management 5. Retrieved from: http://www.extension.iastate.edu/Publications/SUL2.pdf.

Iverson, L.R., and E.A. Cook. 2000. Urban forest cover of the Chicago region and its relation to household density and income. Urban Ecosystems 4: 105–124.

Jackson LE. 2003. The relationship of urban design to human health and condition. Landscape and Urban Planning 64: 191-200.

Jogesh, T., Carpenter, D., and N. Cappuccino. 2008. Herbivory on invasive exotic plants and their non-invasive relatives. Biological Invasions 10(6): 797-804.

Kashian D.M. and J.A. Witter. 2011. Assessing the potential for ash canopy tree replacement via current regeneration following emerald ash borer-caused mortality on southeastern Michigan landscapes. Forest Ecology and Management 261: 480-488.

Kenney, W.A., van Wassenaer, P.J.E., A.L. Satel. 2011. Criteria and Indicators for Strategic Urban Forest Planning and Management. Arboriculture & Urban Forestry 2011. 37(3): 108–117.

Kollin, C. 2006. How green infrastructure measures up to structural stormwater service: Quantifying the contribution of trees and vegetation. Stormwater 7(5).

Kramer, P.J. 1987. The role of water stress in tree growth. J. Arboric. 13:33–38.

Kuo, F. and W. Sullivan. 2001. Environment and crime in the inner city: Does vegetation reduce crime? Environment and Behavior 33(3): 343-367.

Kuna-Dibbert, B. and M. Krzyzanowski. 2005. Health risk assessment of transport-related air pollultion. In *Health effects of transport-related air pollution*. (M. Krzyzanowski, ed.). World Health Organization.

Larcher, W. 1980. Physiological plant ecology. Springer-Verlag,Berlin, 303 p.

Lonsdale, W.M. (1999) Global patterns of Plants Invasions and the concept of invasibility. Ecology 80(5): 1522–1536.

Luck, M., and J. Wu. 2002. A gradient analysis of urban landscape pattern: A case study from the Phoenix metropolitan region, Arizona, USA. Landscape Ecology 17:327–339.

Maas, J., van Dillen, S.M.E., Verheij, R.A., and P.P. Groenewegen. 2009. Social contacts as a possible mechanism behind the relation between green space and health. Health & Place 15: 586-595.

Martin, C.A., Warren, P.S., and A.P. 2004. Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, AZ. Landscape and Urban Planning 69: 355–368.

Mattson, W.J., and R.A. Haack 1987. The role of drought in outbreaks of plant-eating insects. BioScience 37:110-118.

Matyssek, R., Günthardt-Goerg, M.S., Saurer, M., and T. Keller. 1992. Seasonal growth in leaves and stem, and phloem structure of birch (*Betula pendula*) under low ozone concentrations. Trees 6: 96–76.

McPherson, E.G., and J. Muchnick. 2005. Effects of street tree shade on asphalt concrete pavement performance. Journal of Arboriculture 31(6):303-310.

McWilliam, W., Eagles, P., Seasons, M., and R. Brown. 2010. Assessing the degradation effects of local residents on urban forests in Ontario, Canada. Arboriculture & Urban Forestry 36(6): 253-260.

McWilliam W., Eagles, P., Seasons, M., and R. Brown. 2012. Evaluation of planning and management approaches for limiting residential encroachment impacts within forest edges: A Southern Ontario case study. Urban Ecosystems 15(3): 753-772.

Millar, C., Stephenson, N.L., and S.L. Stephens. 2007. Climate change and forests of the future: Managing in the face of uncertainty. Ecological Applications, 17(8): 2145–2151.

Mok, J.-H., H.C. Landphair, and J.R. Naderi. 2006. Landscape Improvement Impacts on Roadside Safety in Texas. *Landscape and Urban Planning* 78:263-274.

Naderi, J.R. 2003. Landscape Design in the Clear Zone: Effect of Landscape Variables on Pedestrian Health and Driver Safety. *Transportation Research Record* 1851:119-130.

Nilsson, K., Konijnendijk, C.D., and T.B. Randrup. 1999. Urban forestry: Where people meet trees. In: Proceedings of International Conference on Community Forestry, December 7–8, 1999, London. http://www.communityforest.org.uk/tpsn.html.

Nowak, D.J. 1993. Historical vegetation change in Oakland and its implications for urban forest management. Journal of Arboriculture 9(15):313-319.

Nowak, D.J. 1994. Atmospheric carbon dioxide reduction by Chicago's urban forest. In Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep. NE-186. McPherson, E.J., Nowak, D.J., and R.A. Rowntree, eds. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 83-94.

Nowak, D.J. and D.E. Crane. 2002. Carbon storage and sequestration by urban trees in the USA. Environmental Pollution 116: 381-389.

Nowak, D.J., D.E. Crane, and J.C. Stevens. 2006. Air pollution removal by urban trees and shrubs in the United States. Urban Forestry & Urban Greening 4.

O'Connor, C.J., Ashford, K.P. and D.J. Spedding. 1987. Germination and metabolism of *Pinus radiata* pollen in the presence of sulphur dioxide. J. Plant Physiol. 126: 373-8.

Ordóñez, C. and P.N. Duinker. 2013. An analysis of urban forest management plans in Canada: Implications for urban forest management. Landscape and Urban Planning 116: 36-47.

Osborne, L.L. and D.A. Kovacic. 1993. Riparian Vegetated Buffer Strips in Water-Quality Restoration and Stream Management. Freshwater Biology 29:243-258.

Parsons, R., L.G. Tassinary, R.S. Ulrich, M.R. Hebl, and M. Grossman-Alexander. 1998. The View From the Road: Implications for Stress Recovery and Immunization. *Journal of Environmental Psychology* 18, 2:113–140.

Pembina Institute and Credit Valley Conservation. 2009. Natural Credit: Estimating the Value of Natural Capital in the Credit River Watershed.

Percy, K.E., 2002. Is air pollution an important factor in forest health? pp. 23-42 In: R.C. Szaro, A. Bytnerowicz and J. Oszlanyi (Eds.), Effects of Air Pollution on Forest Health and Biodiversity in Forests of the Carpathian Mountains, IOS Press, Amsterdam

Perkins, H.A., Heynen, N., Wilson, J., 2004. Inequitable access to urban reforestation: the impact of urban political economy on housing tenure and urban forests. Cities 21 (4): 291–299.

Pickett, S.T.A., Collins, S.C., and J.J.Armesto. 1987a. A hierarchical consideration of causes and mechanisms of succession. Vegetatio 69:109–114.

Pickett, S.T.A., Collins, S.C., and J.J. Armesto. 1987b. Models, mechanisms and pathways of succession. Botanical Review 53:335–371.

Pickett, S.T.A., Burch, W.R., Jr., Dalton, S.E., Foresman, T.W., Grove, J.M., and R.A.Rowntree. 1997. A conceptual framework for the study of human ecosystems in urban areas. Urban Ecosystems 1:185–201.

Pickett, S.T.A., Cadenasso M.L., Grove, J.M., Boone, C.G., Groffman, P.M., Irwin, E., Kaushal, S.S., Marshall, V., McGrath, B.P., Nilon, C.H., Pouyat, R.V., Szlavecz, K., Troy, A., and P. Warren. 2011. Urban ecological systems: Scientific foundations and a decade of progress. Journal of Environmental Management 92: 331-362.

Ranta, P. Viljanen, V., and T. Virtanen. 2013. Spatiotemporal dynamics of plant occurrence in an urban forest fragment. Plant Ecology 214: 669-683.

Riley, A.L. 1998. Restoring Streams in Cities: A Guide for Planners Policymakers and Citizens. Island Press, Washington, D.C.

Roe, J. and P. Aspinall. 2011. The restorative outcomes of forest school and conventional school in young people with good and poor behaviour. Urban Forestry & Urban Greening 10: 205-212.

Rowntree, R.A. 1984. Ecology of the urban forest- Introduction to Part I. Urban Ecology 8(1/2):1-11.

Sander, H., Polasky, S., and R.G. Haight. 2010. The value of urban tree cover: A hedonic property price model in Ramsey and Dakota Counties, Minnesota, USA. Ecological Economics 69: 1646-1656.

Sanders, R.A. 1984. Urban vegetation impacts on the urban hydrology of Dayton Ohio, Urban Ecology 9:361-376.

Scott, K.I.,Simpson, J.R., and E.G. McPherson. 1999. Effects of tree cover on parking lot microclimate and vehicle emissions. Journal of Arboriculture 25(3):129-142.

Schaefer, R. R. 1996. Red-cockaded Woodpecker reproduction and provisioning of nestlings in relation to habitat. M.Sc. Thesis. Stephen F. Austin State University, Nacogdoches, TX. 78. pp.

Simberloff, D. with D.R. Towns and I.A.E. Atkinson. 1997. Restoration of New Zealand islands: Redressing the effects of introduced species. Pacific Conservation Biology 3:99-124.

Simpson, J.R. and E.G. McPherson. 1996. Potential of tree shade for reducing residential energy use in California. Journal of Arboriculture 22(1):10-18.

Simpson, J.R. and E.G. McPherson. 2000. Effects of urban trees on regional energy use and avoided carbon. In Preprints, 3rd urban environment symposium; 2000 August 14-18; Davis, CA. Washington, DC: American Meteorological Society:143-144.

Smith, W.H. 1990. Air pollution and forests, Springer-Verlag. New York.

Statistics Canada. 2009. 2006 Community Profiles: Ajax. Last modified: 2009-03-10.

Taha, H. 1996. Modeling the impacts of increased urban vegetation on the ozone air quality in the south coast air basin. Atmospheric Environment 30(20): 3423-3430.

Takano, T., Nakamura, K., and M. Watanabe. 2002. Urban residential environments and senior citizens' longevity in megacity areas: the importance of walkable green spaces. Journal of Epidemiology and Community Health 56(12): 913-918.

Thompson, I.D., M.D. Flannigan, B. M. Wotton and R. Suffling. 1998. The effects of climate change on landscape diversity: An example in Ontario forests. Environmental Monitoring and Assessment 49: 213-233.

Tremblay, M.A. and C.C. St. Clair. 2011. Permeability of a heterogeneous urban landscape to the movements of forest songbirds. Journal of Applied Ecology 48: 679-688.

Ulrich, R. 1984. View through window may influence recovery from surgery. Science 224: 420-421.

Volney, W.J.A. and R.A. Fleming. 2000. Climate change and impacts of boreal forest insects. Agriculture, Ecosystems and Environment 82:283-294.

White, M.P., Alcock, I., Wheeler, B.W., and M.H. Depledge. 2013. Would you be happier living in a greener urban area? A fixed-effects analysis of panel data. Psychological Science 24(6) 920-928.

Wilkinson, K. 1991. *The Community in Rural America*. New York, NY: Greenwood Press

Wolch, J., Jerrett, M., Reynolds, K., McConnell, R., Chang, R., Dahmann, N., Brady, K., Gilliland, F., Su, J.G., and K. Berhane. 2011. Childhood obesity and proximity to urban parks and recreational resources: A longitudinal cohort study. Health & Place 17: 207-214.

Wolf, K.L. 1999. Nature and commerce: Human ecology in business districts. In *Building Cities of Green* (C. Kollin, ed): Proceedings of the 9th National Urban Forest Conference. Washington, D.C: American Forests.

Wu. J. 2008. Toward and landscape ecology of cities: Beyond buildings, trees, and urban forests. In *Ecology, Planning, and Management of Urban Forests: International Perspectives*. M.M. Carreiro *et al.* (eds). Springer.

Wu, J., and J.L. David. 2002. A spatially explicit hierarchical approach to modeling complex ecological systems: theory and applications. Ecological Modeling 153:7–26.

Zerbe, J.I. 2006. Thermal Energy, Electricity, and Transportation Fuels from Wood. Forest Products Journal. 56 (1).

Zipperer, W.C. 2008. Applying ecosystem management to urban forestry. In *Ecology, Planning, and Management of Urban Forests: International Perspectives.* M.M. Carreiro *et al.* (eds). Springer.

Zipperer, W.C., Wu, J., Pouyat, R.V., and S.T.A Pickett. 2000. The application of ecological principles to urban and urbanizing landscapes. Ecological Applications 10:685–688.

Appendix B: Glossary of Terms

Adaptive capacity: The ability of an ecosystem to withstand and adapt to changes in the environment. Adaptive capacity is higher in ecosystems with greater diversity of species and genetic variability among species, as these factors determine greater resiliency in the face of change or disturbance.

Canopy cover: The amount of land, typically represented as a percentage, covered by tree canopies as viewed from a two-dimensional, birds-eye perspective; does not account for detailed information such as tree height, species, or leaf area.

Carbon sequestration: The process of removing and capturing carbon, in the form of carbon dioxide (CO2), from the atmosphere. During photosynthesis, trees and plants take carbon dioxide in through the stomata and synthesize it with water and light energy to produce carbohydrates. As carbon sequestration is performed mainly by leaves, large trees sequester greater amounts of carbon than small trees on a per tree basis.

Carbon storage: The long-term storage of carbon (C) following removal from the atmosphere. Trees store carbon in the form of woody tissue; therefore, large trees store greater amounts of carbon than small trees on a per tree basis.

Drip line: A line under a tree in the shape of the outermost contour of the tree's crown; so called because it receives most of the rain water dripped by the tree's leaves.

Ecosystem services: Services delivered by natural features as a result of their natural functioning that benefit human populations, including, but not limited to, air pollution removal, erosion control, and climate moderation.

Exotic species: [See **Non-native species**]

Extensive management: Large-scale tree management that occurs on the landscape level; e.g. woodlot management.

Forest: An ecosystem dominated by trees and usually defined by at least 30% tree canopy cover, but also including associated plants, shrubs, soils, and fungi, as well as microbes, insects, and wildlife for which the forest provides habitat and sources of food. A forest also performs vital functions such as soil nutrient cycling, water filtration, erosion control, and climate moderation.

Green infrastructure: Natural features that are managed by humans and often incorporated into conventionally built infrastructure to provide ecosystem services in urban zones. Examples include green roofs, living walls, and engineered wetlands.

Greenspace: Areas dominated by natural features, usually within developed zones and contrasting with adjacent areas dominated by built infrastructure, that provide ecosystem services and are often open to public access. Can include highly tended spaces (ex. Cemeteries) or natural ecosystems (ex. Urban woodlots or wetlands).

Intensive management: Small-scale tree management that focuses on individual tree maintenance; e.g. street and yard trees.

Invasive species: Species of flora and fauna that, when present in an ecosystem, are able to spread aggressively and may become dominant. Non-native invasive species (e.g. European buckthorn), which are introduced as a result of human activity, are present in an ecosystem outside of their natural range and therefore have few or no natural predators or controls to limit their spread. As a result, they often out-compete native species, reduce overall species diversity, and negatively affect ecosystem functioning. Native invasive species (e.g. goldenrod spp.) are often species that become established in disturbed environments and create an early successional stage that, over time, will change naturally into a climax ecosystem.

Leaf area density: An estimation of the surface area of the leaves growing on a given unit of land; calculated using data recorded during a sample tree inventory and extrapolated to represent the portion of land covered by the inventory. This measurement provides more information on forest structure and function than canopy cover.

Native species: Species of flora and fauna that are indigenous to a particular locality or region, regardless of political or jurisdictional boundaries.

Natural heritage: Natural features deemed significant for their common cultural, economic, historical, or ecological importance and therefore deserving of continuous preservation or conservation.

Natural system: Self-regulating features of the landscape that precede large scale human development and that exist with minimal intervention by humans; e.g. ravines, natural forests.

Non-native species: Species of flora and fauna growing in an area outside of their natural range. Non-native species may originate in foreign countries (also called **exotic species**), or they may originate from other areas of the same country or province. For example, horsechestnut, native to eastern Europe, is non-native in Canada; pitch pine (*Pinus rigida*) is native to eastern Ontario, but is non-native in the Greater Toronto Area.

Positive feedback loop: A cycle in which a discernible cause produces an increase within a system, which feeds into the initial cause, thereby increasing the magnitude of its effects.

Riparian zone: An area of land adjacent to a river, forming a buffer between land and water. Riparian zones play important ecological roles in river habitats, such as erosion control and sediment filtration, and usually contain unique types of vegetation adapted to wet conditions.

Root zone: The three-dimensional area under the ground surface occupied by a tree's roots and from which they derive nutrients and water. The majority of a tree's roots are in the upper 6 inches of soil where water and nutrients are most readily absorbed. A natural and uninhibited root zone typically extends well beyond the **drip line**. Soil compaction and constrained root zones have negative effects on tree growth and vitality.

Soil profile: The accumulated distinct horizontal layers of soil (called horizons) that have developed as a result of natural weathering and deposition of nutrients, water, air, and organic matter. Soil profiles vary according to a number of factors, but in southern Ontario, healthy soil profiles under most conditions typically consist of layers (horizons) of organic matter, topsoil, subsoil, and parent material. Additional layers may also exist.

Species Diversity: A crucial element of ecological resiliency, in other words an ecosystem's capacity to recover quickly from disturbances.

Tree inventory: A systematic catalogue of trees typically created as a census and/or for forest management. Usually includes detailed information on tree species, size, condition, etc.

Urban forest: The totality of the trees, shrubs, grasses, and plants, along with their associated fungi, microbes, soils, insects, and wildlife, that exist in developed areas of settled human populations and their zones of influence. Includes intensively managed street and yard trees, and extensively managed woodlots.

Urban heat island: The effect of heat intensification in urban zones caused by the high proportion of impervious ground cover and building materials (e.g. asphalt, concrete, buildings) and the relatively low proportion of tree cover. Urban surface temperatures increase due to the high heat absorption and retention properties of impervious materials. Higher surface temperature can then lead to higher air temperatures as the heat retained in impervious materials is slowly emitted.

Urban nature: Natural features that exist within areas of settled human populations and their zone of influence, and which are valued for recreation, education, and natural ecosystem services.

Appendix C: Land Use Categories

MPAC Code	Description
	OPEN SPACE
103	Municipal park (excludes Provincial parks, Federal parks, Campgrounds)
490	Golf Course
702	Cemetery
491	Ski Resort
382	Mobile home park – more than one mobile home on a parcel of land, which is a mobile park operation.
486	Campground
109	Large land holdings, greater than 1000 acres
703	Cemetery with non-internment services
	RESIDENTIAL LOW
301	Single family detached (not on water)
302	More than one structure used for residential purposes with at least one of the structures occupied permanently
303	Residence with a commercial unit
304	Residence with a commercial/ industrial use building
305	Link home – are homes linked together at the footing or foundation by a wall above or below grade.
307	Community lifestyle (not a mobile home park) – Typically, a gated community under single ownership.
309	Freehold Townhouse/Row house – more than two units in a row with separate ownership
311	Semi-detached residential – two residential homes sharing a common center wall with separate ownership.
313	Single family detached on water – year round residence
314	Clergy Residence
322	Semi-detached residence with both units under one ownership – two residential homes sharing a common center wall.
332	Typically a Duplex – residential structure with two self-contained units.
363	House-keeping cottages - no American plan – typically a mini resort where you rent a cabin. No package plan available. All activities, meals, etc. are extra.
364	House-keeping cottages - less than 50% American plan – typically a mini resort where you rent a cabin and package plans are available. Activities, meals, etc. maybe included.
365	Group Home as defined in Claus 240(1) of the Municipal Act, 2001 – a residence licensed or funded under a federal or provincial statute for the accommodation of three to ten persons, exclusive of staff, living under supervision in a single housekeeping unit and who, by reason of their emotional, mental, social or physical condition or legal status, require a group living arrangement for their well b eing.
366	Student housing (off campus) – residential property licensed for rental by students.
381	Mobile home – one or more mobile home on a parcel of land, which is not a mobile home park operation.
382	Mobile home park – more than one mobile home on a parcel of land, which is a mobile park operation.
383	Bed and breakfast establishment
	RESIDENTIAL MEDIUM

127	Townhouse block - freehold units
350	Row housing, with three to six units under single ownership
352	Row housing, with seven or more units under single ownership
333	Residential property with three self-contained units
334	Residential property with four self-contained units
335	Residential property with five self-contained units
336	Residential property with six self-contained units
360	Rooming or boarding house – rental by room/bedroom , tenant(s) share a kitchen, bathroom and living quarters.
361	Bachelorette, typically a converted house with 7 or more self-contained units
373	Cooperative housing – equity – Equity Co-op corporations are owned by shareholders. The owners of shares do not receive title to a unit in the building, but acquire the exclusive use of a unit and are able to participate in the building's management.
	RESIDENTIAL HIGH
340	Multi-residential, with 7 or more self-contained units (excludes row-housing)
370	Residential Condominium Unit
341	Multi-residential, with 7 or more self-contained residential units, with small commercial unit(s)
378	Residential Leasehold Condominium Corporation – single ownership of the development where the units are leased.
	COMMERCIAL AND INDUSTRIAL
400	Small Office building (generally single tenant or owner occupied under 7,500 s.f.)
401	Small Medical/dental building (generally single tenant or owner occupied under 7,500 s.f.)
402	Large office building (generally multi - tenanted, over 7,500 s.f.)
403	Large medical/dental building (generally multi - tenanted over 7,500 s.f.)
405	Office use converted from house
406	Retail use converted from house
407	Retail lumber yard
408	Freestanding Beer Store or LCBO - not associated with power or shopping centre
409	Retail - one storey, generally over 10,000 s.f.
410	Retail - one storey, generally under 10,000 s.f.
411	Restaurant - conventional
412	Restaurant - fast food
413	Restaurant - conventional, national chain
414	Restaurant - fast food, national chain
415	Cinema/movie house/drive-in
416	Concert hall/live theatre
417	Entertainment complex - with a large cinema as anchor tenant
419	Automotive service centre, highway - 400 series highways
420	Automotive fuel station with or without service facilities
421	Specialty automotive shop/auto repair/ collision service/car or truck wash
422	Auto dealership
423	Auto dealership - independent dealer or used vehicles
425	Neighbourhood shopping centre - with more than two stores attached, under one ownership, with anchor - generally less than 150,000 s.f.
426	Small box shopping centre less than 100,000 s.f. minimum 3 box stores with one anchor
427	Big box shopping/power centre greater than 100,000 s.f. with 2 or more main anchors such as discount or grocery stores with a collection of box or strip stores and in a commercial concentration concept

428	Regional shopping centre
429	Community shopping centre
430	Neighbourhood shopping centre - with more than 2 stores attached, under one ownership, without anchor - generally less than 150,000 s.f.
431	Department store
432	Banks and similar financial institutions, including credit unions - typically single tenanted, generally less than 7,500 s.f.
433	Banks and similar financial institutions, including credit unions - typically multi tenanted, generally greater than 7,500 s.f.
434	Freestanding supermarket
435	Large retail building centre, generally greater than 30,000 s.f.
436	Freestanding large retail store, national chain - generally greater than 30,000 s.f.
438	Neighbourhood shopping centre with offices above
441	Tavern/public house/small hotel
444	Full service hotel
445	Limited service hotel
446	Apartment hotel
447	Condominium Hotel Unit
450	Motel
451	Seasonal motel
460	Resort hotel
461	Resort lodge
462	Country inns & small inns
463	Fishing/hunting lodges/resorts
465	Child and community oriented camp/resort
470	Multi-type complex - defined as a large multi-use complex consisting of retail/office and other uses (multi res/condominium/hotel)
471	Retail or office with residential unit(s) above or behind - less than 10,000 s.f. gross building area (GBA), street or onsite parking, with 6 or less apartments, older downtown core
472	Retail or office with residential unit(s) above or behind - greater than 10,000 s.f. GBA, street or onsite parking, with 7 or more apartments, older downtown core
473	Retail with more than one non-retail use
475	Commercial condominium
476	Commercial condominium (live/work)
477	Retail with office(s) - less than 10,000 s.f., GBA with offices above
478	Retail with office(s) - greater than 10,000 s.f., GBA with offices above
480	Surface parking lot - excludes parking facilities that are used in conjunction with another property
481	Parking garage - excludes parking facilities that are used in conjunction with another property
482	Surface parking lot - used in conjunction with another property
483	Parking garage - used in conjunction with another property
705	Funeral Home
711	Bowling alley
713	Casino
704	Crematorium
105	Vacant commercial land
106	Vacant industrial land
	UTILITIES AND TRANSPORTATION
496	Communication buildings
555	O.P.G. Hydraulic Generating Station

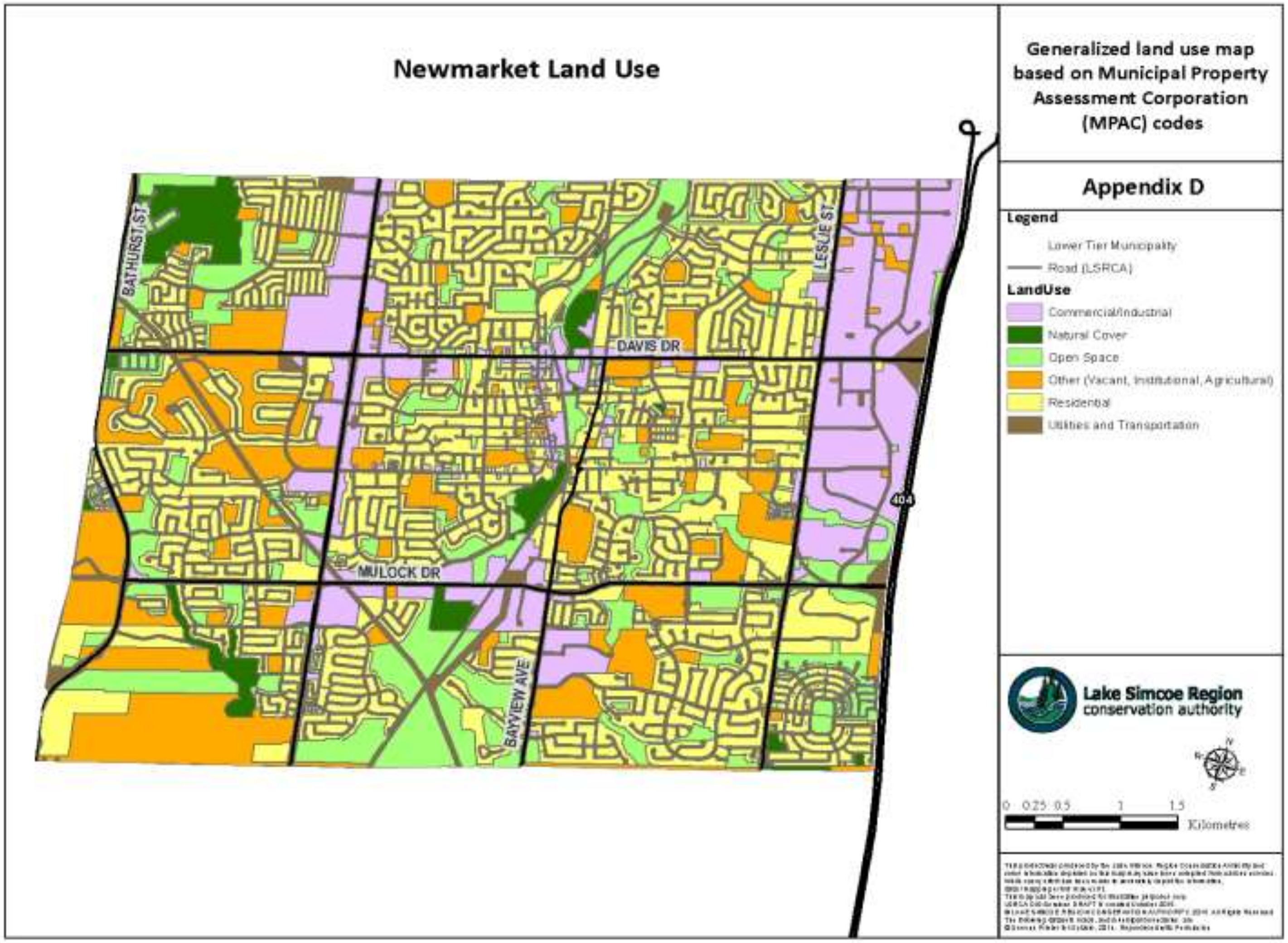
556	O.P.G. Nuclear Generating Station
557	O.P.G. Fossil Generating Station
558	Hydro One Transformer Station
559	MEU Generating Station
560	MEU Transformer Station
561	Hydro One Right-of-Way
562	Private Hydro Rights-of-Way
563	Private Hydraulic Generating Station
564	Private Nuclear Generating Station
565	Private Generating Station (Fossil Fuels and Cogen)
566	Private Transformer Station
567	Wind Turbine
741	Airport Authority
742	Public transportation - easements and rights
743	International bridge/tunnel
588	Pipelines - transmission, distribution, field & gathering and all other types including distribution connections
589	Compressor station - structures and turbines used in connection with transportation and distribution of gas
597	Railway right-of-way
598	Railway buildings and lands described as assessable in the Assessment Act
599	GO transit station/rail yard
737	Federal airport
738	Provincial airport
739	Local government airport
740	Airport leasehold
744	Private airport/hangar
745	Recreational airport
746	Subway station
748	Transit garage
749	Public transportation - other
755	Lighthouses
824	Government - wharves and harbours
826	Government - special educational facility
828	Government - canals and locks
830	Government - navigational facilities
832	Government - historic site or monument
840	Port authority - port activities
842	Port authority - other activities
495	Communication towers - with or without secondary communication structures
155	Land associated with power dam
	INSTITUTIONAL
601	Post-secondary education - university, community college, etc
602	Multiple occupancy educational institutional residence located on or off campus
605	School (elementary or secondary, including private)
608	Day Care
610	Other educational institution (e.g. schools for the blind, deaf, special education, training)
611	Other institutional residence
621	Hospital, private or public
623	Continuum of care seniors facility
624	Retirement/nursing home (combined)
625	Nursing home
626	Old age/retirement home

627	Other health care facility
630	Federal penitentiary or correctional facility
631	Provincial correctional facility
632	Other correctional facility
700	Place of worship - with a clergy residence
701	Place of Worship - without a clergy residence
730	Museum and/or art gallery
731	Library and/or literary institutions
733	Convention, conference, congress centre
734	Banquet hall
735	Assembly hall, community hall
736	Clubs - private, fraternal
750	Scientific, pharmaceutical, medical research facility (structures predominantly other than office)
760	Military base or camp (CFB)
761	Armoury
762	Military education facility
805	Post office or depot
806	Postal mechanical sorting facility
810	Fire Hall
812	Ambulance Station
815	Police Station
822	Government - agricultural research facility - predominantly non-farm property (office building, laboratories)
	AGRICULTURE
200	Farm property without any buildings/structures
201	Farm with residence - with or without secondary structures; no farm outbuildings
210	Farm without residence - with secondary structures; with farm outbuildings
211	Farm with residence - with or without secondary structures; with farm outbuildings
220	Farm without residence - with commercial/industrial operation
221	Farm with residence - with commercial/industrial operation
222	Farm with a winery
223	Grain/seed and feed operation
224	Tobacco farm
225	Ginseng farm
226	Exotic farms i.e emu, ostrich, pheasant, bison, elk, deer
227	Nut Orchard
228	Farm with gravel pit
229	Farm with campground/mobile home park
230	Intensive farm operation - without residence
231	Intensive farm operation - with residence
232	Large scale greenhouse operation
233	Large scale swine operation
234	Large scale poultry operation
235	Government - agriculture research facility - predominately farm property
236	Farm with oil/gas well(s)
260	Vacant residential/commercial/ industrial land owned by a non-farmer with a portion being farmed
261	Land owned by a non-farmer improved with a non-farm residence with a portion being farmed
262	Land owned by a farmer improved with a non-farm residence with a portion being farmed

	NATURAL COVER
240	Managed forest property, vacant land not on water
241	Managed forest property, vacant land on water
242	Managed forest property, seasonal residence not on water
243	Managed forest property, seasonal residence on water
244	Managed forest property, residence not on water
245	Managed forest property, residence on water
107	Provincial park
108	Federal park
134	Land designated and zoned for open space
102	CA lands
	OTHER
120	Water lot (entirely under water)
492	Marina - located on waterfront - defined as a commercial facility for the maintenance, storage, service and/or sale of watercraft
493	Marina - not located on waterfront - defined as a commercial facility for the maintenance, storage, service and/or sale of watercraft
487	Billboard
111	Island under single ownership
385	Time-share, fee simple
386	Time share, right-to-use
391	Seasonal/recreational dwelling - first tier on water
392	Seasonal/recreational dwelling - second tier to water
395	Seasonal/recreational dwelling - not located on water
150	Mining lands - patented
151	Mining lands - unpatented
130	Non-buildable land (walkways, buffer/berm, storm water management pond,etc)
100	Vacant residential land not on water
101	Second tier vacant lot – refers to location not being directly on the water but one row back from the water
368	Residential Dockominium – owners receive a deed and title to the boat slip. Ownership is in fee simple title and includes submerged land and air rights associated with the slip. Similar to condominium properties, all common elements are detailed in the declaration.
306	Boathouse with residence above
110	Vacant residential/recreational land on water
140	Common land
375	Co-ownership – percentage interest/share in the co-operative housing.
371	Life Lease - No Redemption. Property where occupants have either no or limited redemption amounts. Typically Zero Balance or Declining Balance Life Lease Types.
372	Life Lease - Return on Invest. Property where occupants can receive either a guaranteed return or a market value based return on the investment. Typically, represented by Fixed Value, Indexed-Based, or Market Value Life Lease Types.
715	Race track, auto
716	Racetrack - horse, with slot facility
717	Racetrack - horse, without slot facility
718	Exhibition/fair grounds
720	Commercial sport complex
722	Professional sports complex
725	Amusement park
726	Amusement park - large/regional

710	Recreational sport club – non-commercial (excludes golf clubs and ski resorts)
489	Driving range/golf centre - stand alone, not part of a regulation golf course
721	Non-commercial sports complex
112	Multi-residential vacant land
113	Condominium development land - residential (vacant lot)
114	Condominium development land – non-residential (vacant lot)
115	Property in process of redevelopment utilizing existing structure(s)
125	Residential development land
379	Residential phased condominium corporation – condominium project is registered in phases.
369	Vacant land condominium (residential - improved) – condo plan registered against the land.
374	Cooperative housing - non-equity – Non-equity Co-op corporations are not owned by individual shareholders, the shares are often owned by groups such as unions or non-profit organizations which provide housing to the people they serve. The members who occupy the co-operative building do not hold equity in the corporation. Members are charged housing costs as a result of occupying a unit.
169	Vacant land condominium (residential)-defined land that’s described by a condominium plan
377	Condominium parking space/unit – separately deeded.
376	Condominium locker unit – separately deeded.
380	Residential common elements condominium corporation – consists only of the common elements not units

Appendix D: Generalized land use map based on Municipal Property Assessment Corporation (MPAC) codes.



Appendix E: i-Tree Eco Model – Detailed Methodology

Adapted from: Nowak *et al.* 2008. A Ground-based Method of Assessing Urban Forest Structure and Ecosystem Services. Arboriculture and Urban Forestry. 34(6):347-358.

The i-Tree Eco model uses a sampling procedure to estimate various measured structural attributes about the forest (e.g., species composition, number of trees, diameter distribution) within a known sampling error. The model uses the measured structural information to estimate other structural attributes (e.g., leaf area, tree and leaf biomass) and incorporates local environmental data to estimate several functional attributes (e.g., air pollution removal, carbon sequestration, building energy effects). Economic data from the literature is used to estimate the value of some of the functions. The model has 5 modules:

1: Urban Forest Structure

Urban forest structure is the spatial arrangement and characteristics of vegetation in relation to other objects (e.g., buildings) within urban areas (e.g., Nowak 1994a). This module quantifies urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass), value, diversity, and potential risk to pests.

Sampling

i-Tree Eco assessments have used two basic types of sampling to quantify urban forest structure: randomized grid and stratified random sampling. With the randomized grid sampling the study area is divided into equal-area grid cells based on the desired number of plots and then one plot is randomly located within each grid cell. The study area can then be subdivided into smaller units of analysis (i.e., strata) after the plots are distributed (post-stratification). Plot distribution among the strata will be proportional to the strata area. This random sampling approach allows for relatively easy assessment of changes through future measurements (urban forest monitoring), but likely at the cost of increased variance (uncertainty) of the population estimates.

With stratified random sampling, the study area is stratified prior to distributing the plots and plots are randomly distributed within each stratum (e.g., land use). This process allows the user to distribute the plots among the strata to potentially decrease the overall variance of the population estimate. For example, since tree effects are often the primary focus of sampling, the user can distribute more plots into strata that have more trees. The disadvantage of this approach is that it makes long-term change assessments more difficult due to the potential for strata to change through time.

There is no significant difference in cost or time to establish plots regardless of sampling methods for a fixed number of plots. However, there are likely differences in estimate precision. Pre-stratification, if done properly, can reduce overall variance as it can focus more plots in areas of higher variability. Any plot size can be used in i-Tree ECO, but the typical plot size used is 0.04 ha (0.1 ac). The number and size of plots will affect total cost of the data collection as well as the variance of the estimates (Nowak *et al.* 2008).

Data Collection Variables

There are four general types of data collected on an i-Tree Eco plot: 1) general plot information (Table 1) – used to identify the plot and its general characteristics, 2) shrub information (Table 2) - used to estimate shrub leaf area/biomass, pollution removal and volatile organic compound (VOC) emissions by shrubs, 3) tree information (Table 3) – used to estimate forest structural attributes, pollution removal, VOC emissions, carbon storage and sequestration, energy conservation effects, and potential pest impacts of trees, and 4) ground cover data - used to estimate the amount and distribution of various ground cover types in the study area.

Typically, shrubs are defined as woody material with a diameter at breast height (dbh; diameter of stem at height of 1.3m from ground) less than 2.54 cm, while trees have a dbh greater than or equal to 2.54 cm (1 in). Trees and shrubs can also be differentiated by species (i.e., certain species are always a tree or always a shrub), or with a different dbh minimum threshold. For example, in densely forested areas, increasing the minimum dbh to 12.7 cm (5 in.) can substantially reduce the field work by decreasing the number of trees measured, but less information on trees will be attained. Woody plants that are not 30.5 cm (12 in) in height are considered herbaceous cover (e.g., seedlings). Shrub masses within each plot are divided into groups of same species and size, and for each group, appropriate data are collected (Table 2). Tree variables (Table 3) are collected on every measured tree.

Field data are collected during the summer leaf-on season in order to accurately assess crown parameters and tree condition. More detailed information on plot data collection methods and equipment can be found in the i-Tree User's Manual (i-Tree 2012).

Leaf area and leaf biomass

Leaf area and leaf biomass of individual open-grown trees (crown light exposure (CLE) of 4-5) are calculated using regression equations for deciduous urban species (Nowak 1996). If shading coefficients (per cent light intensity intercepted by foliated tree crowns) used in the regression did not exist for an individual species, genus or hardwood averages are used. For deciduous trees that are too large to be used directly in the regression equation, average leaf-area index (LAI: m^2 leaf area per m^2 projected ground area of canopy) is calculated by the regression equation for the maximum tree size based on the appropriate height-width ratio and shading coefficient class of the tree. This LAI is applied to the ground area (m^2) projected by the tree's crown to calculate leaf area (m^2). For deciduous trees with height-to-width ratios that are too large or too small to be used directly in the regression equations, tree height or width is scaled downward to allow the crown to the reach maximum (2) or minimum (0.5) height-to-width ratio. Leaf area is calculated using the regression equation with the maximum or minimum ratio; leaf area is then scaled back proportionally to reach the original crown volume.

For conifer trees (excluding pines), average LAI per height-to-width ratio class for deciduous trees with a shading coefficient of 0.91 is applied to the tree's ground area to calculate leaf area. The 0.91 shading coefficient class is believed to be the best class to represent conifers as conifer forests typically have about 1.5 times more LAI than deciduous forests (Barbour *et al.* 1980) and 1.5 times the average shading coefficient for deciduous trees (0.83, see Nowak 1996) is equivalent to LAI of the 0.91 shading coefficient. Because pines have lower LAI than other conifers and LAI that are comparable to hardwoods (e.g., Jarvis and Leverenz 1983; Leverenz and Hinckley 1990), the average shading coefficient (0.83) is used to estimate pine leaf area.

Leaf biomass is calculated by converting leaf-area estimates using species-specific measurements of g leaf dry weight/m^2 of leaf area. Shrub leaf biomass is calculated as the product of the crown volume occupied by leaves (m3) and measured leaf biomass factors (g m-3) for individual species (e.g., Winer *et al.* 1983; Nowak 1991). Shrub leaf area is calculated by converting leaf biomass to leaf area based on measured species conversion ratios (m^2 g-1). Due to limitations in estimating shrub leaf area by the crown-volume approach, shrub leaf area is not allowed to exceed a LAI of 18. If there are no leaf-biomass-to-area or leaf-biomass-to-crown-volume conversion factors for an individual species, genus or hardwood/conifer averages are used.

For trees in more forest stand conditions (higher plant competition), leaf area index for more closed canopy positions (CLE = 0-1) is calculated using forest leaf area formula based on the Beer-Lambert Law:

$LAI = \ln(I/Io)/-k$

where I = light intensity beneath canopy; Io = light intensity above canopy; and k = light extinction coefficient (Smith *et al.* 1991). The light extinction coefficients are 0.52 for conifers and 0.65 for hardwoods (Jarvis and Leverenz, 1983). To estimate the tree leaf area (LA):

$LA = [\ln((1-xs)/-k\ ] \times \pi r2$

where xs is average shading coefficient of the species and r is the crown radius. For CLE = 2-3: leaf area is calculated as the average of leaf area from the open-grown (CLE = 4-5) and closed canopy equations (CLE = 0-1).

Estimates of leaf area and leaf biomass are adjusted downward based on crown leaf dieback (tree condition). Trees are assigned to one of 7 condition classes: Excellent (< 1 dieback); Good (1-10 per cent dieback); Fair (11-25 per cent dieback); Poor (26-50 per cent dieback); Critical (51-75 per cent dieback); Dying (76-99); Dead (100 per cent dieback). Condition ratings range between 1 indicating no dieback and 0 indicating 100-per cent dieback (dead tree). Each class between excellent and dead is given a rating between 1 and 0 based on the mid-value of the class (e.g., fair = 11-25 per cent dieback is given a rating of 0.82 or 82-per cent healthy crown). Tree leaf area is multiplied by the tree condition factor to produce the final leaf area estimate.

Species Diversity

A species diversity index (Shannon-Wiener) and species richness (i.e., number of species) (e.g., Barbour 1980), are calculated for living trees for the entire city. The proportion of the tree population that originated from different parts of the country and world is calculated based on the native range of each species (e.g., Hough 1907; Grimm 1962; Platt 1968; Little 1971, 1976, 1977, 1978; Viereck and Little 1975; Preston 1976; Clark 1979; Burns and Honkala 1990a,b; Gleason and Cronquist 1991).

Structural Value

The structural value of the trees (Nowak *et al.*, 2002a) is based on methods from the Council of Tree and Landscape Appraisers (CTLA 1992). Compensatory value is based on four tree/site characteristics: trunk area (cross-sectional area at dbh), species, condition, and location. Trunk area and species are used to determine the basic value, which is then multiplied by condition and location ratings (0-1) to determine the final tree compensatory value. Local species factors, average replacement cost, and transplantable size and replacement prices are obtained from ISA publications. If no species data are available for the state, data from the nearest state are used. Condition factors are based on per cent crown dieback. Available data required using location factors based on land use type (Int. Soc. of Arboric. 1988): golf course = 0.8; commercial/industrial, cemetery and institutional = 0.75; parks and residential = 0.6; transportation and forest = 0.5; agriculture = 0.4; vacant = 0.2; wetland = 0.1.

Insect Effects

The proportion of leaf area and live tree population, and estimated compensatory value in various susceptibility classes to gypsy moth (Liebhold *et al.,* 1995; Onstad *et al.*, 1997), Asian longhorned beetle (e.g., Nowak *et al.*, 2001) and emerald ash borer (ash species) are calculated to reveal potential urban forest damage associated with these pests.

2: Biogenic Emissions

Volatile organic compounds (VOCs) can contribute to the formation of O3 and CO (e.g., Brasseur and Chatfield 1991). The amount of VOC emissions depends on tree species, leaf biomass, air temperature, and other environmental factors. This module estimates the hourly emission of isoprene (C5H8), monoterpenes (C10 terpenoids), and other volatile organic compounds (OVOC) by species for each land use and for the entire city. Species leaf biomass (from the structure module) is multiplied by genus-specific emission factors (Nowak *et al.,* 2002b) to produce emission levels standardized to 30oC (86oF) and photosynthetically active radiation (PAR) flux of 1,000 µmol m-2 s-1. If genus-specific information is not available, then median emission values for the family, order, or superorder are used. Standardized emissions are converted to actual emissions based on light and temperature correction factors (Geron *et al.,* 1994) and local meteorological data. As PAR strongly controls the isoprene emission rate, PAR is estimated at 30 canopy levels as a function of above-canopy PAR using the sunfleck canopy environment model (A. Guenther, Nat. Cent. for Atmos. Res. pers. comm. 1998) with the LAI from the structure calculations.

Hourly inputs of air temperature are from measured National Climatic Data Center (NCDC) meteorological data. Total solar radiation is calculated based on the National Renewable Energy Laboratory Meteorological/Statistical Solar Radiation Model (METSTAT) with inputs from the NCDC data set (Maxwell 1994). PAR is calculated as 46 per cent of total solar radiation input (Monteith and Unsworth 1990).

Because tree transpiration cools air and leaf temperatures and thus reduces biogenic VOC emissions, tree and shrub VOC emissions are reduced in the model based on air quality modeling results (Nowak *et al.,* 2000). For the modeling scenario analyzed (July 13-15, 1995) increased tree cover reduced air temperatures by 0.3o to 1.0oC resulting in hourly reductions in biogenic VOC emissions of 3.3 to 11.4 per cent. These hourly reductions in VOC emissions are applied to the tree and shrub emissions during the in-leaf season to account for tree effects on air temperature and its consequent impact on VOC emissions.

3: Carbon Storage and Annual Sequestration

This module calculates total stored carbon, and gross and net carbon sequestered annually by the urban forest. Biomass for each measured tree is calculated using allometric equations from the literature (see Nowak 1994c; Nowak *et al.,* 2002b). Equations that predict above-ground biomass are converted to whole tree biomass based on root-to-shoot ratio of 0.26 (Cairns *et al.,* 1997). Equations that compute fresh-weight biomass are multiplied by species- or genus- specific-conversion factors to yield dry-weight biomass. These conversion factors, derived from average moisture contents of species given in the literature, averaged 0.48 for conifers and 0.56 for hardwoods (see Nowak *et al.,* 2002b).

Open-grown, maintained trees tend to have less above-ground biomass than predicted by forest-derived biomass equations for trees of the same dbh (Nowak 1994c). To adjust for this difference, biomass results for urban trees are multiplied by a factor 0.8 (Nowak 1994c). No adjustment is made for trees found in more natural stand conditions (e.g., on vacant lands or in forest preserves). Since deciduous trees drop their leaves annually, only carbon stored in wood biomass is calculated for these trees. Total tree dry-weight biomass is converted to total stored carbon by multiplying by 0.5 (Forest Products Lab 1952; Chow and Rolfe 1989).

The multiple equations used for individual species were combined together to produce one predictive equation for a wide range of diameters for individual species. The process of combining the individual formulas (with limited diameter ranges) into one, more general, species formula produced results that were typically within 2% of the original estimates for total carbon storage of the urban forest (i.e., the estimates using the multiple equations). Formulas were combined to prevent disjointed sequestration estimates that can occur when calculations switch between individual biomass equations.

If no allometric equation could be found for an individual species the average of results from equations of the same genus is used. If no genus equations are found, the average of results from all broadleaf or conifer equations is used.

To estimate monetary value associated with urban tree carbon storage and sequestration, carbon values are multiplied by $22.8/tonne of carbon ($20.7/ton of carbon) based on the estimated marginal social costs of carbon dioxide emissions for 2001-2010 (Fankhauser 1994).

Urban Tree Growth and Carbon Sequestration

To determine a base growth rate based on length of growing season, urban street tree (Frelich, 1992; Fleming 1988; and Nowak 1994c), park tree (DeVries 1987), and forest growth estimates (Smith and Shifley 1984) were standardized to growth rates for 153 frost free days based on: Standardized growth = measured growth x (153/ number of frost free days of measurement).

Average standardized growth rates for street (open-grown) trees were 0.83 cm/yr (0.33 in/yr). Growth rates of trees of the same species or genera were then compared to determine the average difference between standardized street tree growth and standardized park and forest growth rates. Park growth averaged 1.78 times less than street trees, and forest growth averaged 2.29 times less than street tree growth. Crown light exposure measurements of 0-1 were used to represent forest growth conditions; 2-3 for park conditions; and 4-5 for open-grown conditions. Thus, the standardized growth equations are:

Standardized growth (SG) = 0.83 cm/yr (0.33 in/yr) x number of frost free days / 153

and for: CLE 0-1: Base growth = SG / 2.26; CLE 2-3: Base growth = SG / 1.78; and

CLE 4-5: Base growth = SG.

Base growth rates are adjusted based on tree condition. For trees in fair to excellent condition, base growth rates are multiplied by 1 (no adjustment), poor trees' growth rates are multiplied by 0.76, critical trees by 0.42, dying trees by 0.15, and dead trees by 0. Adjustment factors are based on per cent crown dieback and the assumption that less than 25-per cent crown dieback had a limited effect on dbh growth rates. The difference in estimates of carbon storage between year *x* and year *x+1* is the gross amount of carbon sequestered annually.

4: Air Pollution Removal

This module quantifies the hourly amount of pollution removed by the urban forest, its value, and associated per cent improvement in air quality throughout a year. Pollution removal and per cent air quality improvement are calculated based on field, pollution concentration, and meteorological data.

This module is used to estimate dry deposition of air pollution (i.e., pollution removal during nonprecipitation periods) to trees and shrubs (Nowak *et al.,* 1998, 2000). This module calculates the hourly dry deposition of ozone (O3), sulfur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), and particulate matter less than 10 microns (PM10) to tree and shrub canopies throughout the year based on tree-cover data, hourly Ontario Ministry of the Environment weather data, and U.S. Environmental Protection Agency (EPA) pollution-concentration monitoring data.

The pollutant flux (F; in g m -2 s-1) is calculated as the product of the deposition velocity (Vd; in m s-1) and the pollutant concentration (C; in g m-3):

Deposition velocity is calculated as the inverse of the sum of the aerodynamic (Ra), quasi-laminar boundary layer (Rb) and canopy (Rc) resistances (Baldocchi *et al.,* 1987):

Hourly meteorological data from the closest weather station (usually airport weather stations) are used in estimating Ra and Rb. In-leaf, hourly tree canopy resistances for O3, SO2, and NO2 are calculated based on a modified hybrid of big-leaf and multilayer canopy deposition models (Baldocchi *et al.,* 1987; Baldocchi 1988).

As CO and removal of particulate matter by vegetation are not directly related to transpiration, Rc for CO is set to a constant for in-leaf season (50,000 s m-1 (15,240 s ft-1)) and leaf-off season (1,000,000 s m-1 (304,800 s ft-1)) based on data from Bidwell and Fraser (1972). For particles, the median deposition velocity from the literature (Lovett 1994) is 0.0128 m s-1 (0.042 ft s-1) for the in-leaf season. Base particle Vd is set to 0.064 m s-1 (0.021 ft s-1) based on a LAI of 6 and a 50-per cent resuspension rate of particles back to the atmosphere (Zinke 1967). The base Vd is adjusted according to actual LAI and in-leaf vs. leaf-off season parameters. Bounds of total tree removal of O3, NO2, SO2, and PM10 are estimated using the typical range of published in-leaf dry deposition velocities (Lovett 1994). Per cent air quality improvement is estimated by incorporating local or regional boundary layer height data (height of the pollutant mixing layer). More detailed methods on module can be found in Nowak *et al.* 2006a.

The monetary value of pollution removal by trees is estimated using the median externality values for the United States for each pollutant. These values, in dollars per tonne (metric ton: mt) are: NO2 = $6,752 mt-1 ($6,127 t-1), PM10 = $4,508 mt-1 ($4,091 t-1), SO2 = $1,653 mt-1

($1,500 t-1), and CO = $959 mt-1 ($870 t-1) (Murray *et al.,* 1994). Recently, these values were adjusted to 2007 values based on the producer’s price index (Capital District Planning Commission 2008) and are now (in dollars per metric ton (t)): NO2 = $9,906 mt-1 ($8,989 t-1), PM10 = $6,614 mt-1 ($6,002 t-1), SO2 = $2,425 mt-1 ($2,201 t-1), and CO = $1,407 mt-1 ($1,277 t-1). Externality values for O3 are set to equal the value for NO2.

5: Building Energy Effects

This module estimates the effects of trees on building energy use and consequent emissions of carbon from power plants. Methods for these estimates are based on a report by McPherson and Simpson (1999). Distance and direction to the building is recorded for each tree within 18.3 m (60 ft) of two or one-story residential buildings. Any tree that is smaller than 6.1 meters (20 ft) in height or farther than 18.3 meters (60 ft) from a building is considered to have no effect on building energy use.

Using the tree size, distance, direction to building, climate region, leaf type (deciduous or evergreen) and per cent cover of buildings and trees on the plot, the amount of carbon avoided from power plants due to the presence of trees is calculated. The amount of carbon avoided is categorized into the amount of MWh (cooling), and MBtus and MWh (heating) avoided due to tree energy effects. Default energy effects per tree are set for each climate region, vintage building types (period of construction), tree size class, distance from building, energy use (heating or cooling) and/or leaf type (deciduous or evergreen) depending upon the energy effect of the tree (tree shade, windbreak effects, and local climate effect) (McPherson and Simpson 1999). Default shading and climate effect values are applied to all trees;

heating windbreak energy effects are assigned to each evergreen tree. As shading effect default values are given for only one vintage building type (post-1980), vintage adjustment factors (McPherson and Simpson 1999) are applied to obtain shading effect values for all other vintage types.

Tree Condition Adjustment

The default energy effect values (McPherson and Simpson 1999) are adjusted for the tree condition as follows:

Energy adjustment = 0.5 + (0.5 x tree condition)

where tree condition = 1 - % dieback. This adjustment factor is applied to all tree energy effects for cooling, but only evergreen trees for the heating energy use effects as deciduous trees are typically out-of-leaf during the heating season.

Local Climate Effects

The individual tree effect on climate diminishes as tree cover increases in an area, though the total effect of all trees can increase. Base climate effect values for a tree are given for plots of 10, 30 and 60% cover (McPherson and Simpson 1999). Interpolation formulas (McPherson and Simpson 1999) are used to determine the actual tree value based on the specific plot per cent tree and building cover. For plots with less than 10% cover, the slope between the 10 and 30% cover values are used for the interpolation. Plots with per cent cover greater than 60% used the slope between 30 and 60% cover with a minimum individual tree climate effect of one-third the effect at 60% cover. This minimum is set to prevent a tree from obtaining a negative effect at high cover.

The total shading, windbreak, and climate energy effects due to trees on a plot are calculated by summing the individual tree's energy effects for the particular energy use and housing vintage. These values are adjusted for the distribution of the different vintage types within the climate region (McPherson and Simpson 1999).

Since the default cooling energy effects are determined based on the climate regions' electricity emissions factors it is necessary to convert the cooling energy effects to the state specific equivalent. This conversion is accomplished by multiplying the plot cooling energy effects by the ratio of the state specific electricity emissions factor to the climate region's electricity emissions factor (McPherson & Simpson 1999).

Home heating source distribution (e.g., fuel oil, heat pump, electricity, and natural gas) for the region is used to partition the carbon emissions from heating to the appropriate energy source. Standard conversion factors (t CO2 / MWh, t CO2 / MBtu) are used to convert the energy effect from t CO2 to units of energy saved (MBtus, MWh). Cooling and heating electricity use (MWh) had state specific conversion factors; non-electrical heating fuels (MBtus) used a standard conversion factor because this factor does not vary by region (McPherson and Simpson 1999). Total plot effects are combined to yield the total energy and associated carbon effect due to the urban forest.

References:

Barbour, M.G, J.H. Burk, and W.D. Pitts. 1980. Terrestrial plant ecology. Menlo Park, CA: Benjamin/Cummings. 604 p.

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

Baldocchi, D.D., B.B. Hicks, P. Camara. 1987. A canopy stomatal resistance model for gaseous deposition to vegetated surfaces. Atmospheric Environment. 21: 91-101.

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

Boyd, J.B. 1983. Natural Reproduction of Exotic and Indigenous Trees in Three Urban Environments. M.S. Thesis, Univ. of Wisconsin, Milwaukee, WI. 97 pp.

Brasseur, G.P. and R.B. Chatfield. 1991. The fate of biogenic trace gases in the atmosphere. In: Sharkey, T.D., E.A. Holland, and H.A. Mooney, eds. Trace gas emissions by plants. New York: Academic Press: 1-27.

Burns, R.M. and B.H. Honkala. 1990a. Silvics of North America. Vol. 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture. 675 p.

Burns, R.M. and B.H. Honkala. 1990b. Silvics of North America. Vol. 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture. 877 p.

Buckelew Cumming, A., D.J. Nowak, D.B. Twardus, R. Hoehn, M. Mielke, and R. Rideout. 2007. Urban Forests of Wisconsin 2002: Pilot Monitoring Project 2002. USDA Forest Service, Northeastern Area State and Private Forestry Report, NA-FR-05-07. 33 p. http://www.treesearch.fs.fed.us/pubs/12685 Last accessed June 2008.

Cairns, M.A., S. Brown, E.H. Helmer, and G.A. Baumgardner. 1997. Root biomass allocation in the world's upland forests. Oecologia. 111: 1-11.

The Capital District Regional Planning Commission. 2008. Consumer and producer price indices. http://www.cdrpc.org/CPI_PPI.html Last accessed June 2008.

Chow, P. and G.L. Rolfe. 1989. Carbon and hydrogen contents of short-rotation biomass of five hardwood species. Wood and Fiber Science. 21(1): 30-36.

Clark, D.E. 1979. Sunset New Western Garden Book. Menlo Park, CA: Lane Publ. Co. 512 p.

Council of Tree and Landscape Appraisers. 1992. Guide for plant appraisal. Savoy, IL: International Society of Arboriculture. 103 p.

Derrenbacher, W.E. 1969. Plants and Landscape: An Analysis of Ornamental Planting in Four Berkeley Neighborhoods. Masters thesis, University of California, Berkeley, CA. 231 pp.

deVries, R.E. 1987. A preliminary investigation of the growth and longevity of trees in Central Park. New Brunswick, NJ: Rutgers University 95 p. M.S. thesis.

Dorney, J.R., G.R. Guntenspergen, J.R. Keough, and F. Stearns. 1984. Composition and structure of an urban woody plant community. Urban Ecology. 8:69-90.

Duncan, J.S. Jr. 1973. Landscape taste as a symbol of group identity. Geographical Review 63:334-355.

Dwyer, J.F., E.G. McPherson, H.W. Schroeder, and R.A. Rowntree. 1992. Assessing the benefits and costs of the urban forest. Journal of Arboriculture 18(5):227-234.

Energy Information Administration. 2003a. Sales Revenue Data. 27 Jan 2003.

http://www.eia.doe.gov/electricity/page/sales_revenue.xls. Last accessed April 2003.

Energy Information Administration. 2003b. Energy Markets and End Use. http://www.eia.doe.gov/emeu/states/_states.html. Last accessed April 2003.

Energy Information Administration. 2003c. Natural Gas Monthly. 16 Apr 2003.

http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_monthly/current/pdf/table_15.pdf. Last accessed April 2003.

Energy Information Administration. 2003d. Petroleum Marketing Monthly. Feb

2003. http://www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/petroleum_marketing_monthly/current/pdf/pmmtab18.pdf. Last accessed April 2003.

Energy Information Administration. 2003e. Residential Energy Consumption Survey. 27 Feb 2001. http://www.eia.doe.gov/emeu/consumptionbriefs/recs/heating_oil/region_oil.html. Last accessed April 2003.

Energy Information Administration 2003f. Residential Energy Consumption Survey. 27 Feb 2001. http://eia.doe.gov/emeu/recs/glossary.html. Last accessed April 2003.

Escobedo, F.J, D.J. Nowak, J.E. Wagner, C. Luz de la Maza, and M. Rodriguez. 2006. The socioeconomics and management of Santiago de Chile’s public urban forest. Urban Forestry and Urban Greening. 4:105-114.

Fankhauser, S. 1994. The social costs of greenhouse gas emissions: an expected value approach. The Energy Journal. 15(2): 157-184.

Fleming, L.E. 1988. Growth estimation of street trees in central New Jersey. New Brunswick, NJ: Rutgers University. 143 p. M.S. thesis.

Forest Products Laboratory. 1952. Chemical analyses of wood. Tech. Note 235. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 4 p.

Frelich, L.E. 1992. Predicting dimensional relationships for Twin Cities shade trees. St. Paul, MN: University of Minnesota, Department of Forest Resources. 33 p.

Geron, C.D., A.B. Guenther, and T.E. Pierce. 1994. An improved model for estimating emissions of volatile organic compounds from forests in the eastern United States. Journal of Geophysical Research. 99(D6): 12,773-12,791.

Gilbert, O.L. 1989. The Ecology of Urban Habitats. Chapman and Hall, London. 369 pp.

Gleason, H.A. and A. Cronquist. 1991. Manual of vascular plants of Northeastern United States and Adjacent Canada. Bronx, NY: New York Botanical Garden. 910 p.

Grimm, W.C. 1962. The book of trees. Harrisburg, PA: Stackpole Co. 487 p.

Ham, D., C. Post, D. Vanblaricom, D. Lipscomb, D. Hargett, and D.J. Nowak 2003. Analysis of the explosively urbanizing South Carolina Interstate 85 corridor. Proc. of the 2003 National Urban Forest Conference. San Antonio, TX.

Hough, R.B. 1907. Handbook of the trees of the Northern States and Canada. Lowville, NY: R.B. Hough. 470 p.

Hyams, E.S. 1970. English cottage gardens. Nelson, London, 234 p.

International Society of Arboriculture. 1988. Valuation of landscape trees, shrubs, and other plants. Champaign, IL: International Society of Arboriculture. 50 p.

i-Tree. 2012. i-Tree Eco v5.0 User's Manual. 122 p. http://www.itreetools.org/resources/manuals/Eco_Manual_v5.pdf

Iizumi, S. 1983. The urban vegetation of Tokyo and Sendai, Japan. In: Holzner, W., Werger, M.J., and Ikusima, I. (Eds.) Man's impact on vegetation. Dr. W. Junk Publishers, The Hague. p. 335-340.

Jarvis, P.G. and J.W. Leverenz. 1983. Productivity of temperate, deciduous and evergreen forests. In: Lange, O.L., P.S. Nobel, C.B. Osmond, and H. Ziegler, eds. Physiological plant ecology IV, encyclopedia of plant physiology, volume 12D. Springer-Verlag, Berlin: 233-280.

Jones, A.W. 1957. The flora of the city of London bombed sites. The London Naturalist. 37:189-210.

Jim, C.Y. 1989. The distribution and configuration of tree cover in urban Hong Kong. GeoJournal. 18(2):175-188.

Kinnee, E., C. Geron, and T. Pierce. 1997. United States land use inventory for estimating biogenic ozone precursor emissions. Ecological Applications 7(1):46-58.

Kunick, W. 1982. Comparison of the flora of some cities of the central European lowlands. In: Bornkamm, R., Lee, J.A., and Seaward, M.R. (Eds.) Urban Ecology. Blackwell Science Publication, Oxford. p. 13-22.

Kuo, F.E. and Sullivan, W.C. 2001. Environment and crime in the inner city: does vegetation reduce crime? Environmental Behavior 33(3):343-365.

Leverenz, J.W. and T.M. Hinckley. 1990. Shoot structure, leaf area index and productivity of evergreen conifer stands. Tree Physiology. 6: 135-149.

Liebhold, A.M., K.W. Gottschalk, R. Muzika, M.E. Montgomery, R. Young, K. O'Day, and B. Kelley. 1995. Suitability of North American tree species to the gypsy moth: a summary of field and laboratory tests. Gen. Tech. Rep. NE-211. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 34 p.

Little, E.L. 1971. Atlas of United States trees. Vol. 1. Conifers and important hardwoods. Misc. Pub. 1146. Washington, DC: U.S. Department of Agriculture, Forest Service. 400 p.

Little, E.L. 1976. Atlas of United States trees. Vol. 3. Minor western hardwoods. Misc. Pub. 1314. Washington, DC: U.S. Department of Agriculture, Forest Service. 300 p.

Little, E.L. 1977. Atlas of United States trees. Vol. 4. Minor eastern hardwoods. Misc. Pub. 1342. Washington, DC: U.S. Department of Agriculture, Forest Service. 235 p.

Little, E.L. 1978. Atlas of United States trees. Vol. 5. Florida. Misc. Pub. 1361. Washington, DC: U.S. Department of Agriculture, Forest Service. 138 p.

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

Lozano, J.V. 2004. Distribucion del arbolado urbano en la ciudad de Fuenlabrada y su contribucion a la calidad del aire. Ciudad y Territorio, Estudios Territoriales 36(140):419-427.

Maxwell, E.L. 1994. A meteorological/statistical solar radiation model. In: Proceedings of the 1994 annual conference of the American Solar Energy Society. San Jose, CA: American Solar Energy Society: 421-426.

McBride, J.R., and D.F. Jacobs 1976. Urban forest development: a case study, Menlo Park, California. Urban Ecology. 2:1-14.

McBride, J.R., and D.F. Jacobs 1986. Presettlement forest structure as a factor in urban forest development. Urban Ecology. 9:245-266.

McNeil, J. and C. Vava. 2006. Oakville’s urban forest: Our solution to our pollution. Town of Oakville Report, Oakville, Ontario. 67 p. http://www.oakville.ca/Media_Files/forestry/UFORE.pdf Last accessed June 2008.

McPherson, E.G., 1998. Structure and sustainability of Sacramento’s urban forest. Journal of Arboriculture. 24(4):174-190.

McPherson, E.G. and J.R. Simpson.. 1999. Carbon dioxide reduction through urban forestry: Guidelines for professional and volunteer tree planters. Gen. Tech. Rep. PSW-171. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 237 p.

Miller, P.R., and A.M. Winer 1984. Composition and dominance in Los Angeles Basin urban vegetation.. Urban Ecology. 8:29-54.

Monteith, J.L. and M.H. Unsworth. 1990. Principles of environmental physics. New York: Edward Arnold. 291 p.

Moran, M.A. 1984. Influence of adjacent land use on understory vegetation of New York forests. Urban Ecology. 8:329-340.

Murray F.J., L. Marsh, and P.A. Bradford 1994. New York State Energy Plan, Vol. II: Issue Reports. New York State Energy Office, Albany, NY.

National Center for Atmospheric Research (NCAR). 2008. Model of Emissions of Gases and Aerosols

from Nature (MEGAN). http://bai.acd.ucar.edu/Megan/ Last accessed June 2008.

National Climatic Data Center. 2008. Integrated surface hourly observations. http://ols.nndc.noaa.gov/plolstore/plsql/olstore.prodspecific?prodnum=C00353-CDR-S0001 Last accessed June 2008.

National Oceanic and Atmospheric Administration / U.S. Environmental Protection Agency. 2008. Biogenic Emissions Inventory System (BEIS) Modeling. http://www.epa.gov/asmdnerl/biogen.html. Last accessed June 2008.

New Jersey Department of Environmental Protection. 2002. DEP Announces $1 Million Urban Airshed Reforestation Project From Conectiv Enforcement Settlement. Press release 02/111, 10/26/02. http://www.state.nj.us/dep/newsrel/releases/02_0111.htm. Last accessed June 2008.

Nowak, D.J. 1991. Urban forest development and structure: analysis of Oakland, California. Berkeley, CA: University of California. 232 p. Ph.D. dissertation.

Nowak, D.J. 1994a. Understanding the structure of urban forests. Journal of Forestry. 92(10): 42-46.

Nowak, D.J. 1994b. Urban forest structure: the state of Chicago's urban forest. In: McPherson, E.G, D.J. Nowak and R.A. Rowntree. Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. USDA Forest Service General Technical Report NE-186. pp. 3-18; 140-164.

Noak, D.J. 1994c. Atmospheric carbon dioxide reduction by Chicago's urban forest. In: McPherson, E.G.; Nowak, D.J.; Rowntree, R.A., eds. Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep. NE-186. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 83-94.

Nowak, D.J. 1996. Estimating leaf area and leaf biomass of open-grown deciduous urban trees. Forest Science. 42(4): 504-507.

Nowak, D.J., K.L. Civerolo, S.T. Rao, G. Sistla, C.J. Luley, and D.E. Crane. 2000. A modeling study of the impact of urban trees on ozone. Atmospheric Environment. 34: 1601-1613.

Nowak, D.J. and D.E. Crane. 2000. The urban forest effects (UFORE) model: quantifying urban forest structure and functions. In Hansen M. and T. Burk (Eds.), Proceedings: Integrated tools for natural resources inventories in the 21st century. IUFRO Conference, 16-20 August 1998, Boise, ID. General Technical Report NC-212, U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN. pp. 714-720.

Nowak, D.J. and D.E. Crane. 2002. Carbon storage and sequestration by urban trees in the USA. Environmental Pollution 116(3):381-389.

Nowak, D.J., D.E. Crane, and J.F. Dwyer. 2002a. Compensatory value of urban trees in the United States. Journal of Arboriculture 28(4):194-199

Nowak, D.J., D.E. Crane, and J.C. Stevens. 2006a. Air pollution removal by urban trees and shrubs in the United States. Urban Forestry and Urban Greening 4:115-123.

Nowak, D.J., D.E. Crane, J.C. Stevens, and M. Ibarra. 2002b. Brooklyn's urban forest. General Technical Report NE-290, U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, PA. 107.

Nowak, D.J. and J.F. Dwyer. 2007. Understanding the benefits and costs of urban forest ecosystems. In: Kuser, J. (ed.) Urban and Community Forestry in the Northeast. Springer Science and Business Media. New York. pp. 25-46.

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

Nowak, D.J., R. Hoehn, D.E. Crane, J.C. Stevens, and J.T. Walton. 2006b. Assessing urban forest effects and values: Minneapolis' urban forest. Resource Bulletin NE-166. U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, PA. 20 p.

Nowak, D.J., R. Hoehn, D.E. Crane, J.C. Stevens, and J.T. Walton. 2006c. Assessing urban forest effects and values: Washington DC's urban forest. Resource Bulletin NRS-1. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA. 24 p.

Nowak, D.J., R. Hoehn, D.E. Crane, J.C. Stevens, and J.T. Walton. 2006d. Assessing urban forest effects and values: Casper's urban forest. Resource Bulletin NRS-4. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA. 20 p.

Nowak, D.J., R. Hoehn, D.E. Crane, J.C. Stevens, and J.T. Walton. 2007b. Assessing urban forest effects and values: Philadelphia's urban forest. Resource Bulletin NRS-7. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA. 22 p.

Nowak, D.J., R. Hoehn, D.E. Crane, J.C. Stevens, and J.T. Walton. 2007c. Assessing urban forest effects and values: San Francisco's urban forest. Resource Bulletin NRS-8. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA. 22 p.

Nowak, D.J., R. Hoehn, D.E. Crane, J.C. Stevens, and J.T. Walton. 2007d. Assessing urban forest effects and values: New York City's urban forest. Resource Bulletin NRS-9. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA. 22 p.

Nowak, D.J., P.J. McHale, M. Ibarra, D. Crane, J. Stevens, and C. Luley. 1998. Modeling the effects of urban vegetation on air pollution. In: Gryning, S.E. and N. Chaumerliac (eds.) *Air Pollution Modeling and Its Application XII*. Plenum Press, New York. pp. 399-407.

Nowak, D.J. and P. O'Connor. 2001. Syracuse urban forest master plan: guiding the city's forest resource in the 21st century. *USDA Forest Service General Technical Report*. 50 p.

Nowak, D.J., J. Pasek, R. Sequeira, D.E. Crane, and V. Mastro. 2001. Potential effect of Anoplophora glabripennis (Coleoptera: Cerambycidae) on urban trees in the United States. Journal of Economic Entomology. 94(1):116-122.

Nowak, D.J., R.A. Rowntree, E.G. McPherson, S.M. Sisinni, E. Kerkmann and J.C. Stevens. 1996. Measuring and analyzing urban tree cover. Landscape and Urban Planning 36:49-57.

Nowak, D.J., J.T Walton, J.C. Stevens, D.E. Crane, and R.E. Hoehn. 2008. Effect of plot and sample size on timing and precision of urban forest assessments. Arboriculture and Urban Forestry (in press).

Numata, M. 1977. The impact of urbanization on vegetation in Japan. In: Miyawaki, A., and Tuxen, R. (Eds.) Vegetation Science and Environmental Protection. Maruzen Co. Ltd., Tokyo. p. 161-171.

Onstad, D.W., D.J. Nowak, and M.R. Jeffords. 1997. Potential defoliation of trees by outbreak populations of gypsy moth in the Chicago area. Journal of Arboriculture. 23(2): 57-64.

Peper, P.J. and E.G. McPherson. 1998. Comparison of five methods for estimating leaf area index of open-grown deciduous trees. Journal of Arboriculture. 24(2):98-111.

Platt, R. 1968. Discover American trees. New York: Dodd, Mead and Co. 256 p.

Preston, R.J. 1976. North American trees. Ames, IA: Iowa State University Press. 399 p.

Profous, G. 1984. Forest changes in the Bronx. Journal of Forestry. 82:559-560.

Profous, G., R.A. Rowntree, and R.E. Loeb 1988. The urban forest landscape of Athens, Greece: aspects of structure, planning and management. Arboricultural Journal. 12:83-107.

Richards, N.A., J.R. Mallette, R.J. Simpson, and E.A. Macie. 1984. Residential greenspace and vegetation in a mature city: Syracuse, New York. Urban Ecology. 8:99-125.

Rowntree, R.A. 1984. Forest canopy cover and land use in four eastern United States cities. Urban Ecology. 8:55-67.

Sanders, R.A. 1983. Configuration of tree canopy cover in urban land uses. Geographical Perspectives. 51:49-53.

Santamour, F.S. Jr. 1983. Woody-plant succession in the urban forest: filling cracks and crevices. Journal of Arboriculture. 9:267-270.

Schmid, J.A. 1975. Urban Vegetation: A Review and Chicago Case Study. Research Paper, Dept. of Geography, Univ. of Chicago, Chicago. vol. 161, 266 pp.

Smith, F.W., D.A. Sampson, and J.N. Long. 1991. Comparison of leaf area index estimates from allometrics and measured light interception. Forest Science. 37(6): 1682-1688.

Smith, W.B. and S.R. Shifley. 1984. Diameter growth, survival, and volume estimates for trees in Indiana and Illinois. Res. Pap. NC-257. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 10 p.

Sukopp, H., H.P. Blume, and W. Kunick 1979. The soil, flora, and vegetation of Berlin's waste lands. In: Laurie, I. (Eds.) Nature in Cities. John Wiley and Sons, New York, NY. p. 115-132.

U.S. Department of Labor and Statistics. 2003. Consumer Price Indices. 16 Apr 2003. http://www.ftp.bls.gov/pub/special.requests/cpi/cpiai.txt. Last accessed April 2003.

U.S. Environmental Protection Agency. 2008. Technology Transfer Network (TTN) Air Quality System (AQS). http://www.epa.gov/ttn/airs/airsaqs/detaildata/downloadaqsdata.htm Last accessed June 2008.

Viereck, L.A. and E.L Little. 1975. Atlas of United States trees. Vol. 2. Alaska trees and common shrubs. Misc. Publ. 1293. Washington, DC: U.S. Department of Agriculture, Forest Service. 109 p.

Westphal, L.M.. 2003. Urban greening and social benefits: a study of empowerment outcomes. Journal of Arboriculture. 29(3):137-147.

Whitney, G.G. 1985. A quantitative analysis of the flora and plant communities of a representative midwestern U.S. town. Urban Ecology. 9:143-160.

Winer, A.M.; D.R. Fitz, P.R. Miller, R. Atkinson, D.E. Brown, W.P. Carter, M.C. Dodd, C.W. Johnson, M.A. Myers, K.R. Neisess, M.P. Poe, and E.R. Stephens. 1983. Investigation of the role of natural hydrocarbons in photochemical smog formation in California. Riverside, CA: Statewide Air Pollution Research Center.

Wolf, K.M. 2003. Public response to the urban forest in inner-city business districts. Journal of Arboriculture. 29(3):117-126.

Yang, J., J. McBride, J. Zhou, and Z. Sun. 2005. The urban forest in Beijing and its role in air pollution reduction. Urban Forests and Urban Greening. 3(2): 65-78.

Zinke, P.J. 1967. Forest interception studies in the United States. In: Sopper, W.E.; Lull, H.W., eds. Forest hydrology. Oxford, UK: Pergamon Press: 137-1

Appendix F: Criteria and Indicators for Strategic Urban Forest Planning and Management

Source: Kenney, W.A., van Wassenaer, P.J.E, and A.L. Satel. 2011. Criteria and Indicators for Strategic Urban Forest Planning and Management. Arboriculture & Urban Forestry 2011. 37(3): 108–117

Shaded cells indicate the current state of the vegetation resource, community framework and management practice in Newmarket, as proposed by Town of Newmarket urban forestry staff.

Vegetation Resource: Newmarket					
Criteria	**Performance Indictors**				**Key Objective**
	Low	**Moderate**	**Good**	**Optimal**	
Relative Canopy Cover	The existing canopy cover equals 0 - 25% of the potential	The existing canopy cover equals 25-50% of the potential	The existing canopy cover equals 50-75% of the potential	The existing canopy cover equals 75-100% of the potential	Achieve climate-appropriate degree of tree cover, community wide
Age distribution of trees in the community	Any Relative DBH (RDBH) class (0-25% RDBH, 26-50% RDBH, etc.) represents more than 75% of the tree population.	Any RDBH class represents between 50% and 75% of the tree population.	No RDBH class represents more than 50% of the tree population	25% of the tree population is in each of four RDBH classes.	Provide for uneven-aged distribution city-wide as well as at the neighbourhood and/or street segment level.
Species suitability	Less than 50% of trees are of species considered suitable for the area.	50% to 75% of trees are of species considered suitable.	More than 75% of trees are of species considered suitable for the area.	All trees are of species considered suitable for the area.	Establish a tree population suitable for the urban environment and adapted to the regional environment.

Vegetation Resource: Newmarket					
Criteria	Performance Indictors				Key Objective
	Low	Moderate	Good	Optimal	
Species distribution	Fewer than 5 species dominate the entire tree population city-wide.	No species represents more than 10% of the entire tree population city-wide.	No species represents more than 5% of the entire tree population city-wide.	No species represents more than 5% of the entire tree population city-wide or at the neighbourhood /street segment level.	Establish a genetically diverse tree population city-wide as well as at the neighbourhood and/or street segment level.
Condition of Publicly-owned Trees (trees managed intensively)	No tree maintenance or risk assessment. Request based/reactive system. The condition of the urban forest is unknown	Sample-based inventory indicating tree condition and risk level is in place.	Complete tree inventory which includes detailed tree condition ratings.	Complete tree inventory which includes detailed tree condition and risk ratings.	Detailed understanding of the condition and risk potential of all publicly-owned trees
Publicly-owned natural areas (trees managed extensively, e.g. woodlands, ravine lands, etc.)	No information about publicly-owned natural areas.	Publicly-owned natural areas identified in a “natural areas survey” or similar document.	The level and type of public use in publicly-owned natural areas is documented	The ecological structure and function of all publicly-owned natural areas are documented and included in the city-wide GIS	Detailed understanding of the ecological structure and function of all publicly-owned natural areas.
Native vegetation	No program of integration	Voluntary use of native species on publicly and privately- owned lands.	Use of native species is *encouraged* on a project-appropriate basis in both intensively and extensively managed area	The use of native species is *required* on a project-appropriate basis in both intensively and extensively managed areas.	Preservation and enhancement of local natural biodiversity

Community Frame Work: Newmarket					
Criteria	**Performance Indictors**				**Key Objective**
	Low	**Moderate**	**Good**	**Optimal**	
Public agency cooperation	Conflicting goals among departments and or agencies.	Common goals but no cooperation among departments and/or agencies.	Informal teams among departments and or agencies are functioning and implementing common goals on a project-specific basis.	Municipal policy implemented by formal interdepartmental/ interagency working teams on ALL municipal projects.	Insure all city departments cooperate with common goals and objectives
Involvement of large private and institutional land holders	Ignorance of issues	Educational materials and advice available to landholders.	Clear goals for tree resource by landholders. Incentives for preservation of private trees.	Landholders develop comprehensive tree management plans (including funding).	Large private landholders embrace city-wide goals and objectives through specific resource management plans.
Green industry cooperation	No cooperation among segments of the green industry (nurseries, tree care companies, etc.) No adherence to industry standards.	General cooperation among nurseries, tree care companies, etc.	Specific cooperative arrangements such as purchase certificates for “right tree in the right place”	Shared vision and goals including the use of professional standards.	The green industry operates with high professional standards and commits to city-wide goals and objectives.

Neighbourhood action	No action	Isolated or limited number of active groups.	City-wide coverage and interaction.	All neighbourhoods organized and cooperating.	At the neighbourhood level, citizens understand and cooperate in urban forest management.
Citizen-municipality-business interaction	Conflicting goals among constituencies	No interaction among constituencies.	Informal and/or general cooperation.	Formal interaction e.g. Tree board with staff coordination.	All constituencies in the community interact for the benefit of the urban forest.
General awareness of trees as a community resource	Trees seen as a problem, a drain on budgets.	Trees seen as important to the community.	Trees acknowledged as providing environmental, social and economic services.	Urban forest recognized as vital to the communities environmental, social and economic well-being.	The general public understanding the role of the urban forest.
Regional cooperation	Communities cooperate independently.	Communities share similar policy vehicles.	Regional planning is in effect	Regional planning, coordination and /or management plans	Provide for cooperation and interaction among neighbouring communities and regional groups.

Resource Management Approach: Newmarket					
Criteria	Performance Indictors				Key Objective
	Low	Moderate	Good	Optimal	
Tree Inventory	No inventory	Complete or sample-based inventory of publicly-owned trees	Complete inventory of publicly-owned trees AND sample-based inventory of privately-owned trees.	Complete inventory of publicly-owned trees AND sample-based inventory of privately-owned trees included in city-wide GIS	Complete inventory of the tree resource to direct its management. This includes: age distribution, species mix, tree condition, risk assessment.
Canopy Cover Inventory	No inventory	Visual assessment	Sampling of tree cover using photographs or satellite imagery	Sampling of tree cover using aerial photographs or satellite imagery included in city-wide GIS	High resolution assessments of the existing and potential canopy cover for the entire community.
City-wide management plan	No plan	Existing plan limited in scope and implementation	Comprehensive plan for publicly-owned intensively and extensively managed forest resources accepted and implemented	Strategic multi-tiered plan for public and private intensively and extensively managed forest resources accepted and implemented with adaptive management mechanisms	Develop and implement a comprehensive urban forest management plan for private and public property.

Municipality-wide funding	Funding for reactive management	Funding to optimize *existing* urban forest.	Funding to provide for net increase in urban forest benefits.	Adequate private and public funding to sustain maximum urban forest benefits.	Develop and maintain adequate funding to implement a city-wide urban forest management plan
City staffing	No staff.	No training of existing staff.	Certified arborists and professional foresters on staff with regular professional development.	Multi-disciplinary team within the urban forestry unit.	Employ and train adequate staff to implement city-wide urban forestry plan
Tree establishment planning and implementation	Tree establishment is *ad hoc*	Tree establishment occurs on an annual basis	Tree establishment is directed by needs derived from a tree inventory	Tree establishment is directed by needs derived from a tree inventory and is sufficient to meet canopy cover objectives	Urban Forest renewal is ensured through a comprehensive tree establishment program driven by canopy cover, species diversity, and species distribution objectives
Tree habitat suitability	Trees planted without consideration of the site conditions.	Tree species are considered in planting site selection.	Community wide guidelines are in place for the improvement of planting sites and the selection of suitable species.	All trees planted with adequate soil quality and quantity, and growing space to achieve their genetic potential.	All publically owned trees are planted in habitats that will maximize current and future benefits provided to the site.

Maintenance of publicly-owned, intensively managed trees	No maintenance of publicly-owned trees	Publicly-owned trees are maintained on a request/reactive basis. No systematic (block) pruning.	All publicly-owned trees are systematically maintained on a cycle longer than five years.	All mature publicly-owned trees are maintained on a 5-year cycle. All immature trees are structurally pruned.	All publicly-owned trees are maintained to maximize current and future benefits. Tree health and condition ensure maximum longevity.
Tree Risk management	No tree risk assessment/ remediation program. Request based/reactive system. The condition of the urban forest is unknown	Sample-based tree inventory which includes general tree risk information; Request based/reactive risk abatement program system.	Complete tree inventory which includes detailed tree failure risk ratings; risk abatement program is in effect eliminating hazards within a maximum of one month from confirmation of hazard potential.	Complete tree inventory which includes detailed tree failure risk ratings; risk abatement program is in effect eliminating hazards within a maximum of one week from confirmation of hazard potential.	All publicly owned trees are safe.
Tree Protection Policy Development and Enforcement	No tree protection policy	Policies in place to protect public trees.	Policies in place to protect public and private trees with enforcement.	Integrated municipal wide policies that ensure the protection of trees on public and private land are consistently enforced and supported by significant deterrents	The benefits derived from large-stature trees are ensured by the enforcement of municipal wide policies.
Publicly-owned natural areas management planning and implementation	No stewardship plans or implementation in effect.	Reactionary stewardship in effect to facilitate public use (e.g. hazard abatement, trail maintenance, etc.)	Stewardship plan in effect for each publicly-owned natural area to facilitate public use (e.g. hazard	Stewardship plan in effect for each publicly-owned natural area focused on sustaining the ecological structure and function of the	The ecological structure and function of all publicly-owned natural areas are protected and, where appropriate,

			abatement, trail maintenance, etc.)	feature.	enhanced.

Appendix G: Total Estimates for Trees in Newmarket by Land Use and Species

		Number of Trees		Carbon ([1]mt)		Gross Seq ([1]mt/yr)		Net Seq ([1]mt/yr)		Leaf Area (km2)		Leaf Biomass ([1]mt)		Values (Can$)	
Land Use	Species	Val	SE	Val	SE	Val	SE	Val	SE	Val	SE	Val	SE	Val	SE
Com/Industrial	Northern white cedar	1495	1493	5.64	5.64	0.93	0.93	0.9	0.9	0.032	0.032	6.08	6.07	94820	94725
	Common lilac	498	498	5.5	5.49	1.36	1.36	1.29	1.29	0.008	0.008	0.78	0.78	36096	36059
	Russian olive	498	498	20.56	20.54	1.11	1.11	1.1	1.09	0.012	0.012	0.87	0.87	20542	20522
	Total	2491	2033	31.7	22.97	3.4	2.5	3.29	2.41	0.051	0.041	7.73	6.87	151458	131571
Natural Cover	Northern white cedar	4157	3965	131.15	127.07	4.89	4.66	2.56	2.35	0.113	0.106	21.72	20.45	1887000	1830986
	Eastern white pine	3464	2806	401.61	335.68	14.68	11.97	11.66	9.18	0.215	0.169	13.83	10.85	6024658	4828147
	Norway maple	3117	1434	364	150.32	18.17	7.66	17.21	7.3	0.346	0.166	18.67	8.98	2434170	1011964
	Scotch pine	1212	1040	144.05	123.95	6.82	6.07	6.18	5.48	0.36	0.357	34.69	34.41	1284244	1035958
	Green ash	5369	2169	477.84	223.61	17.4	8.11	9.61	7.42	0.428	0.176	27.89	11.51	3502336	1992082
	American elm	1386	1210	79.46	76.13	2.83	2.5	-1.7	2.06	0.091	0.076	6.64	5.56	459580	442930
	Paper birch	2078	1119	383.47	238.38	17.88	10.6	16.23	9.97	0.139	0.076	9.71	5.3	2374402	1501237
	Austrian pine	346	345	29.83	29.75	1.11	1.11	1.04	1.04	0.152	0.151	14.63	14.58	315120	314209
	Norway spruce	1212	837	409.28	283.3	11.89	8.24	10.31	7.14	0.968	0.669	161.27	111.48	3355413	2304365
	Red pine	1559	1554	272.69	271.9	9.78	9.75	9.16	9.13	0.184	0.183	26.99	26.91	3100958	3091993
	Quaking aspen	1559	946	166.26	90.45	7.76	4.3	7.07	3.96	0.288	0.167	22.7	13.17	992251	539351
	Honeylocust	173	173	48.85	48.71	1.79	1.78	1.68	1.67	0.017	0.017	1.76	1.75	371785	370710
	European buckthorn	520	376	10.95	9.29	1.14	0.91	1.11	0.89	0.008	0.006	0.37	0.26	46856	38483
	Balsam poplar	866	863	103.78	103.48	4.52	4.51	4.06	4.05	0.07	0.069	5.02	5	703853	701818

	American basswood	1559	1382	34.98	33.9	2.81	2.64	2.61	2.45	0.076	0.071	2.21	2.07	285169	275795
	White ash	1212	1040	314.77	274.91	8.27	7.05	-8.25	8.94	0.212	0.152	12.06	8.61	1515163	1320788
	Tamarack	1905	1900	264.67	263.9	9.22	9.19	8.61	8.59	0.19	0.19	8.81	8.78	4091500	4079671
	Ironwood	173	173	5.33	5.32	0.39	0.39	0.38	0.38	0.018	0.017	4.23	4.22	15483	15438
	Dogwood	1212	837	35.69	30.53	2.76	2.1	2.65	2.01	0.036	0.03	2.69	2.22	232365	198650
	Black willow	346	345	9.45	9.43	0.89	0.89	0.84	0.84	0.02	0.02	1.28	1.28	44174	44047
	Black locust	693	536	96.07	66.03	4.29	3.01	4.07	2.86	0.14	0.121	7.54	6.54	667327	459128
	Bur oak	346	345	43.66	43.53	1.48	1.48	0.22	0.22	0.02	0.02	1.94	1.94	303644	302766
	Amur maple	173	173	0.59	0.59	0.15	0.15	0.14	0.14	0.007	0.007	0.39	0.39	9093	9066
	Total	34638	7512	3828.44	841.24	150.92	33.65	107.47	35.24	4.096	1.087	407.03	143.1	34016545	8819983
Open Space	Northern white cedar	9562	9553	359.2	358.86	10.95	10.94	5.75	5.74	0.701	0.701	134.9	134.77	4912976	4908350
	Eastern white pine	17529	14133	116.24	86.92	11.6	8.07	11.07	7.74	0.604	0.47	38.85	30.22	2349006	1721435
	Norway maple	1062	734	84.16	58.27	4.97	3.44	4.7	3.25	0.207	0.151	11.19	8.14	776893	549488
	White spruce	531	531	139.41	139.28	5.18	5.18	4.65	4.64	0.308	0.307	49.44	49.39	1382119	1380817
	Green ash	1594	1166	28.46	23.18	2.01	1.42	1.92	1.36	0.142	0.112	9.29	7.33	318727	270304
	Blue spruce	1062	1061	6.84	6.84	0.95	0.94	0.92	0.92	0.028	0.028	4.81	4.8	57369	57315
	American elm	3718	2708	118.31	73.05	7.5	4.31	5.58	3.31	0.375	0.224	27.31	16.26	1069260	817574
	Boxelder	3187	2332	765.6	690.3	22.6	17.2	19.58	14.53	1.262	1.096	115.44	100.29	3187771	2926781
	Black walnut	2656	2653	74.07	74	6.38	6.37	6.2	6.19	0.286	0.286	22.91	22.89	543060	542549
	Quaking aspen	5312	4331	475.5	355.6	22.02	17.09	20.16	15.73	0.432	0.314	34.03	24.73	3129415	2258835
	European buckthorn	3187	2683	96.68	81.43	6.58	4.59	6.3	4.4	0.209	0.157	9.29	6.96	871142	707172
	Balsam poplar	2656	2653	405.4	405.02	16.5	16.49	14.75	14.74	0.647	0.647	46.7	46.66	2448731	2446425
	American basswood	1062	1061	20.11	20.09	1.89	1.89	1.84	1.84	0.033	0.033	0.98	0.98	117528	117417
	Tamarack	531	531	5.35	5.34	0.58	0.58	0.56	0.55	0.037	0.037	1.73	1.73	58890	58835
	Corktree	2656	2653	255.06	254.82	13.59	13.58	12.71	12.7	0.58	0.58	43.46	43.42	1804543	1802844
	Ironwood	531	531	45.73	45.69	2.44	2.44	2.26	2.26	0.082	0.082	19.81	19.8	391973	391604
	Dogwood	1062	1061	8.17	8.16	1.23	1.22	1.18	1.18	0.042	0.042	3.12	3.12	67185	67122
	Black willow	531	531	5.31	5.3	0.59	0.59	0.5	0.5	0.01	0.01	0.66	0.66	12308	12297

	Horsechestnut	531	531	15.03	15.02	1.41	1.41	1.38	1.38	0.05	0.05	3.51	3.51	61324	61266
	Kentucky coffeetree	531	531	5.31	5.3	0.78	0.78	0.77	0.76	0.041	0.041	3.08	3.08	33791	33759
	Cottonwood spp	531	531	0.65	0.65	0.23	0.23	0.23	0.23	0.008	0.008	0.51	0.51	13944	13931
	Total	60025	23449	3030.59	1227.27	139.97	47.96	123.01	40.42	6.088	2.268	581.03	246.06	23607954	9997124
Agri. Inst. Vac	Northern white cedar	2333	2330	21.21	21.19	1.76	1.76	1.68	1.68	0.064	0.064	12.35	12.33	200763	200547
	Eastern white pine	7464	5831	240.22	188.89	13.03	9.18	12.37	8.71	0.573	0.452	36.82	29.09	4085900	3463450
	Norway maple	4199	2428	1235.44	847.55	39.54	22.75	35.16	19.94	0.846	0.515	45.66	27.78	8845539	5694624
	Scotch pine	1400	1398	179.28	179.08	5.89	5.89	5.49	5.48	0.461	0.461	44.48	44.43	1819191	1817240
	White spruce	4199	3081	153.44	108.71	7.82	5.5	7.5	5.26	0.465	0.338	74.71	54.32	505681	358611
	Green ash	2799	1942	218.25	196.34	8.9	7.05	7.97	6.2	0.402	0.298	26.24	19.46	1852248	1750820
	Blue spruce	2799	2360	498.85	429.77	16.16	13.64	12.17	9.98	0.927	0.841	157.31	142.61	6230419	5331529
	Boxelder	1400	1027	385.14	379.98	9.88	9.17	7.79	7.11	0.335	0.299	30.63	27.39	1339181	1321079
	Black walnut	2799	2796	517.77	517.21	31.77	31.74	29.73	29.69	1.24	1.239	99.41	99.3	3497783	3494032
	Paper birch	4199	2607	463.82	397.06	26.68	19.34	25.49	18.41	0.3	0.167	20.97	11.66	2971617	2566172
	Norway spruce	2799	2796	879.08	878.14	21.55	21.52	19.32	19.3	2.478	2.475	412.92	412.48	7811343	7802967
	Red pine	2333	1652	475.86	337.74	18.73	13.17	17.34	12.2	0.456	0.324	67.07	47.61	4811924	3503381
	Sugar maple	2333	1905	1606.08	1468.52	39.16	35.66	33.1	29.73	1.056	0.911	63.59	54.87	10004671	9697929
	Silver maple	1400	1398	631.77	631.09	14.03	14.01	11.76	11.75	0.302	0.302	15.92	15.9	3386925	3383293
	American basswood	1400	1398	104.4	104.29	8.02	8.01	7.6	7.6	0.292	0.292	8.53	8.52	1048204	1047080
	White ash	467	466	90.62	90.52	4.01	4.01	3.66	3.65	0.15	0.15	8.51	8.5	850516	849604
	Freeman maple	467	466	7.78	7.77	0.92	0.92	0.9	0.9	0.031	0.031	1.74	1.74	30658	30625
	Black willow	933	932	10.82	10.81	1.49	1.49	1.45	1.44	0.034	0.034	2.15	2.15	48699	48647
	Total	45719	16639	7719.83	3540.33	269.34	99.19	240.47	86.93	10.413	4.012	1129.01	508.37	59341261	23603342
Residential	Northern white cedar	12619	4472	269.06	140.02	18.62	6.9	17.44	6.37	0.925	0.529	177.92	101.77	4045161	2368473
	Eastern white pine	526	525	6.62	6.62	1.14	1.14	1.07	1.07	0.011	0.011	0.68	0.68	53648	53597
	Norway maple	11568	3210	2365.95	1123.79	113.24	38.65	103.8	34.54	3.741	1.245	201.89	67.2	18647359	8721697
	Scotch pine	12094	12082	541.17	540.65	28.69	28.66	23.93	23.91	0.757	0.756	72.93	72.86	5130077	5125197

	White spruce	5784	2063	1471.99	778.59	55.74	24.07	47.9	19.49	2.072	1.093	332.86	175.59	15086783	7772666
	Green ash	1577	896	541.02	312.9	7.78	5.56	-25.89	26.42	0.455	0.299	29.65	19.53	4431059	3313299
	Blue spruce	4206	1405	328.31	132.95	21.96	8.12	20.65	7.6	0.77	0.325	130.67	55.06	3030839	1269847
	American elm	4732	2582	1047.06	627.41	41.53	22.87	27.84	16.08	1.373	0.722	99.84	52.53	6825282	4078382
	Boxelder	4732	1966	568.45	284.06	36.1	15.97	32.72	14.46	1.204	0.556	110.19	50.86	2455581	1240686
	Black walnut	4206	2428	2779.68	1777.11	90.76	55.4	79.91	48.63	3.694	2.1	296.03	168.29	18688562	11890874
	Paper birch	1577	1167	161.06	114.76	14.64	10.27	13.43	9.44	0.216	0.163	15.14	11.39	926910	653422
	Austrian pine	7887	5230	802.9	601.69	29.41	20.67	15.73	12.11	1.108	0.817	106.74	78.78	9129733	6746058
	Norway spruce	2629	2158	270.04	210.67	15.73	12.51	14.48	11.5	0.659	0.468	109.86	77.96	2403118	1909823
	Red pine	3155	1942	517.39	293.89	21.02	13.24	12.54	12.22	0.571	0.325	83.93	47.82	4068903	2468716
	American beech	5784	5778	347.77	347.44	38.21	38.18	35.2	35.17	1.044	1.043	44.48	44.44	1644640	1643076
	Sugar maple	2629	1725	834.44	571.92	39.24	26.56	35.99	24.37	0.642	0.415	38.66	25.01	6428346	4462508
	Honeylocust	4206	2053	667.12	386.05	38.77	21.63	33.2	18.21	0.491	0.292	51.43	30.54	4449997	2556981
	European buckthorn	1052	737	49.27	37.24	3.39	3.39	-0.83	5.26	0.089	0.089	3.96	3.95	282837	282568
	Common juniper	4206	3221	75.2	54.41	4.32	2.93	-0.24	2.58	0.15	0.103	41.64	28.64	390811	285552
	Common lilac	1052	737	18.42	15.82	3.29	2.62	3.19	2.54	0.023	0.016	2.22	1.57	110935	88452
	Silver maple	2629	1138	1196.3	847.35	33.13	19.36	28.55	16.21	1.386	0.919	72.93	48.36	8655685	5920917
	Balsam poplar	526	525	4.78	4.78	1.14	1.13	1.11	1.11	0.024	0.024	1.72	1.71	18066	18049
	White ash	1577	1576	57.82	57.77	9.1	9.09	8.85	8.84	0.202	0.202	11.48	11.47	219592	219383
	Tamarack	526	525	66.39	66.33	3.18	3.18	2.55	2.55	0.165	0.165	7.65	7.65	891563	890714
	Crabapple	2103	1270	236.57	171.17	17.15	11.28	16.2	10.61	0.52	0.397	44.81	34.18	1703313	1227381
	Littleleaf linden	1577	1576	52.87	52.82	5.97	5.96	5.75	5.74	0.187	0.187	14.02	14.01	556430	555901
	Ironwood	1577	1167	258.33	182.8	15.58	11.11	14.56	10.39	0.189	0.138	45.7	33.34	1868335	1323456
	Crimson king norway maple	1577	896	628.39	446.7	22.39	14.43	17.8	11.14	0.502	0.344	28.24	19.37	4071131	2882429
	Freeman maple	1052	737	92.56	71.89	7.59	5.52	7.21	5.24	0.219	0.155	12.3	8.71	668775	541513
	Black cherry	1577	1167	102.7	85.56	4.16	4.15	-18.98	23.44	0.058	0.058	4.47	4.47	73167	73098
	Pear spp	1577	1167	8.02	6.86	2.45	2	2.4	1.96	0.017	0.013	1.3	1	79266	58666
	Mulberry spp	526	525	4.93	4.93	1.3	1.3	1.28	1.28	0.003	0.003	0.26	0.26	17978	17961

	Russian olive	526	525	17.76	17.75	2.71	2.71	2.63	2.63	0.083	0.082	6.18	6.17	61786	61727
	Horsechestnut	526	525	1.94	1.93	0.64	0.64	0.62	0.62	0.007	0.007	0.51	0.51	23661	23639
	Common chokecherry	1052	737	256.94	229.64	13.34	10.5	12.33	9.63	0.221	0.158	17.14	12.23	1434618	1274427
	Balsam fir	526	525	13.96	13.95	1.78	1.78	1.72	1.72	0.025	0.025	2.61	2.61	48561	48515
	Bur oak	526	525	26.16	26.13	2.98	2.98	2.87	2.87	0.004	0.004	0.42	0.42	223773	223560
	Black maple	526	525	546.07	545.55	14.33	14.32	12.24	12.23	0.352	0.351	19.8	19.78	3370336	3367129
	Japanese maple	526	525	11.93	11.92	2.13	2.13	2.08	2.08	0.027	0.027	1.53	1.53	50135	50087
	Red maple	526	525	40	39.97	3.83	3.82	3.66	3.66	0.175	0.175	11.77	11.75	295761	295480
	Hackberry spp	526	525	52.01	51.96	4.35	4.34	3.83	3.83	0.075	0.075	4.42	4.42	373059	372704
	Dawn redwood	526	525	4.24	4.23	0.86	0.86	0.84	0.84	0.02	0.02	1.15	1.15	49510	49463
	Spruce spp	526	525	17.27	17.26			-4.75	4.75						
	Pine spp	526	525	1.75	1.75	0.34	0.34	0.33	0.33	0.01	0.01	0.97	0.97	24766	24742
	Black spruce	526	525	102.55	102.45	4.36	4.35	3.96	3.96	0.216	0.216	40.77	40.73	1055384	1054380
	American sycamore	526	525	1.28	1.28	0.38	0.38	0.34	0.34	0.008	0.008	0.39	0.39	16871	16855
	White cedar	526	525	6.55	6.55	1.53	1.53	1.5	1.5	0.009	0.009	0.69	0.69	32642	32611
	Slippery elm	526	525	9.06	9.05	1.75	1.74	1.7	1.7	0.03	0.03	1.36	1.36	49428	49381
	Total	121988	23745	17482.06	3170.3	802.01	134.49	625.3	127.07	24.728	4.186	2305.32	387.43	1.34E+08	24255501
Trans/Utilities	Eastern white pine	1013	1012	90.04	89.95	3.87	3.86	3.5	3.49	0.166	0.166	10.7	10.69	1453830	1452394
	Norway maple	8107	2767	1047.73	412.99	64.67	21.33	57.8	18.99	1.954	0.702	105.48	37.88	7844201	3026371
	White spruce	2027	1587	163.2	142.01	8.4	6.55	7.99	6.22	0.26	0.23	41.69	36.88	1595738	1429662
	Green ash	507	506	85.94	85.86	2.38	2.37	0.23	0.23	0.221	0.221	14.4	14.38	940997	940068
	Blue spruce	2027	1211	401.33	278.82	18.03	11.49	15.73	9.78	0.582	0.357	98.8	60.57	4003231	2762046
	Boxelder	507	506	216.26	216.05	8.26	8.25	6.21	6.2	0.179	0.179	16.38	16.37	850663	849823
	Paper birch	507	506	49.29	49.24	4.75	4.75	4.55	4.55	0.065	0.064	4.51	4.51	316172	315860
	Norway spruce	507	506	45.58	45.53	3.07	3.06	2.89	2.88	0.125	0.125	20.83	20.81	467094	466633
	Sugar maple	507	506	101.91	101.81	6.73	6.72	6.32	6.31	0.187	0.187	11.28	11.27	801605	800813
	Honeylocust	1013	706	172.71	152.89	9.67	7.53	8.87	6.91	0.133	0.097	13.98	10.12	1281028	1168465
	Common juniper	507	506	49.28	49.23	1.39	1.39	1.2	1.2	0.318	0.317	88.2	88.11	193951	193760

	Common lilac	3040	2117	19.8	11.88	5.21	3.29	5.01	3.21	0.034	0.02	3.32	1.95	180240	127497
	Silver maple	507	506	18.67	18.65	2.45	2.45	2.37	2.37	0.13	0.13	6.84	6.83	50435	50385
	Crabapple	507	506	104.9	104.8	5.76	5.75	5.35	5.34	0.105	0.105	9.02	9.01	717686	716977
	Littleleaf linden	1013	706	68.73	54.49	5.38	3.94	5.1	3.73	0.237	0.198	17.73	14.82	860001	702200
	Crimson king norway maple	507	506	221.65	221.43	8.32	8.32	7.47	7.46	0.29	0.29	16.32	16.3	1701220	1699541
	Freeman maple	507	506	20.69	20.67	2.87	2.87	2.78	2.78	0.115	0.115	6.47	6.46	71561	71490
	Mulberry spp	1013	1012	13.97	13.96	3.11	3.11	3.05	3.05	0.008	0.008	0.7	0.7	47266	47220
	Russian olive	507	506	142.56	142.42	6.91	6.91	6.81	6.81	0.139	0.139	10.42	10.41	824477	823663
	Black locust	507	506	34.14	34.11	3.33	3.33	3.19	3.19	0.045	0.045	2.42	2.41	261531	261273
	Balsam fir	507	506	44.74	44.69	2.55	2.55	2.38	2.37	0.175	0.175	18.26	18.24	371984	371617
	Tree of heaven	1013	706	12.5	9.42	2.4	1.87	2.39	1.86	0.045	0.031	3.33	2.33	45023	31851
	Downy serviceberry	507	506	6.41	6.4	1.49	1.49	1.49	1.49	0.009	0.009	0.54	0.54	29014	28985
	Buckthorn spp	507	506	1.2	1.2	0.48	0.48	0.48	0.48	0.015	0.015	1.12	1.12	20026	20006
	Ginkgo	507	506	1.85	1.85	0.61	0.61	0.6	0.6	0.003	0.003	0.14	0.14	30400	30370
	Magnolia spp	507	506	22.91	22.89	2.63	2.63	2.54	2.54	0.03	0.03	2	1.99	181740	181561
	Shubert chokecherry	507	506	51.31	51.26	4.59	4.59	4.38	4.38	0.059	0.059	4.55	4.55	336325	335993
	Blackberry spp	507	506	43.12	43.08	3.81	3.81	3.64	3.64	0.106	0.106	3.95	3.95	344827	344487
	Total	29894	4501	3252.42	691.25	193.13	32.7	174.3	29.71	5.734	1.102	533.37	134.69	25822267	5713421
Town TOTAL	Total	294755	38358	35345.03	5027.62	1558.77	180.09	1273.83	165.73	51.11	6.416	4963.48	712.57	277,103,659	36821762