IE11.1 - Attachment 2

2018

Prepared by:
KBM Resources Group
Lallemand Inc./BioForest
Dillon Consulting Limited

With Special Advisors
Peter Duinker and James Steenberg, Dalhousie University

Consulting Team

Lallemand Inc./BioForest

Allison Craig, MFC

John Barker, MFC

KBM Resources Group

Rike Burkhardt, MFC, RPF

Ben Kuttner, PhD, RPF

Arnold Rudy, MScF

Dillon Consulting Limited

David Restivo, HBSc, EP

John Fairs, HBA

Sarah Galloway, HBES

Merrilees Willemse, HBA, MCIP, RPP

Dalhousie University (Special Advisors)

Peter Duinker, PhD

James Steenberg, PhD

Acknowledgements

We gratefully acknowledge the contributions of the field crews, who recorded the i-Tree data used to generate many of the findings in this report:

Lallemand Inc./BioForest: Ahmad Alamad, Laura Brodey, George Chen, Jessica Corrigan, Aurora Lavender, Julia Reale

Dillon Consulting Ltd: Trevor Goulet

Our thanks go to the City of Toronto Steering Committee members who provided valuable insight and expertise.

Daniel Boven, Acting Manager
Forestry Policy and Planning

Connie Pinto, Program Standards & Development Officer
Forestry Policy and Planning

Ryan Garnett, Manager
Geospatial Data Integration & Access

Beth McEwen, Manager
Forest & Natural Area Management

Carol Walker, Manager
Urban Forestry – EWMS Project

Raymond Vendrig, Manager
Urban Forestry Renewal

Our thanks go also to the key experts who provided input on the draft key findings.

Amory Ngan, Project Manager, Tree Planting Strategy, Urban Forestry
Andrew Pickett, Urban Forestry Coordinator (A), Urban Forestry
Christine Speelman, Sr. Project Coordinator (A), Urban Forestry
David Kellershohn, Manager, Stormwater Manager, Toronto Water
Jane Welsh, Project Manager, Zoning Bylaw & Environmental Planning, City Planning
Jane Weninger, Sr. Planner, Policy & Research, City Planning
Jackie Hamilton, Research Analyst, Toronto and Region Conservation Authority
Kristina Hausmanis, Project Manager, Public Realm, Transportation Services
Paul Fleiszer, Associate Director (A), Surveillance & Epidemiology, Toronto Public Health
Wendy Strickland, Project Manager, Ravine Strategy, Parks

Contents

List of Tables

List of Figures

Foreword

Toronto's urban forest is a vital city asset contributing to the quality of life in Canada's largest urban centre. Urban trees help to mitigate negative impacts and social consequences of urbanization making cities more resilient to these changes. A city with a well-planned and well-managed urban forest is more sustainable and equitable in terms of climate change mitigation and adaptation, disaster risk reduction, ecosystems conservation, food security, poverty alleviation, and livelihood improvement.

Torontonians have come to understand and value the tremendous contributions trees make to healthy communities. The urban forest increases biodiversity and provides residents with benefits such as cleaner air, improved physical and mental well-being and energy savings. Economic benefits include enhancements to property values, tourism and consumer spending.

Ten years ago, the City of Toronto carried out its first urban forest study, the results of which were reported in *Every Tree Counts: A Portrait of Toronto's Urban Forest*. Based on the study's results, a forest management strategy was developed. The strategy directs the City's programs and policies necessary to sustain and enhance the urban forest for the economic, environmental, social, and public health benefits of its citizens.

The 2018 Toronto Canopy Study examines the current state of the urban forest using state-of-the-art technologies and tools to discover changes and trends in the size and character of the urban forest over the last ten years. Applying the same methodologies used in the previous study, together with improved data analysis software, the Tree Canopy study presents the subtle and not so subtle changes in the size, composition, health and distribution of Toronto's urban forest.

In general, the results of the study are encouraging. The slight increase in canopy cover since 2008 is good news. Tree planting programs have contributed considerably to the increase as the number of trees has grown by over a million trees in ten years despite significant losses as a result of the 2013 ice storm and infestations of emerald ash borer and Asian long-horned beetle. The City's efforts to grow and maintain high quality street trees are reflected in a dramatic increase in street tree condition. However, there are some concerning trends that need attention. Analysis of land cover data indicates a loss of permeable surfaces across a number of land uses resulting in a decrease of available growing space for future canopy expansion. The spread of invasive species threatens the quality and function of the urban forest contributing to the decline of the average tree condition across the city.

Toronto's urban forest management program is advancing in the right direction, however the results of the study support the need for continued investment to maintain and enhance a resilient, sustainable and equitable urban forest. Growth through ongoing planting of new trees on both public and private land remains important to supporting a healthy livable city. Nevertheless, with increased competition for valuable land and the increased threat of invasive species on forest health, the protection and stewardship of existing trees, forests, natural areas and plantable space has never been more critical.

Jason Doyle, Director, Urban Forestry

1 | Executive Summary

1.1 | Context

This report presents the results of an update to the first tree canopy study, *Every Tree Counts – A Portrait of Toronto's Urban Forest*, published by the City of Toronto in 2009, and later updated in 2013. A decade has passed since the original study was undertaken, and this 2019 update offers an opportunity to look at what has changed in Toronto's urban forest over that ten-year period. Using established methodologies developed by the United States Department of Agriculture (USDA) Forest Service, studies of this kind are an important part of the adaptive management cycle. They allow City managers to work with reliable data to adjust program activities that reflect the changing nature of the urban forest and evolving management issues.

The report provides information about broad changes and trends in the urban forest over time. It provides data on the extent, size class, composition and condition of the urban forest. It also provides insight on trends in selected geographies, in this case eight different land use classes in the city. It also offers information about the amount and dollar value of several key ecosystem services provided by the urban forest.

Finally, the study uses this available spatial data to map where the urban forest has changed. This data is used conjunction with other City data sets to examine any possible correlations between factors impacting trees (e.g. ice storm, development activity and ice storm damage) and their effects on Toronto's tree canopy. All of this information combined with the local knowledge and expertise of City staff will help managers develop appropriate policy and program responses.

As with every study, there are limitations to the extent that a cause-and-effect relationship can be established. There are known factors contributing to tree cover change, like the tens of thousands of ash trees (*Fraxinus* spp.) removed because of the emerald ash borer (*Agrilus planipennis* Fairmaire) pest that will have a clear connection to canopy cover loss. There are other impacts, like the damage from a severe ice storm in 2013 and ongoing development activity for which the effects are harder to quantify. Many of the study results are most reliable for describing broad trends across the City and less reliable at the individual site or neighbourhood scale. Other City of Toronto databases and information can help support this analysis, but in some cases the study will raise new questions that need further investigation as part of ongoing urban forestry program planning and operational management adjustments.

Since the first tree canopy study was initiated in 2008, the urban forest has experienced significant environmental pressures:

- The emerald ash borer (EAB) pest was first detected in the Greater Toronto Area in 2007. Since then, EAB has led to the removal of thousands of ash trees out of an estimated total ash population of 860,000.[1]
- In December 2013, Toronto was affected by a severe ice storm, experiencing substantial damage to municipal forestry infrastructure and related costs of approximately $106 million in emergency response and follow-up, of which Hazard Abatement costs related to trees were estimated at $30.32 million.[2]
- The presence and abundance of invasive plant species has increased significantly in certain land uses, particularly in natural areas. Nearly one third (32.5%) of the understory shrub leaf area in ravines and natural areas is comprised of invasive species, compared to 15% in 2008.
- Changing climate is having an effect on Toronto's urban forest. While it was not the principal study objective to quantify the effects of climate change on the urban forest, known and expected effects of climate change on trees include:
    - drought stress
    - damage to early tree growth from changing freeze/thaw cycles
    - increased occurrence of and vulnerability to insects and disease
    - more frequent and severe extreme weather events causing tree damage, soil erosion, and additional emergency response and operational maintenance costs

In the face of these pressures, the study data supports some of the expected downward trends in forest health and condition. However, the data also reflects some positive outcomes of investments in urban forest management over the last ten years. In this respect, the results of the 2018 study update tell a good news/bad news story in terms of the trends observed.

[1] As estimated in the UFORE (now i-Tree Eco) study in 2008.

[2] Impacts from the December 2013 Extreme Winter Storm Event on the City of Toronto, 2014 Staff Report. URL: https://www.toronto.ca/legdocs/mmis/2014/cc/bgrd/backgroundfile-65676.pdf

1.2 | Key Study Findings

Key findings of this study highlight some positive trends between 2008 and 2018 as well as areas for further investigation.

- On average, canopy increased by about 1.8 percentage points across Toronto from 26.6%[3] to 28.4%[4] over the ten-year study period (2008 to 2018).
- The number of trees in the city increased over ten years, from 10.2 to 11.5 million.
- Over half of the city's tree cover is found in ravines (57.4%) with the rest in residential yards, commercial and industrial areas, institutional properties, and City-owned right-of-ways and parks. The amount of tree cover in Toronto's ravines has remained stable over the last 10 years.
- In spite of the increase in the amount of canopy and the tree population, the total leaf area (described in square metres) of the urban forest has decreased and as a result, the annual amount and value of the ecological services provided by the forest have declined as well.
- The health and condition of street trees has improved markedly and there has been a net gain of over 12,000 street trees since 2008. The street tree population is characterized by better overall condition, higher species diversity, and a higher proportion of medium and large trees.
- 70% of trees on Open Space 1 lands (parks and natural areas) are native species.

Looking at change in the urban forest overall, there are also some less positive trends noted that may have implications for the future direction and benefits provided by the City's urban forest.

- While canopy increased overall in the ten-year study period, the increase peaked at 29.1% in 2014, after which tree cover growth levelled off or possibly declined (though not statistically significant) to 28.4% in 2018.

---

[3] Tree and shrub cover was assessed at approximately 26.6% (SE = 0.4) using random point sampling of 10,000 points from leaf-on aerial imagery from 2009. This was reported in *Assessing Urban Forest Effects and Values: Toronto's Urban Forest,* a 2013 report prepared for the City of Toronto by the USDA Forest Service Northern Research Station.

[4] Tree and shrub cover was assessed at approximately 28.4% (SE = 0.5) as part of the 2018 tree canopy study update, using random point sampling of 10,000 points from 2018 leaf-on satellite imagery at 50cm resolution.

- The distribution of tree cover across the city remains uneven. Toronto's 140 neighbourhoods include a mix of land uses, from highly industrial versus those that are predominantly residential. The effects of land use on tree cover are evident - there is a significant difference (60.9 percentage points) in the amount of tree cover in the most treed versus the least treed neighbourhoods in Toronto.
- Average tree condition has declined across the city, with 69.8% of trees in excellent or good condition compared to 81.6% in 2008.
- Invasive tree cover increased from 10% to 14% between 2008 and 2018 in the Open Space 1 land use (parks and natural areas).
- Even more concerning is the increase in invasive shrub leaf area, which more than doubled from 15% in 2008 to 32.8% in 2018 in the Open Space 1 land use.
- There was an overall increase of 1.4 percentage points in impervious land cover (hard surface) between 2008 and 2018 across the City of Toronto. This represents an area of approximately 892 hectares, or the equivalent of about 1,670 football fields[5] increase in hard surface over the ten-year study period.
- The highest rate of increase in impervious surface is on Commercial and Institutional lands (2.6% and 1.8%, respectively).
- The most area converted to impervious land cover was in the Single Family Residential and Utility and Transportation land uses (349 and 114 ha, respectively).

1.3 | Overview of Study Results

1.3.1 | State of Toronto's Street Trees

Toronto's street trees are a good news story. Since 2008, the city's population of street trees has increased by approximately 12,000 trees, bringing the total to 614,227.[6] This increase is a result of enhanced tree planting programs despite widespread damage from the 2013 ice storm and the significant loss of ash trees from the EAB infestation.

Street trees are in better condition than in 2008. About 74.4% of Toronto's street trees are in excellent or good condition, compared to 49% in 2008. This is the outcome of investing in Toronto's street tree population with more proactive maintenance programs, prompt removal of dead/dying trees, enhanced tree planting standards for development (including minimum soil volume requirements since 2010) and a proactive planting program with appropriate species selection.

[5] An American football field is 0.535 hectares in size.

[6] Includes all trees planted in municipal right-of-ways, as recorded in the City of Toronto's street tree database, as of June 5, 2018.

The size class distribution in the street tree population has also improved over the ten-year study period with a higher proportion of trees in the large diameter size classes, which provide more benefits than trees in the small diameter size classes.

In terms of species composition, the maple genus (*Acer* spp.) is still relatively high in the street tree population. Maples still represent 28% of the trees assessed in the 2018 inventory. This makes the street tree population more vulnerable to pests and diseases that affect maple, such as the Asian long-horned beetle (*Anoplophora glabripennis* Motschulsky). However, the number of street tree species (richness) has increased since the last study, which will contribute to the resilience of Toronto’s street tree population to insect pests, disease and the impacts of climate change.

Street trees provide proportionately more urban forest benefits, representing 19.4% of the total structural value of the urban forest, while accounting for only 5.4% of the total tree population. The data shows that this important asset is contributing valuable ecological services and improving the livability of neighbourhoods and business areas across the city. **Table 1** provides a summary of trends by key indicators for street trees from 2008-2018.

Table 1. Toronto's street tree population by key indicators. (Source: TMMS database, 2018 Street Trees Benefits Analysis)

Indicator	2008	2018	Trend
Population	~600,000	614,227	Positive
# of Street Tree Species & Varieties[7]	144	241	Positive (a more diverse population means increased resilience to pests, disease and other environmental impacts)
# Small Trees (<15.2 cm DBH)	47%	43%	Positive (closer to the ideal size class of 40%)
% Trees in Excellent or Good Condition	49%	74.4%	Positive (population is in better overall condition)
Norway maple as % of population (invasive)	22%	13.5%	Positive (population of this invasive species is decreasing)
% Maple Genus (Vulnerability to Invasive Pests and Diseases)	34%	28%	Positive (lower percentage means fewer street trees vulnerable to specific pests)

The results of undertaking proactive management of street trees have produced the following benefits for the city and its residents:

- Increased ecosystem services due to increased street tree population, larger proportion of medium-large size trees and improved street tree condition;

[7] Some of the disparity in numbers may be due to methodology. In 2018 i-Tree Eco v6 was used to analyze the street tree population. This updated application accommodates a longer list of species and varieties than the i-Tree software did in 2008.

- Cost off-setting in other areas of management (e.g., stormwater runoff, pollution removal, climate change mitigation, etc.);
- Improved efficiency of forest operations by increasing proactive versus reactive management;
- Improved aesthetics and property value where existing trees mature and contribute positively to the walkability/livability of neighbourhoods and business areas; and,
- Reduced vulnerability of street trees to pests and diseases, avoiding long term costs of treatment, removal, and replacements.

In the urban forest, street trees have the most challenging growing conditions. They are exposed to road salt, soil compaction from foot and vehicle traffic, vandalism, heat stress in summer, and are often found in small growing spaces with limited amounts and poor quality of soils.

Continued investment in regular maintenance and the preservation and creation of growing space for street trees through improved development standards and implementation of the Toronto Green Streets programs will ensure that the city continues to derive maximum benefits from its valuable street tree population.

1.3.2 | State of the Urban Forest

The amount of canopy has increased in the last ten years despite substantial pressures on the urban forest. Canopy cover increased from 26.6% in 2008 to 28.4% in 2018[8]. It is worth noting that most of that increase occurred between 2008 and 2014, after which the percent of canopy cover levelled off or declined[9] slightly from 2014 levels of 29.1% (the decline was not statistically significant).

This change after 2014 coincides with the aftermath of the 2013 ice storm as well as the peak of the EAB infestation and tree removals. It is also possible that residential housing construction and other development in the city are having detrimental effects on the forest canopy. About 3,650 development projects were active during the 2008-2018 study period.[10] A 2018 research study undertaken in a downtown Toronto neighbourhood linked building permits to higher rates of tree mortality at both the parcel

[8] Based on 10,000 point sample of high resolution orthoimagery for the years 2013, 2014, 2017 and 2018. Canopy cover is the amount of land area covered by trees and shrubs when viewed from above.

[9] Statistical significance was determined using the standard errors associated with canopy cover estimates.

[10] Toronto City Planning, Research and Information.

and street-section scale. This is because construction activities can be a significant factor in tree decline and mortality due to mechanical injuries to trees, excessive pruning, root severing due to trenching, and restricted root growth caused by soil compaction. The study findings suggest that “where concentrated changes in housing stock are occurring, substantial losses of trees and associated ecosystem services are possible.” [11] Further investigation of development impacts at the site level would help clarify what factors are having the most significant effects on Toronto’s tree canopy, based on a comparison of 2008 and 2018 canopy study data.

Table 2 provides a summary of change in key forest indicators for Toronto’s urban forest, based on a comparison of 2008 and 2018 study data.

Table 2. Urban forest changes, 2008-2018. (Source: 2018 i-Tree Eco plot data)

Indicator	2008	2018	Trend
Forest Cover, Composition And Condition			
Canopy Cover[12]	26.6%	28.4%	Positive
Tree Population	10.2 million	11.5 million	Positive
Total Leaf Area	101,500 ha	90,516 ha	Negative (slight decrease in leaf area despite increase in tree population)
% Trees in Good or Excellent Condition	81.6%	69.8%	Negative (overall decrease in number of trees rated excellent or good condition)
Number of Tree Species	116	179	Positive (increased species diversity can increase resilience to pests and disease & other environmental impacts) Negative (if more invasive species)

[11] Steenberg, J., Robinson, P.J. and A. Millward. 2018. The influence of building renovation and rental housing on urban trees. Journal of Environmental Planning and Management. URL: https://www.researchgate.net/publication/317371669_The_influence_of_building_renovation_and_rental_housing_on_urban_trees

[12] Random point sampling of 2018 leaf-on aerial imagery. All other results in table are from i-Tree Eco plot data.

Indicator	2008	2018	Trend
Ten Most Common Species	57.7% of population	52.6% of population	Positive (slight increase in overall diversity)
Native Tree Species (natural areas)	70%	70%	No significant change
Invasive Shrub Cover in Open Space 1 land use	15%	32.5%	Negative (largely buckthorn)
Trees Under 15.2 cm DBH	68.6%	72.9%	*Positive Long-term positive effects as new trees grow and expand the urban tree canopy*
Ownership And Structural Value			
Structural Value	$7.1 billion	$7.04 billion	*No significant change*
Trees on Private Property	60%	54.4%	*Relative proportion of private trees may have decreased due to increased annual planting on public land and impacts from development*
Ecosystem Services			
Carbon Storage	1.1 million tonnes	1.1 million tonnes	*No significant change*
Gross Annual Carbon Sequestration	46,700 tonnes	35,170 tonnes	*Negative (due to reduced overall leaf area)*
Annual Air Pollution Removal	1,905 tonnes	972 tonnes	*Negative, with some change related to changing study methodologies*
Annual Energy Savings	41,200 MW	47,871 MW	*Positive*
Avoided Runoff	n/a	331,745 m^3	*Not measured in 2008; new baseline for future studies*

Overall, there are some areas of improvement noted with the amount of canopy cover increasing since the last study in 2008 and some positive changes in species diversity. However, the total leaf area of the urban forest has actually decreased, which may reflect the removal of thousands of mature ash, removals and mortality from ice storm damage, other mature trees lost to age and to impacts of redevelopment and the lesser contributions of recently planted/young trees to the total leaf area of the urban forest. A decline in leaf area translates to a loss of benefits provided by the urban forest.

Average tree condition has also declined, with an 11.8 percentage point reduction in trees rated in “excellent or good” condition (from 81.6% to 69.8%). This may reflect the aftermath of the ice storm, as well as insect pest cycles. For example, evidence of gypsy moth (*Lymantria dispar dispar*) damage was detected in the Open Space 1, Open Space 2, Multifamily Residential, and Single Family Residential lands. Defoliation by insect pests (even if temporary) will affect the condition rating of trees. Approximately 2.35% of trees were observed to exhibit damage from this pest.

Forest health routinely fluctuates over the short term in response to various environmental factors. This is why long-term monitoring is important for detecting relevant trends to address over time. Meanwhile, pest management programs like the gypsy moth aerial spray contribute to mitigating tree loss and improving tree condition in the shorter term. A decline in tree condition also contributes to a loss of benefits, as stress factors and poor health inhibit trees' ability to function at optimal levels.

Compared to street trees, the condition of the urban forest in the city's natural areas (assessed in the study as part of the Open Space 1 land use) is not faring as well. About 57.4% of the city's tree cover is found in the ravines[13]. There has been a significant shift in the ecological character of these areas over the last ten years, in terms of the number of mid- and understory invasive species. The study data shows that invasive tree cover has increased from 10% to 14% over the 10-year study period and invasive shrubs now represent 32.5% of the total shrub leaf area on Open Space 1 lands, compared to 15% in 2008.

Toronto's natural heritage system supports the city's 86 Environmentally Significant Areas (ESAs) which are primarily located within valleys, ravines and along the waterfront. These areas function as important migration corridors through the city and beyond its boundaries. Toronto's ravines are a main contributor to the natural heritage system and are home to many species of breeding birds, small mammals, amphibians, reptiles, insects and rare native plants.

Many ravines and other natural areas now have large populations of invasive species like dog-strangling vine (*Vincetoxicum rossicum*), Japanese knotweed (*Reynoutria japonica*), garlic mustard (*Alliaria petiolata*), common buckthorn (*Rhamnus cathartica*), and others. This is a significant finding because invasive species disrupt native ecosystems by preventing the regeneration of native flora, which are valuable resources for many species of native insects, mammals, and birds. By outcompeting native vegetation, invasive species also tend to produce monocultures, which can reduce biodiversity and ecological resilience. Norway maple (*Acer platanoides*), also commonly found in ravines, is another invasive species that causes significant challenges for

[13] Areas regulated under Toronto's Ravine and Natural Feature Protection By-law. Estimates of tree cover in ravines based on land cover classification data.

regeneration of native plants in the understory and has contributed to extreme soil erosion in some areas.

The degradation of these areas has costs not only to native biodiversity, but also to the city in the form of soil and erosion management and expensive restoration activities where invasive species have taken hold.

The City of Toronto has recently developed a Ravine Strategy to direct the protection and management of the city's 11,000 ha of ravine area. The Ravine Strategy presents an opportunity to improve active management in ravines to slow the further degradation of Toronto's natural areas. One outcome of the Strategy to date is a long-term forest health monitoring program (200 permanent sample plots) in partnership with the University of Toronto. This program will monitor forest condition in ravine forests and natural areas and will help to inform management activities in natural areas across the city. Managing invasive species in ravines will be a high priority for urban forest management in Toronto moving forward.

The state of Toronto's urban forest also impacts directly on the ecological health of the watersheds in which Toronto is located. Currently, three of Toronto's eight watersheds support the minimum desired level of 30% tree cover that contributes to somewhat healthy aquatic ecosystems. One of those three watersheds, the Don watershed, has lost tree cover since 2008 and risks falling below the 30% tree cover threshold. Maintaining the connections between urban forest management and forest health will help to support local and regional ecological resilience.

1.4 | Conclusions

Overall, the study findings demonstrate the positive impacts of investing in urban forest management. Regular tree maintenance programs have improved street tree condition and a focus on proper species/stock selection in tree planting has improved the diversity and quality of the city's tree population.

A proactive tree planting program and strengthened tree planting requirements for development sites has helped maintain and increase canopy over the last ten years despite the challenges posed by forest pests, urban development and extreme weather.

Many cities in the GTA face the challenge of meeting canopy goals and enhancing a healthy urban forest while meeting the demands of intensification. The province's growth strategy mandates more intense urban development in the largest city in Canada, which is also the fourth most populous municipality in North America. The population of the Toronto grew by 4.3% between 2011 and 2016.[14] Growth policies along with zoning and urban design standards have contributed to a loss of growing

[14] Census to census growth rate for Toronto CMA, Statistics Canada 2016.

space for trees and vegetation within cities. This is a direct consequence of the continuing increase in the amount of hard/paved surface across the City. At the same time, many municipalities, including Toronto, have set canopy cover goals to support the livability of cities and maintain a minimum functionality of ecosystem services.

In order to continue making progress toward increasing the canopy, the City needs to ensure that appropriate levels of tree retention and tree protection are achieved. Increased efforts to preserve and create growing space and conditions and integrate trees into the urban landscape are also needed as intensification continues. Tree planting in the public realm is important, but the focus on tree planting and tree stewardship on private land needs to continue as there are competing demands and limited available planting space to increase the tree canopy on public lands. A high priority area for the City will be to develop and implement management programs to improve forest health and to manage invasive species within the city's ravines and natural areas. A summary of key findings from the study follows (**Table 3)**.

Table 3. Summary of key findings.

	KEY FINDINGS
	Canopy Cover Extent and Distribution
1.	Overall, there was a 1.8 percentage point increase in canopy cover between 2008 (26.6%) and 2018. However, canopy cover levelled off (or declined slightly) from a high of 29.1% in 2014 to 28.4% in 2018.
2.	Canopy cover increased in all land uses. Canopy cover is lowest (< 10%) in Commercial and Industrial land uses compared to other land uses in the Toronto (all other land uses range between approximately 17%- 58% canopy cover).
3.	Only three of Toronto's seven watersheds currently meet the recommended 30% tree cover required to maintain minimum watershed function.
4.	More than half of Toronto's tree cover (57.4%) is located in the city's ravines. Tree cover in ravines remained relatively stable from 2008-2018.
5.	There is a wide range of tree cover across Toronto neighbourhoods, with a 60.9 percentage point difference between the neighbourhood with the highest tree cover (High Park-Swansea at 65.2%) and the neighbourhood with the lowest tree cover (Bay Street Corridor at 4.3%). This is affected by factors like land use, presence of parks & ravines and rates of growth and development, among other things.

	KEY FINDINGS
6.	Out of 140 neighbourhoods in Toronto, 83 had an increase in tree cover while 57 had a decrease. Of those neighbourhoods with a change in canopy cover, 22 showed statistically significant change. Fourteen neighbourhoods showed an increase and eight showed a decrease. This is consistent with the finding of overall positive tree cover change across the city.
	Land Cover Change
7.	The amount of impervious surface in Toronto has increased by 1.4% from 47.9% to 49.2% between 2009 and 2018. The highest rate of change is in the Utility & Transportation land use (of 4.8 percentage points increase in hard surface). However, the most area converted from pervious to impervious is found in the Single Family Residential land use, which saw a 349 ha increase in hard surface from 2009-2018.
	Urban Forest Benefits
8.	Despite an increase in canopy cover and tree population, the total leaf area of the urban forest decreased by about 11% (from 101,500 in 2008 to 90,516 hectares in 2018).
	Tree Planting
9.	The proportion of trees on public property has increased by 5.6 percentage points, while the proportion of the tree population on private property has decreased from 60% in 2008 to 54.4% in 2018. Factors in this shift could be the result of successful public tree planting programs and natural regeneration.
10.	Overall tree species richness has increased in the urban forest, from 116 species in 2008 to 179 species in 2018. 10% of the 179 species identified are invasive.15 However, these species represent 18% of the City's current tree population.
	Forest Health and Condition

[15] Using the same list of invasive species from *Every Tree Counts* (2013), as per Canadian Botanical Conservation Network. This number may be higher depending on the source.

	KEY FINDINGS
11.	Native tree canopy (leaf area) in the Open Space 1 lands remained relatively stable between 2008 and 2018, at around 70%. The leaf area of invasive tree species in Open Space 1 lands increased from 10% in 2008 to 14% in 2018. The leaf area of invasive shrubs in natural areas (Open Space 1 land use) more than doubled in ten years, from 15% in 2008 to 32.5% in 2018. Commercial lands have the lowest proportion of tree canopy composed of native species (21%) and the highest proportion of tree canopy composed of invasive species (54%).
12.	Average tree condition across the urban forest has declined – in 2008, 82% of trees were rated in excellent or good condition. In 2018, that number declined to 70%, with an increase in standing dead trees also observed (7% in 2018 vs. 4% in 2008).
13.	The amount and value of ecological services provided by the urban forest has declined as a result of less total leaf area of the urban tree canopy despite an increase in the number of trees.
	Street Trees
14.	Street tree condition has improved, with 74.4% of street trees in good or excellent condition compared to 49% in 2008. This shows the effects of regular tree maintenance.
15.	The size class distribution of street trees has improved and includes an increased number of larger trees (45cm DBH and up), which produce more urban forest benefits.
	Prioritizing Planting Area
16.	In total, there are 28,668 hectares of possible planting area (PPA) across the city of Toronto. Approximately 52% of this area or 14,822 hectares consist of pervious land cover types. By comparison, there are 64,167 hectares of existing tree canopy cover across the City. The greatest amount of available pervious planting area by land use is on Single Family Residential lands (5,292 ha), followed by Open Space 1 (1,902 ha), Open Space 2 (1,935 ha) and Industrial (1,733 ha) lands. The greatest amount of impervious PPA is found on Single Family Residential (4,946 ha), Industrial (3,765 ha) and Multifamily Residential lands (1,425 ha).

	KEY FINDINGS
17.	Available pervious planting area is unevenly distributed across the city's 140 neighbourhoods. The amount of available area ranges from 328 ha in Woburn to 4.9 ha in North St. James Town. This is a result, in part, to the intensity of land uses in some neighbourhoods and reveals the inequitable benefits derived from the urban forest by some neighbourhoods. The most area of impervious PPA, by available hectares, is found in Single Family Residential (4946 hectares), Industrial (3765 ha) and Multifamily Residential lands (1435 ha).

2 | Introduction

2.1 | Study Background

The City of Toronto Official Plan recognizes the importance of the urban forest and recommends protection and enhancement of the existing urban forest resource. The Urban Forestry Branch of the Parks, Forestry and Recreation Division provides the essential services needed to protect, maintain, and enhance the urban forest both on public and private property. Urban Forestry works with City Planning, Toronto Water, Transportation Services and other divisions and agencies to develop and implement programs to protect, maintain and expand the city's tree canopy.

The City has committed to sustaining and expanding the urban forest as described in *Sustaining and Expanding the Urban Forest: Toronto's Strategic Forest Management Plan 2012-2022*. Developed in consultation with internal and external stakeholders, the Plan provides the direction necessary to achieve a healthy, sustainable urban forest. It includes the following six strategic goals:

1. Increase canopy cover;
2. Achieve equitable distribution;
3. Increase biodiversity;
4. Increase awareness;
5. Promote stewardship; and,
6. Improve monitoring.

The first city-wide analysis of Toronto's urban forest was carried out in 2008. The results were published in *Every Tree Counts: A Portrait of Toronto's Urban Forest* (2009, revised 2013) and *Assessing Urban Forest Effects and Values, Toronto Urban Forest* (2013). Utilizing land use mapping (provided by the City of Toronto) together with field data collected at sample plots across the city, the USDA Forest Service completed an i-Tree Eco analysis (formerly known as UFORE) that provided information on species composition, condition, size class distribution and quantitative measures of ecological services and value. This information led to several high-level recommendations that have since been implemented through the development of more detailed operational plans.

2.2 | 2018 Study Purpose and Objectives and Methodologies

2.2.1 | Purpose and Objectives

In order to monitor changes in the structure and function of the urban forest and to measure progress toward strategic goals, the Strategic Forest Management Plan (SFMP) recommended that a tree canopy assessment be undertaken every 10 years. Hence, the purpose and objectives of this 2018 study are to:

- Update information on the current composition, structure and distribution of Toronto's urban forest;
- (Re)quantify several key ecological services and benefits provided by the urban forest;
- Identify opportunities for increasing sustainable tree cover; and,
- Compare and evaluate current conditions and urban forest attributes to the baseline conditions to help measure progress toward achievement of the City's urban forestry goals and objectives.

As with every study, there are limitations to the extent that a cause-and-effect relationship can be asserted. For this study, information pertaining to the causes and effects of the changes in the urban forest can only be inferred through examination of potential factors that could contribute to the changes detailed herein. This study uses the data analysis to try and determine what is happening at the individual site or neighbourhood level. Other City databases and information can help support this analysis, but in some cases the study will raise new questions that need further investigation as part of ongoing urban forestry program planning and operational management adjustments.

The report summarizes the findings of this 2018 update. The report draws on the following inputs, similar to those used in 2008:

1. i-Tree Eco plot data (407 plots)
2. Street Tree Benefits Analysis (using Toronto street tree data)
3. A continuous land cover classification completed by the City of Toronto, as input to various mapping products and further urban tree canopy/possible planting area analyses
4. Background and status reports on the implementation of previous plan and study recommendations
5. Feedback from a workshop and iterative discussions with City of Toronto and key experts

To the extent possible, the 2018 study compares available key indicators to assess change in the urban forest over a 10-year period. It should be noted that there are some limitations to direct comparability of data, given changes in context, study methodologies and data resolution.

More details on the merits and limitations of the different methodologies used to classify land cover and capture change follow.

2.2.2 | Land and Tree Cover Assessment Methodologies

The area covered by trees and shrubs in urban regions has become a standard metric for evaluating the distribution and extent of canopy cover. Using either airborne or satellite imagery, canopy cover is generally the two-dimensional, orthogonal projection of tree and shrub canopies onto the plane of the ground surface[16], and is measured in units of area (square metres, hectares, etc.) and often reported as percent canopy cover. The properties of greatest interest in the evaluation of canopy cover are quantity and spatial distribution[17].

In addition, the estimation of canopy cover is usually complemented by the estimation of the extent and distribution of other land cover types (e.g., grass, bare earth, buildings, roads, other impervious cover, etc.), such that increases or decreases in canopy cover can be contextualized by comparing changes in the distribution and extent of other land cover types over time.

Using both aerial and satellite imagery, the two most common approaches to sampling canopy cover are: 1) the manual photo-interpretation of randomly distributed point samples over defined areas, and 2) the automated continuous classification of land cover types based on spectral signature and previously measured and mapped features such as building footprints, roads, etc. In recent years, the height of image features measured using LiDAR (Airborne laser scanning a.k.a. **Li**ght **D**etection **A**nd **R**anging) data has increasingly been used to distinguish tree from shrub cover based on height. In 2018, LiDAR was used to complement the automated land cover classification analysis. In both cases, the resulting data in this study were post-stratified to look at attributes of interest at different geographic scales (e.g., ward, neighbourhood, and watershed).

Each approach has its advantages and limitations. In the manual interpretation approach, the land cover type at a specific point position is tallied for each of the pre-determined land cover types, including canopy cover. The proportion of sample points represented by each land cover type statistically represents the relative amount of each land cover type, expressed in terms of percent cover for the area sampled. Because a standard error for each cover type estimate can be calculated, the statistical

---

[16] Jeffrey T. Walton; David J. Nowak; Eric J. Greenfield. 2008. Assessing urban forest canopy cover using airborne or satellite imagery. Arboriculture & Urban Forestry 34(6): 334-340

[17] Ibid.

significance of differences within and among land cover types over time can readily be assessed.

As these estimates are based on point sampling, the precise spatial distribution of the estimated canopy cover cannot be determined. Hence, it is a powerful tool to rapidly sample, detect and assess land cover type change over large areas, but unless a very high density of points is sampled in smaller areas, such as at the neighborhood scale or the city block scale, the standard errors associated with those estimates tend to be very high resulting in much less reliable estimates.

The automated continuous classification of land cover can be undertaken using either airborne or satellite imagery, but due to the complexity of image classification techniques it is often performed on medium resolution multi-spectral satellite imagery. There are many available image classification techniques including normalized difference vegetation index (NDVI), pixel-based and object-oriented classification image features, and various other hybrid techniques.[18]

The principal advantage to the automated continuous classification of tree cover and other land cover types is that it is spatially explicit and can be mapped at any scale with spatial accuracy only constrained by the resolution of the imagery used. The main disadvantage of this approach is that the statistical significance associated with different estimates of land cover cannot be determined with confidence. This is due to the fact that classification errors cannot be easily detected, since it is virtually impossible to ground truth the classification across large areas typically involved in canopy cover assessments. Most often, manual corrections are made to the data as part of quality assurance checks, which renders the determination of statistically different estimates within and among land cover types at multiple spatial scales virtually impossible. The automated continuous classification approach used in 2008 made a number of manual corrections post-analysis. In 2018, no manual correction was performed.

Table 4 provides a summary of the key differences between the two methodologies for producing trend information about Toronto's urban forest.

[18] Ibid

Table 4. Summary of differences between canopy cover methodologies.

Description	Point Sampling	Automated Land Cover Classification
Imagery	Can use either airborne or satellite imagery. Best results are obtained using high resolution leaf-on colour airborne imagery. Can use leaf-off imagery but this tends to underestimate canopy.	Can use either airborne or satellite imagery. Due to the complexity of image classification techniques it is often performed on medium resolution colour satellite imagery. Requires multi-spectral leaf-on colour imagery with a near infrared (NIR) band to detect vegetation/tree cover.
Spatially explicit	No However, data may be aggregated at different spatial scales for mapping, provided that a sufficient number of point samples are tallied to produce an acceptable standard error for the spatial unit of interest e.g., ward, neighbourhood, land use.	Yes Spatially explicit and can be mapped at any scale, and is only constrained by the resolution of the imagery used. Can provide parcel-level information on land/tree cover for detailed mapping and analysis. Can be used for spatially- explicit change detection.
Known accuracy	Yes Possible to calculate the standard error associated with cover type distribution estimates. It is also possible to calculate confidence intervals. Therefore, statistical accuracy of the resulting estimates can be assessed. The point sampling approach is repeatable and useful to assess the statistical significance of differences in cover type estimates over periods of time for which comparable imagery is available	No The main disadvantage of this approach is that there is no simple way to assess the accuracy of the classification outcomes. This is due to the fact that classification errors cannot be easily or consistently detected, since it is virtually impossible to ground truth the classification across the large areas typically involved in urban forest canopy cover assessments. One cannot calculate the standard error associated with the classification outcomes. The classification approach can be repeated using modern data analytics algorithms.

Description	Point Sampling	Automated Land Cover Classification
Cost and time	Low cost, low time & technology requirements.	High cost, time intensive, specialized software requirements.
Utility	Best for statistically reliable estimates and change assessments of land and canopy cover. Change assessments at smaller spatial scales e.g., neighbourhoods, require pre-stratification to ensure enough points are sampled for acceptable accuracies.	Best for mapping spatial extent and distribution of land and tree cover at a single moment in time. Reliability of change detection, especially at smaller scales, cannot be ascertained due to limited replicability of the approach and corresponding differences in cover type classification accuracies, which cannot be measured.

2.2.3 | i-Tree Eco Assessment

i-Tree is a suite of software applications developed by the United States Department of Agriculture (USDA) Forest Service and partners. It is used to collect data on urban forest features and calculate the physical properties of the resource and the value of benefits they provide. i-Tree Eco is used by municipalities to determine the forest structure, environmental effects, and economic value within the study area. i-Tree Eco and other i-Tree applications have been used by municipalities, regional governments, non-profit organizations, and other groups around the world to study urban forests and communicate their benefits to stakeholders.

On a municipal scale, i-Tree Eco is employed using a plot-based approach to sampling the urban forest. Field crews collect data on the trees and shrubs located in each plot, including tree diameter at breast height (DBH), tree height, species, and condition. After the data are uploaded, the software makes calculations from the plot data to produce estimations of the characteristics and value of the study area's entire urban forest. The results include analysis of structural attributes such as species composition, tree size class distribution, leaf area, and tree condition; environmental services such as pollution removal, carbon storage and sequestration, and home energy savings; and the financial value related to structure and environmental services. i-Tree Eco may also be used to forecast future urban forest conditions and calculate risk to forest resources from pest infestations.

3 | Planning Context

Ontario's body of provincial legislation, plans, and policies can both enable and hinder the protection and growth of the urban forest. Their influence cannot be overstated, as development and intensification under the provincial growth strategy has significant implications for the short- and long-term outlook of the urban forest and the city's natural heritage system. Opportunities for and constraints to sustaining and enhancing the urban forest are influenced by policies from the following planning policy documents and planning authorities:

- Ontario's *Planning Act* (1990)
- Provincial Policy Statement
- *City of Toronto Act, 2006*
- Growth Plan for the Greater Golden Horseshoe, 2017
- Greenbelt Plan (2004, 2017)
- Decisions made by the Local Planning Appeal Tribunal (LPAT, former Ontario Municipal Board)
- Decisions made by the Committee of Adjustment panel and if applicable, appealed by Toronto Local Appeal Board (TLAB)

At the municipal level, these are implemented through the following development review processes:

- Official Plan
- Secondary Plans
- Zoning Bylaw Amendments
- Site Plan Applications
- Committee of Adjustment Applications – Minor Variance and Consent to Sever
- Design Guidelines
- Toronto Green Standard
- Toronto Complete Streets
- Green Streets Technical Guidelines

Forest management in Toronto also happens in concert with many other guiding plans and strategies. Context is provided by other relevant environmental plans including:

- Toronto's Wet Weather Flow Master Plan (2003)
- Climate Change, Clear Air and Sustainable Energy Plan (2007), later replaced by Transform TO (2017) and Resilience Strategy (2019)
- The Climate Change Adaptation Strategy (2008)
- Identification of Potential Environmentally Significant Areas (ESAs) in the Toronto
- Toronto Ravine Strategy (2017)

- Toronto and Region Conservation Authority Terrestrial Natural Heritage System Strategy (2007)
- Toronto Public Health – Protecting Vulnerable People from Health Impacts of Extreme Heat, Shade Guidelines (2010)

Toronto is experiencing significant development activity and population growth. From 2008 to 2018 about 3,650 development projects were active.[19] The 2017 Growth Plan forecasts the city's population will grow to 3.4 million people and provide 1.7 million jobs by 2041.

Planning and zoning requirements have impacts on whether growing space is retained for trees, and to some extent how those are protected. While most of the planning decisions are made by other City Divisions, they have a major impact on Urban Forestry's ability to protect green space and retain and plant new trees. A number of competing uses (e.g., infrastructure requirements) between City Divisions also impact the ability to integrate trees into the urban landscape as well as the ability to retain green space. Many of the established planning and review processes limit what can be required as part of development applications, where tree removals or loss of growing space is concerned.

This context highlights one of the main challenges to continued expansion and maintenance of the urban forest under increasing intensification scenarios. Evidence for this pressure comes from the study data, which shows an increase of 1.4 percentage points (from 47.9% to 49.2%)[20] of impervious land cover in the City, which may be attributed to urban growth and development over the study period. Moving forward, increased collaboration between City Divisions will be a key part of supporting the maintenance and expansion of the tree canopy.

3.1 | Forestry Service Pillars: Maintain, Protect, Plant, Plan

The Urban Forestry branch of Parks, Forestry and Recreation Division plays a critical role in the maintenance and management of Toronto’s urban forest. Forestry’s four service pillars are: Maintain, Protect, Plant and Plan.

Maintain

- Includes tree maintenance activities like pruning, tree risk management, tree removal and pest treatments (e.g., aerial gypsy moth spray, ash injections) and forest management activities like prescribed burns and invasive species control.

[19] Toronto City Planning, Research and Information.

[20] 2009 leaf-on point sampling data (from 2013 Assessing Urban Forest Effects and Values report) and 2018 leaf-on point sampling data.

Protect

- Development and enforcement of policy and by-laws to protect the urban forest, including Street Tree, Private Tree, Ravine and Natural Feature Protection and Parks By-laws as well as education and outreach to promote the value of Toronto's urban forest.

Plant

- Tree planting is an ongoing activity that helps maintain and ideally grow the urban forest. Planting has been a particular focus in the last planning cycle, and a Tree Planting Strategy will support ongoing efforts to successfully plant trees, on both public and private land.

Plan

- Urban Forestry works with many other divisions and partners to plan and execute a sustainable and effective urban forestry program. Planning includes all aspects of adaptive management, from studies and reports to management plans, to monitoring and implementation of new technologies and innovations in urban forest management.

Urban Forestry Branch leads efforts to manage and grow the urban forest. Activities of other City Divisions are critical to the long-term success of this work. City Planning, in the pre-application consultation stage, could assist Urban Forestry by ensuring that the applicant is made aware of potential impacts to the natural environment and that the applicant is provided with ideas on how to lessen or mitigate potential impacts at this early planning stage. Many urban forestry programs have been developed or are in progress. These program elements are those over which Urban Forestry has some direct control or responsibility. This includes foundational work like:

- Completing and updating forest inventories
- Writing management plans
- Developing and administering tree-bylaws
- Developing and implementing proactive tree maintenance programs
- Putting emergency response procedures in place
- Updating work management and asset management systems
- Maximizing tree planting on available public lands
- Ensuring tree planting through review of development applications
- Implementing effective pest monitoring and response programs
- Implementing infrastructure improvements such as tree planting specifications for planting trees in hard surfaces
- Inputting Toronto Green Standards v3 performance measures

Moving forward, it is fair to say that further expansion of Toronto's canopy will require increased and intensive collaboration across City divisions as well as the participation of private land owners to address the challenges of growing trees in an increasingly urbanized environment. Some of the key urban forest challenges for Toronto include:

- Expanding the canopy under a scenario of decreasing growing space and increasing urban intensification;
- Mitigating the future impacts of climate change on the urban forest;
- Managing pest and disease infestations that could have large-scale impacts (e.g., Asian long-horned beetle remains a threat);
- Developing a realistic strategy and priorities for managing invasive species and protecting native biodiversity, particularly in the City's natural areas and ravines;
- Managing increasing use and recreational pressures in the City's natural areas;
- Engaging effectively with citizens and developers to communicate the value of the City's urban forest;
- Maintaining adequate operational funding to meet the ongoing maintenance requirements of an expanding tree canopy as well as additional funding to address significant forest health issues as identified in this report.

Despite these challenges, effective management of the urban forest is achievable with a recognition of the many important contributions of the urban forest to the City's resilience and livability.

4 | Progress Report on Past Study and Plan Recommendations

Toronto's urban forestry program reflects the strategic direction provided in the Strategic Forest Management Plan and the key findings of the first tree canopy study in 2008. The City is applying an adaptive management approach to the management of Toronto's urban forests. Adaptive management is an iterative process in which managers test hypotheses and adjust decisions and actions based on experience, evidence and actual changes.[21]

Over the last 10 years, new forestry programs, plans and policies have been developed and adapted to address the changing environmental conditions impacting the urban forest, based on the results of a first tree canopy study and subsequent research (Figure 1). This information has been used to set the direction for the forestry program, which will again be adjusted based on the findings from this 2018 Canopy Study update.

[21] George H. Stankey, Roger N. Clark, Bernard T. Bormann. 2005. Adaptive Management of Natural Resources: Theory, Concepts, and Management Institutions. USDA Forest Service. General Technical Report PNW-GTR-654. URL: http://www.icmbio.gov.br/portal/images/stories/imgs-unidades-coservacao/usda.pdf

THE ADAPTIVE MANAGEMENT CYCLE

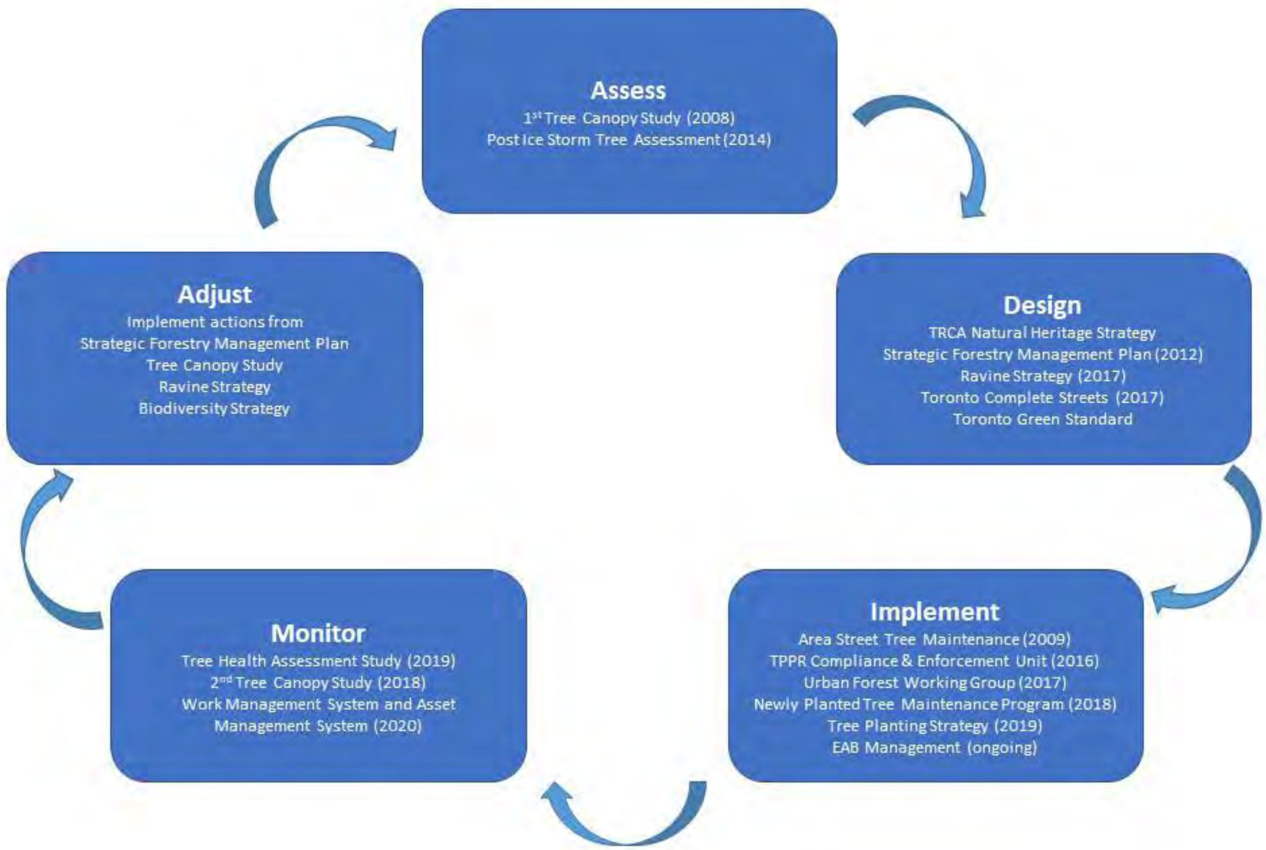


Figure 1. The adaptive management cycle in relation to Toronto's urban forestry program.

Progress in several areas can be related to implementing past study and plan recommendations, which have resulted in some noted improvements to the City's forestry assets as discussed in this report.

In order to develop relevant actions in response to the 2018 canopy study findings, a review of the status of previous recommendations from the 2012 Strategic Forest Management Plan is included here. Some of these recommendations are still relevant and should be carried forward in future management programs.

An overview is provided in Table 5. For a more a detailed summary, see Appendix F. The actions taken are grouped under the 'four pillars' of the City's urban forestry program and reflect some of the work that has been completed or is in progress.

Table 5. Status of activities from the Strategic Forest Management Plan 2012-2022

PROGRAM AREA
MAINTAIN
Toronto Green Standard, Version 3 – Ecology performance measures (with City Planning). Development Features • Create landscapes that support tree growth and enhance the urban forest • Protect, restore and enhance Ravine and Natural Feature Protected Areas • Enhancement of native plant and animal species, habitat and ecosystems
A proactive Area Street Tree Maintenance program is working toward an average 7-year maintenance cycle.
A proactive Area Park Tree Maintenance program is working toward an average 7-year maintenance cycle.
Natural Environment and Community Programs (planting and stewardship) are ongoing for natural areas.
Funding and in-kind support for Adopt-a-Park-Tree and Adopt-A-Street-Tree programs.
PROTECT
Urban Forestry's Tree Protection and Plan Review (TPPR) compliance and enforcement unit is in place to enforce tree protection requirements of the City's private, public and ravine and natural feature tree bylaws.
PLANT
Council approved the creation of a Tree Canopy Reserve Fund, to support efforts to expand the tree canopy.
PLAN

PROGRAM AREA
Internal Urban Forestry Working Group with representatives from Tree Protection and Plan Review, Forestry Policy and Planning and Commercial Trees (2018) established to coordinate and develop processes to ensure the Urban Forestry units are working together to improve services, processes and organization. This includes: • Developing a standard commenting process to provide consistent and collaborative Urban Forestry technical comments when reviewing projects, developments and interdivisional initiatives. • Developing strategies and polices that affect multiple Urban Forestry sections to improve overall group functionality such as the development of the new street tree planting details.
Toronto Complete Streets Guidelines, Toronto Green Streets Technical Guidelines, Toronto Green Standard, Toronto Ravine Strategy, Environmentally Significant Area Management, Parkland Acquisition Strategy and Natural Environment Trails Strategy are in progress or completed.
A new work and asset management system is in development.
The City is developing a long term forest health monitoring program (200 plots) to be established in the City's ravines in order to provide more detailed information about the health and condition of natural areas.
Urban Forestry developed a species diversity policy for planting in 2018.

Natural systems are complex and the work to manage tree canopy loss, forest condition and species composition in the City is an ongoing process. Pressures on the forest shift over time and require the ability to adapt and adjust to new threats as they arise.

A good example of how this has worked well in the past was the coordinated response between regulatory agencies and different levels of government when the Asian long-horned beetle (ALHB) threatened Ontario's forests. A crisis was averted through the cooperation of many City staff with other agencies, but also because the significance of the threat was prioritized with investments to follow through on reaction and response. Management of the EAB infestation is another good example of the type of sustained investment and response required to properly manage a serious forest health problem.

The findings of the 2018 canopy study support work already in progress and identify new areas of management required to make continued gains toward the City's tree canopy goals.

5 | 2018 Tree Canopy Study Findings

5.1 | Distribution of Canopy in Toronto

Overall, canopy cover across the city of Toronto is 28.4%[22] with the distribution varying across wards and neighbourhoods (Figure 2). Concentrations of canopy are visible along the major Toronto river systems, including the Rouge, Don and Humber Rivers. Areas of low canopy overlap with Employment Areas and pre-employment areas, such as the Port Lands.

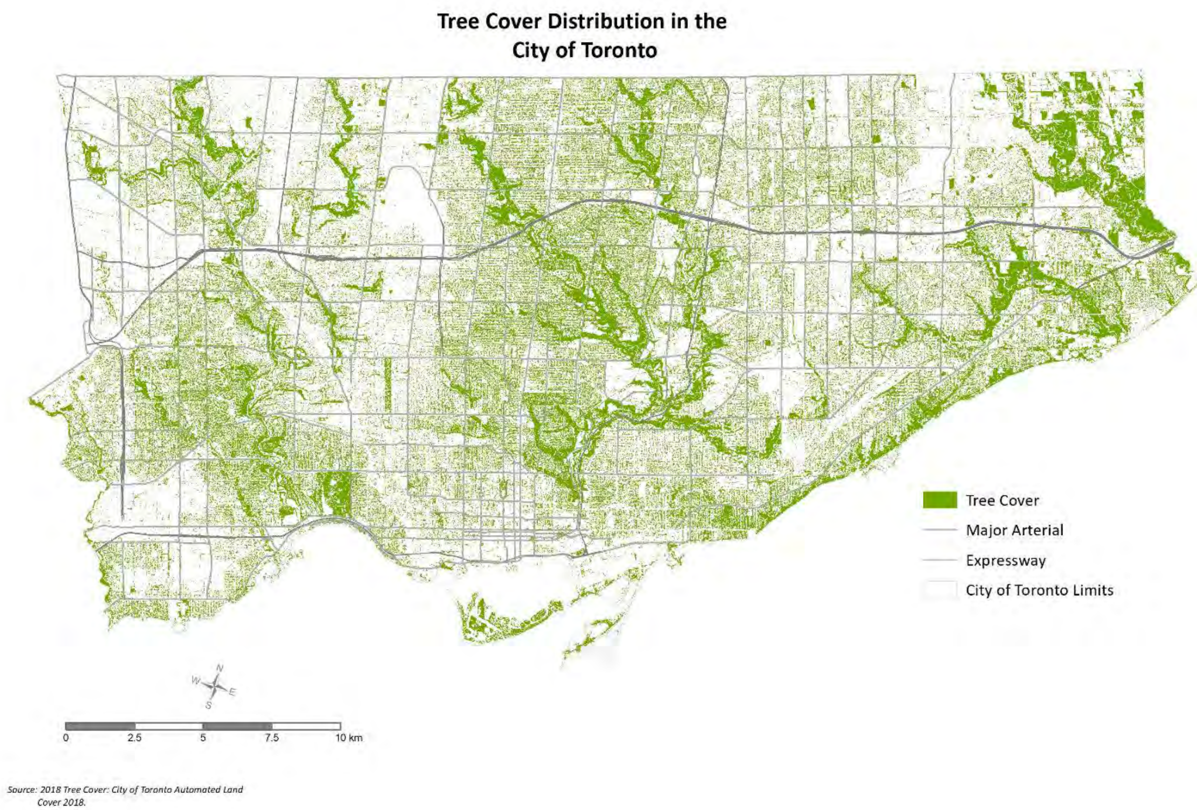


Figure 2. Tree cover distribution in Toronto. (Source: 2018 land cover data, City of Toronto)

Over half of Toronto's tree cover (57.4%) is located within the area defined under the *Ravine and Natural Feature Protection By-law* (Figure 2) with the balance located in non-ravine areas such as front and back yards, along City right-of-ways, and in parks. Tree cover in the city's ravines remains relatively stable, showing a slight decrease of 0.8 percentage points from 2008-2018 (**Table 6**). At approximately 11,181 ha, the area covered by the Ravine and Natural Feature Protection By-law represents approximately 17% of Toronto's land area (Figure 3).

[22] Random point sampling of 2018 leaf-on satellite imagery.

Table 6. Tree Cover Change within Ravine and Natural Feature Protection By-law Area. (Source: 2008 and 2018 land cover data, City of Toronto)

Year	Tree Cover (ha)	Total Ravine Area (ha)	Tree Cover %	Change (Percentage Points)
2008	6,503.1		58.16	
2018	6,415.2	11,180.6	57.37	**-0.8**

Key finding: More than half of Toronto's tree cover (57.4%) is located in the city's ravines. Tree cover in ravines remained relatively stable from 2008-2018, showing a possible small decline of 0.8 percentage points.[23]

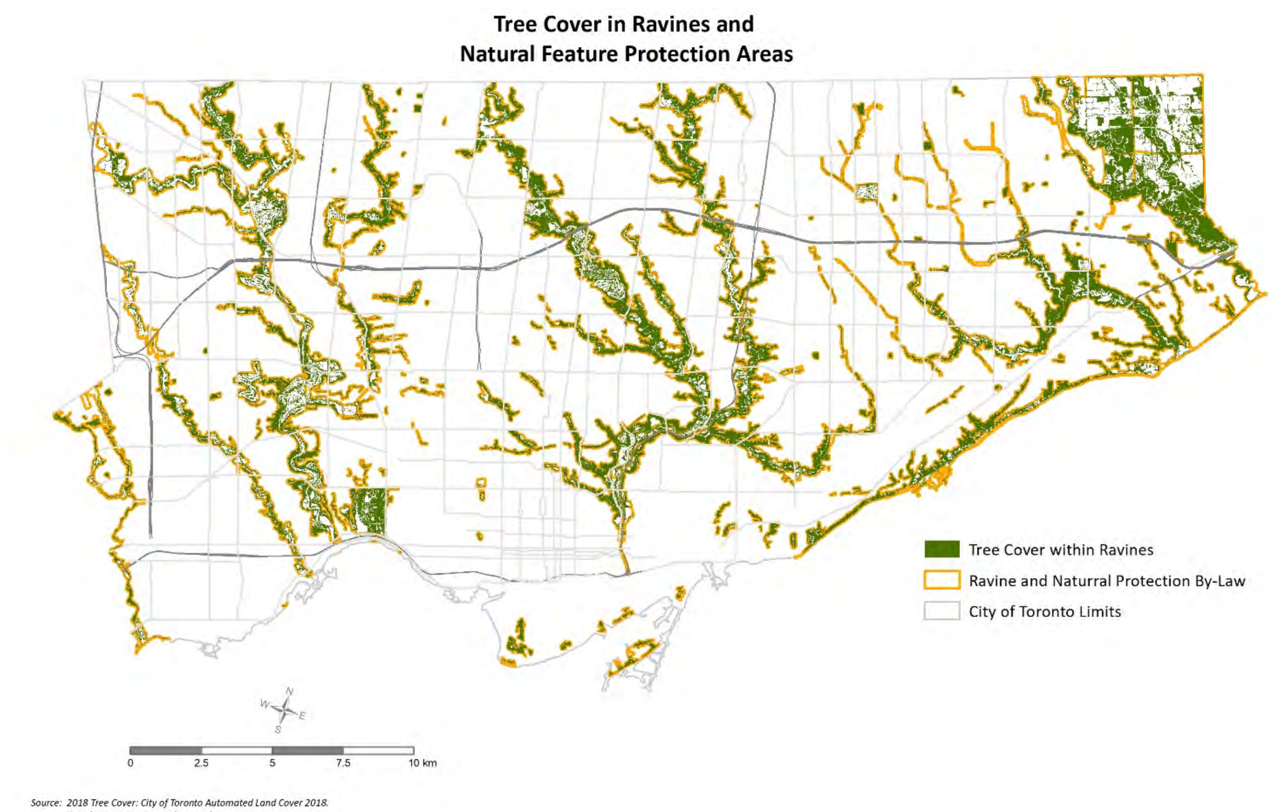


Figure 3. Tree cover in ravines (as defined by the Ravine and Natural Feature Protection By-law). (Source: 2018 land cover data, City of Toronto)

[23] Based on 2008 and 2018 City of Toronto land cover data change detection, statistical accuracy not available.

Another way to look at the distribution of tree cover is by neighbourhood and ward boundaries. See Figures 4 and 5.

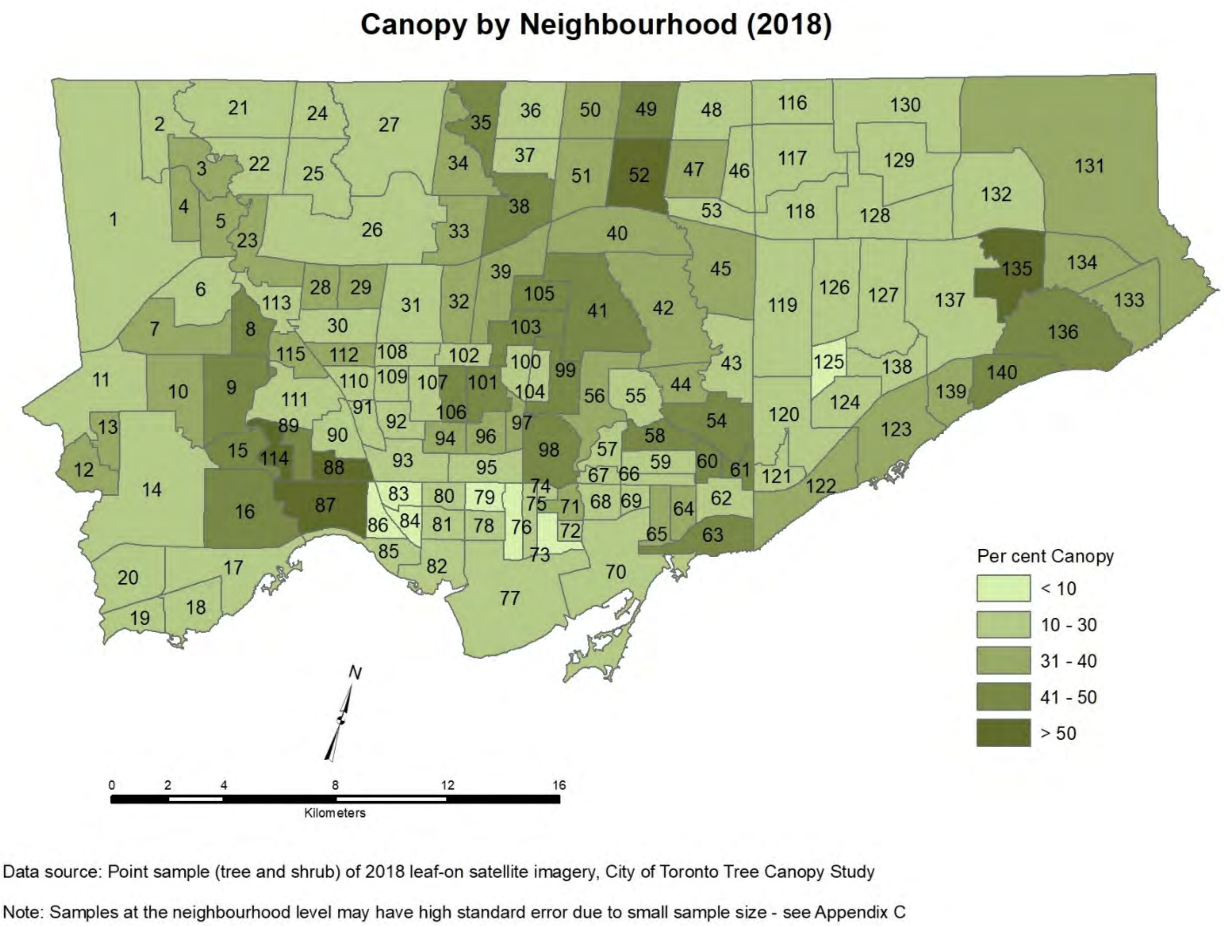


Figure 4. Canopy in Toronto neighbourhoods (Source: 2018 leaf-on point sample)

There is a 60.9 percentage point difference between the neighbourhood with the highest canopy in 2018 (High Park-Swansea at 65.2%) and the neighbourhood with the lowest canopy in 2018 (Bay Street Corridor at 4.3%).[24] This wide range of tree cover within the city is influenced in part by land use types within each neighbourhood. Some neighbourhoods include large sections of wooded ravines while others are dominated by commercial or industrial land uses. In the latter case, the Bay Street Corridor with low canopy is a highly urbanized area stretching between Bloor and Front streets to the north and south. The neighbourhood includes hospitals and research facilities, the Financial District, the Eaton Centre and City

[24] Based on 2018 Tree Canopy Study point sampling data. *Note: Some estimates of canopy at the neighbourhood level have high standard error as a result of small sample size.* See Appendix I for standard error by neighbourhood.

Hall/Nathan Phillips Square. Queen's Park provides most of the green space in this dense downtown neighbourhood, which contains relatively few residential areas, most of which are apartments and condos.[25] By contrast, High Park-Swansea encompasses a mature, residential neighbourhood with semi-detached homes that were built in the early 20th century. At its centre is the 161 hectare High Park, which also contributes extensively to the overall neighbourhood canopy.[26]

Table 7 shows canopy cover for the most and least treed neighbourhoods in Toronto, as they were first reported in the 2008 tree canopy study.[27] As per the city-wide estimates, canopy remained relatively stable in most neighbourhoods, with four of these neighbourhoods showing a statistically significant change (Rosedale-Moore Park and Bridle Path-Sunnybrook York Mills with a decrease in tree canopy, Milliken and Humber Summit with an increase in canopy).

[25] https://www.toronto.com/community-static/4550528-bay-street-corridor/

[26] https://www.toronto.com/community-static/4555246-high-park-swansea/

[27] Derived from point sampling 2009 (2013 Assessing Urban Forest Effects and Values) and 2018 leaf-on imagery.

Table 7. Change in canopy in the five most treed Toronto neighbourhoods from 2009-2018 (Source: 2009 leaf-on point sampling data from 2013 Assessing Urban Forest Effects and Values report, 2018 leaf-on point sampling data).

Neighbourhood	% Canopy 2009 with % Standard Error	% Canopy 2018	10-year Change in Canopy (percentage points)
*Rosedale-Moore Park (98)	61.8 (SE 5.9)	44.9 (SE 6.0)	-16.9
*Bridle Path-Sunnybrook-York Mills (41)	55.6 (SE 4.1)	47.1 (SE 4.2)	-8.5
Mount Pleasant East (99)	54.8 (SE 7.7)	44.9 (SE 7.1)	-9.9
Morningside (135)	53.8 (SE 5.6)	52.7 (SE 5.2)	-1.1
Forest Hill South (101)	51.2 (SE 7.8)	40.6 (SE 8.7)	-10.6

***Statistically significant change in canopy (tree and shrub) as measured by point sampling.**

Table 8. Change in canopy in the five least treed Toronto neighbourhoods from 2009-2018 (Source: 2009 leaf-on point sampling data from 2013 Assessing Urban Forest Effects and Values report, 2018 leaf-on point sampling data).

Neighbourhood	% Canopy 2009 with % Standard Error	% Canopy 2018	10-year Change in Canopy (percentage points)
Bay Street Corridor (76)	6.7 (SE 4.6)	4.3 (SE 4.3)	-2.4
Junction Area (90)	6.7 (SE 4.6)	15.0 (SE 6.1)	8.3
*Milliken (130)	8.1 (SE 2.1)	13.1 (SE 2.7)	5.0
New Toronto (18)	8.7 (SE 4.2)	15.2 (SE 5.1)	6.5
*Humber Summit (21)	8.8 (SE 3.0)	15.8 (SE 3.3)	7.0

***Statistically significant change in canopy (tree and shrub) as measured by point sampling.**

While it is not realistic to expect an equitable distribution of canopy everywhere in the City, some municipalities are interested in narrowing the gap where opportunities for increasing canopy are identified. Some of the benefits of increasing canopy in deficient areas include the following:

- More even distribution of the benefits of trees and ecological services provided across the entire city e.g., intercepting storm water runoff, pollution reduction, etc.
- It addresses possible social equity issues around the benefits derived from canopy, which may be less in lower income neighbourhoods. In one example, researchers from the University of California at Berkeley looked at 63,436 census block groups from across the US covering 304 metropolitan areas. They identified areas most at risk in extreme heat waves as related to a lack of tree cover or the presence of high amounts of impervious surfaces. Both factors have been shown to exacerbate the urban heat island effect, suggesting that people who live in these neighborhoods may be at the highest heat risk as temperatures warm with climate change. The US study also found that lower-income neighborhoods were substantially less likely to have trees and are therefore more vulnerable.[28]
- More continuous canopy also has benefits for biodiversity, as even single urban trees can provide habitat and connections between urban green spaces for e.g., birds and other fauna.
- From a public health perspective, trees also support active transportation, helping to make neighbourhoods more walkable, cyclable and livable.

The 2014 Boston research study, however, also notes some of the challenges to increasing urban canopy to address social justice issues. The study found that even when tree planting initiatives focus specifically on increasing canopy for environmental justice communities (and this could apply to any highly urbanized land use), equitable distribution of urban trees is difficult to achieve. The difficulties noted are a result of both policy and funding aspects, but also ecological ones, including the physical availability of tree planting sites in some urban communities.[29] Using the 2018 land cover data to complete a priority planting area map can prioritize areas based on criteria of interest, including available planting space as well as existing canopy levels and land ownership. This will help inform what is possible to achieve, as well as support an effective land owner outreach strategy.

Key finding: There is a wide range of canopy across Toronto neighbourhoods, with a 60.9 percentage point difference between the neighbourhood with the highest canopy (High Park-Swansea at 65.2%) and the neighbourhood with the lowest canopy (Bay Street Corridor at

[28] Danford, Rachel S.; Cheng, Chingwen; Strohbach, Michael W.; Ryan, Robert; Nicolson, Craig; and Warren, Paige S. 2014. What Does It Take to Achieve Equitable Urban Tree Canopy Distribution? A Boston Case Study. Cities and the Environment 7:1, Article 2. URL: https://digitalcommons.lmu.edu/cgi/viewcontent.cgi?article=1123&context=cate

[29] Ibid.

4.3%). This is affected by factors like land use, presence of parks & ravines and rates of growth and development, among other things.

Figure 5. Canopy by Toronto ward. (Source: 2018 leaf-on point sampling data), reflecting similar trends as those at the neighbourhood scale. Parkdale-High Park has the highest canopy at 48.5% (standard error 3.1), which is in part a function of having Toronto's largest urban park located within the ward as well as a mature residential neighbourhood. The highly urbanized Spadina-Fort York has the lowest canopy at 12.9% (standard error 2.0)[30]. As with the City's neighbourhoods, there is a significant disparity between the most and least treed wards, with a 35.6 percentage point difference in tree cover.

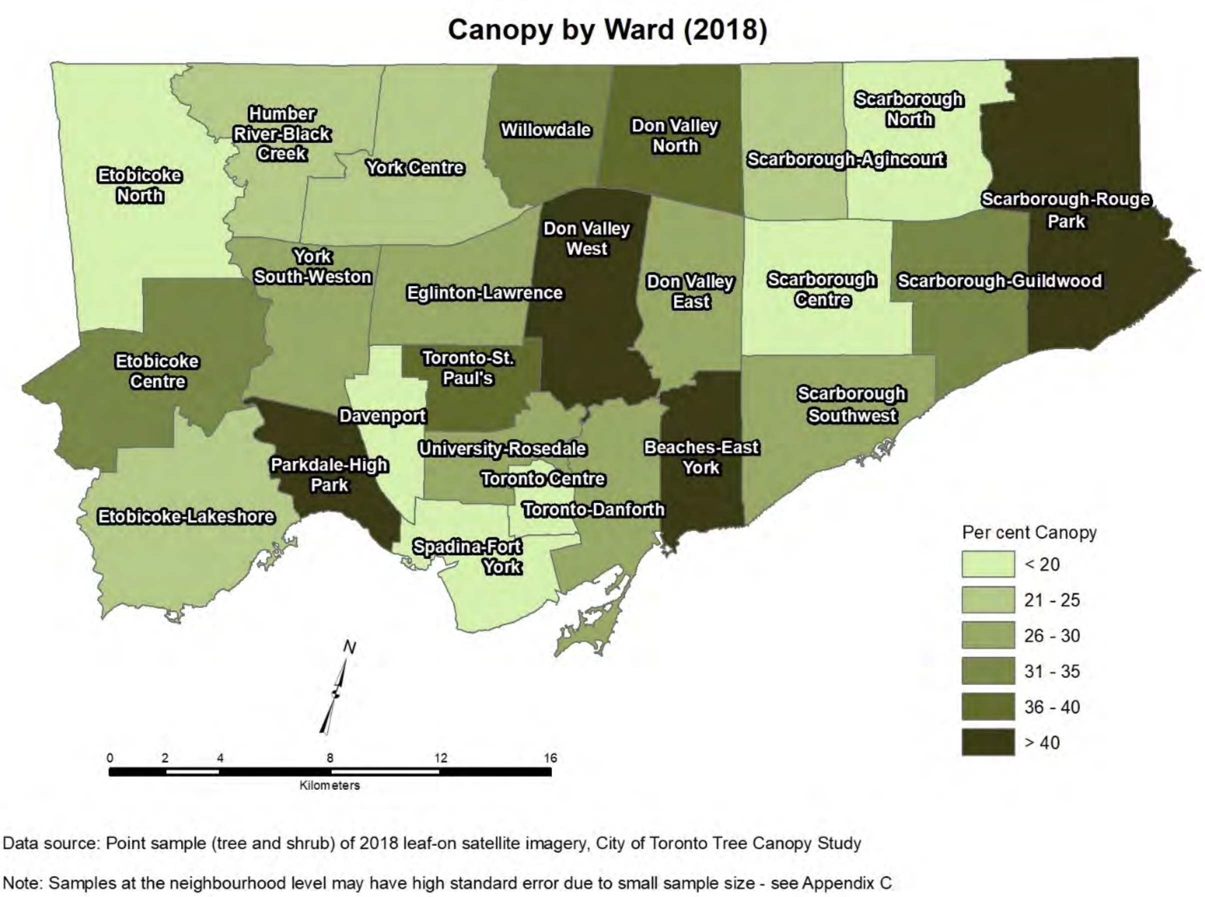


Figure 5. Canopy by Toronto ward. (Source: 2018 leaf-on point sampling data)

[30] Data from 2018 leaf-on imagery point sample summarized by ward for the 2018 Tree Canopy Study.

5.2 | Canopy Change Assessment

5.2.1 | Overall Canopy Change Across Toronto

Since 2008, overall canopy has increased across the city of Toronto, from 26.6 % in 2008 to 28.4% in 2018 (Figure 6).[31] While this suggests a positive trend, the increase happened between the years of 2008-2014, reaching a high of 29.1% in 2014. After 2014, the data suggest a slight decline (-0.7 percentage points, though not statistically significant) in the amount of canopy in the city, bringing the current estimate to 28.4%.

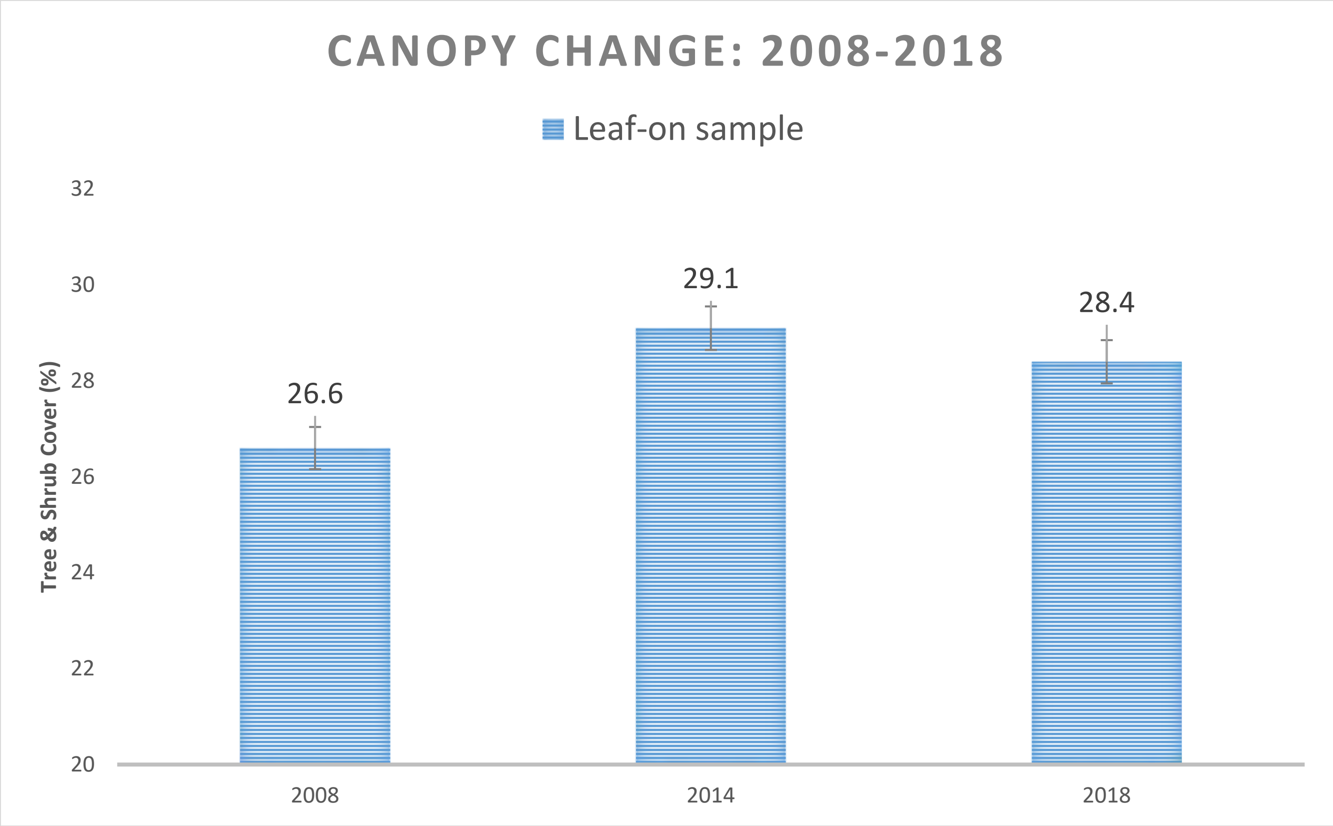


Figure 6. Change in canopy in Toronto from 2008-2018 (Source: 2018 leaf-on point sampling data)

[31] Tree and shrub cover was assessed at approximately 26.6 percent (SE = 0.4) using random point sampling of 10,000 points from leaf-on aerial imagery from 2009. This was reported in Assessing Urban Forest Effects and Values: Toronto's Urban Forest, a 2013 report prepared for the City of Toronto by the USDA Forest Service Northern Research Station. Tree and shrub cover was assessed at approximately 28.4% (SE 0.5) as part of the 2018 tree canopy study update, using random point sampling of 10,000 points from 2018 leaf-on satellite imagery at 50cm resolution.

Key findings:

Toronto has 28.4% canopy (standard error of 0.5%).

Overall, there was a 1.8 percentage point increase in canopy between 2008 and 2018.

The slight decrease after 2014 seems to coincide with the aftermath of the December 2013 ice storm, and the peak of EAB infestation and ash removals in Toronto. Development is also a likely contributor to canopy loss, particularly in areas of urban intensification. The following statistics put pressures on the urban forest in perspective:

- There were 33,343 service requests related to the 2013 ice storm, and these were only for City-owned trees. By comparison, the average number of storm calls per year is around 7,000. City-owned street trees make up only 5.4% of the total tree population.
- 122,691 ash trees were removed from City right-of-ways and properties between 2011 and 2018.
- About 3,650 development projects were active between 2009 and 2018.[32]

The quality and health of the urban forest is an equally important measure of program success and will be examined in more detail in relevant sections of this report.

The amount of tree canopy is one of several indicators that can be used to measure the success of Toronto's urban forestry program. The increase in canopy between 2008 and 2018 can be considered evidence of the program's achievements. However, indicators of sustainable urban forestry measure not only the amount, but also the quality of canopy. Because change detection doesn't consider which species are contributing to the canopy increase, the role of invasive species and their potential contributions to the increase in canopy should be examined in future monitoring and studies.

EAB and ice storm damage are possible factors in the levelling-off of canopy expansion after 2014. Other impacts from urban intensification (development) may also have contributed to this decline. The following maps correlate areas of tree cover loss (as per change in 2008 and 2018 land cover data) to locations of EAB removals, ice storm service requests and building permits across the City, which all occurred during the 10 year study period.

While it is not possible to make statistically supportable inferences from these data within the scope of this study, possible correlations could be verified by further investigation at a finer (e.g., neighbourhood) scale.[33] This preliminary assessment shows 96% of parcels with an ice storm service call correlated with parcels that showed a loss in tree cover. The reason for this

[32] Toronto City Planning, Research and Information.

[33] There is no measure of statistical accuracy associated with the 2018 land cover dataset. See Appendix G for automated land cover classification methodology.

would need to be investigated through closer examination of maintenance or tree removal activities performed in response to service calls, where there is a possible tree cover loss.

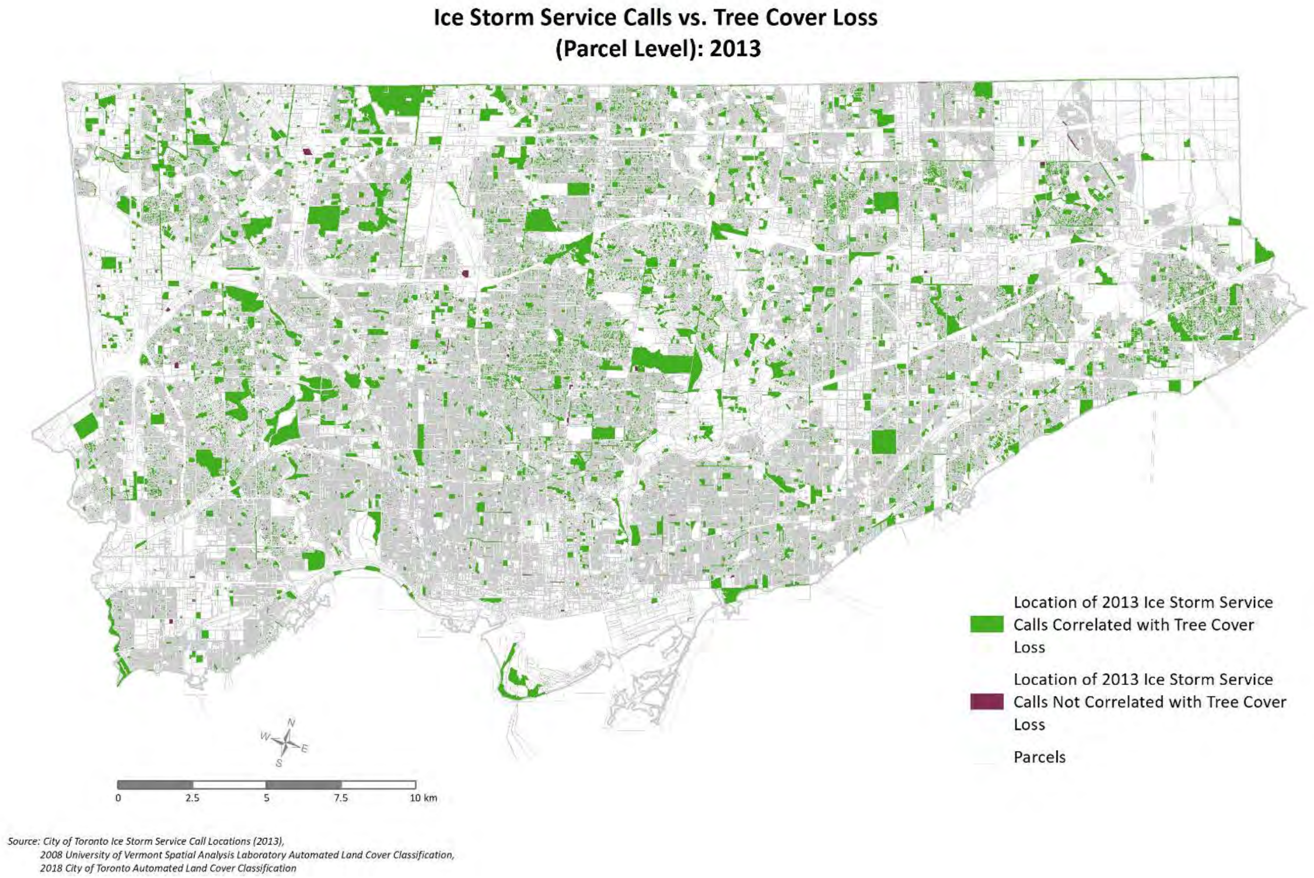


Figure 7. Location of 2013 ice-storm related service requests compared to parcels with tree cover change. (Source: Land cover classification 2008-2018 change assessment overlay with service request location data from City database).

Figure 8 shows areas of tree cover change (loss) as they related to EAB-related tree removal locations. A high correlation between City tree removals and tree cover loss would be expected. The mapping shows an 89% correlation, which is lower than the correlation between ice storm service calls and areas of tree cover loss (Figure 7).

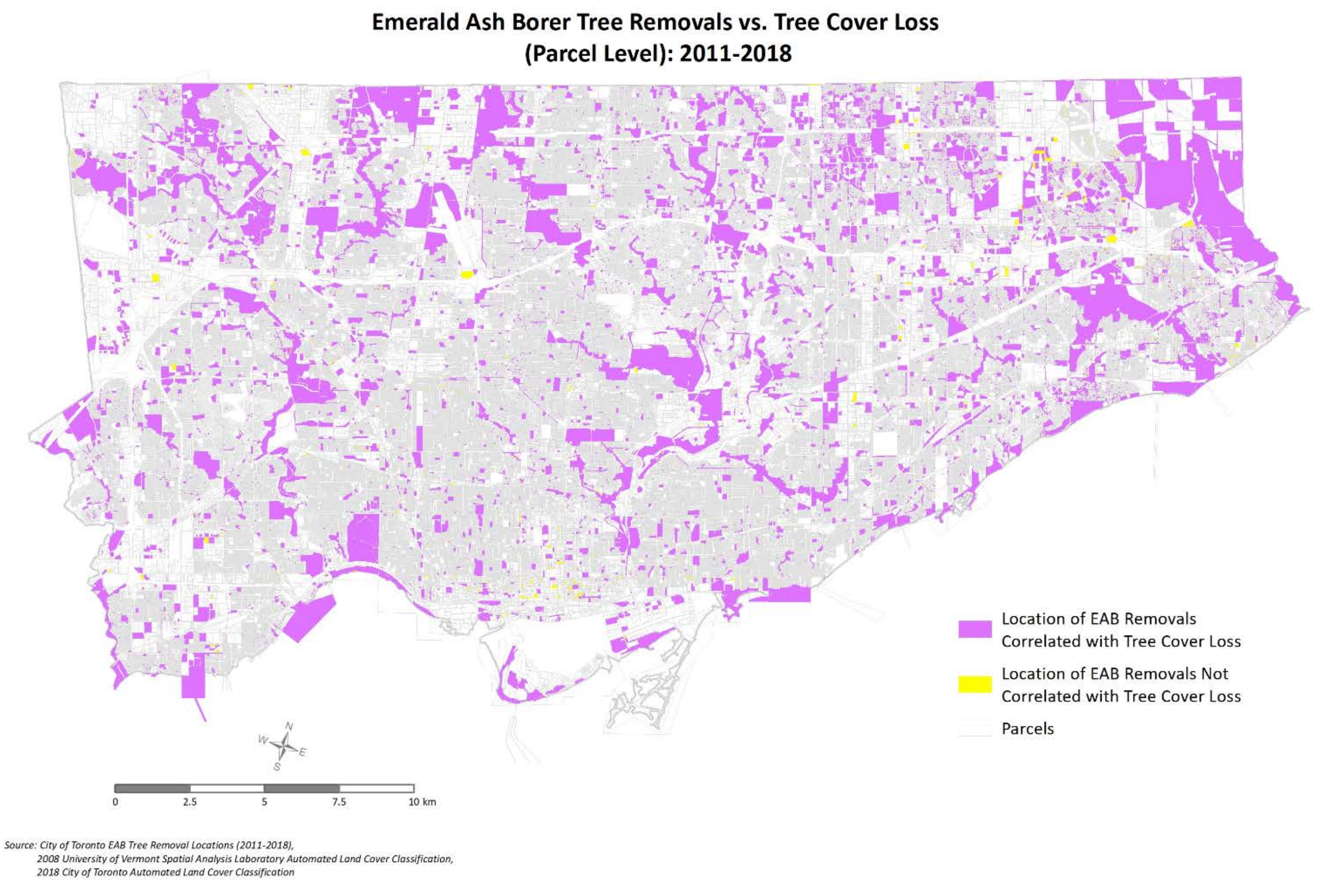


Figure 8. Location of EAB removals (2008-2018) compared to parcels with tree cover change (loss) (Source: Land cover classification 2008-2018 change assessment overlay with EAB tree removal location data from City database).

It is possible that some of the tree cover loss related to EAB was mitigated by prompt tree replacement in many areas where removals occurred. City data shows that the peak of EAB removals (street trees) occurred by 2013, and park trees in 2015 (Figure 9). Assuming prompt replanting of ash removed, this would have allowed for several years of new tree cover development and possibly reduced the correlation between removals and tree cover loss as measured in 2018.

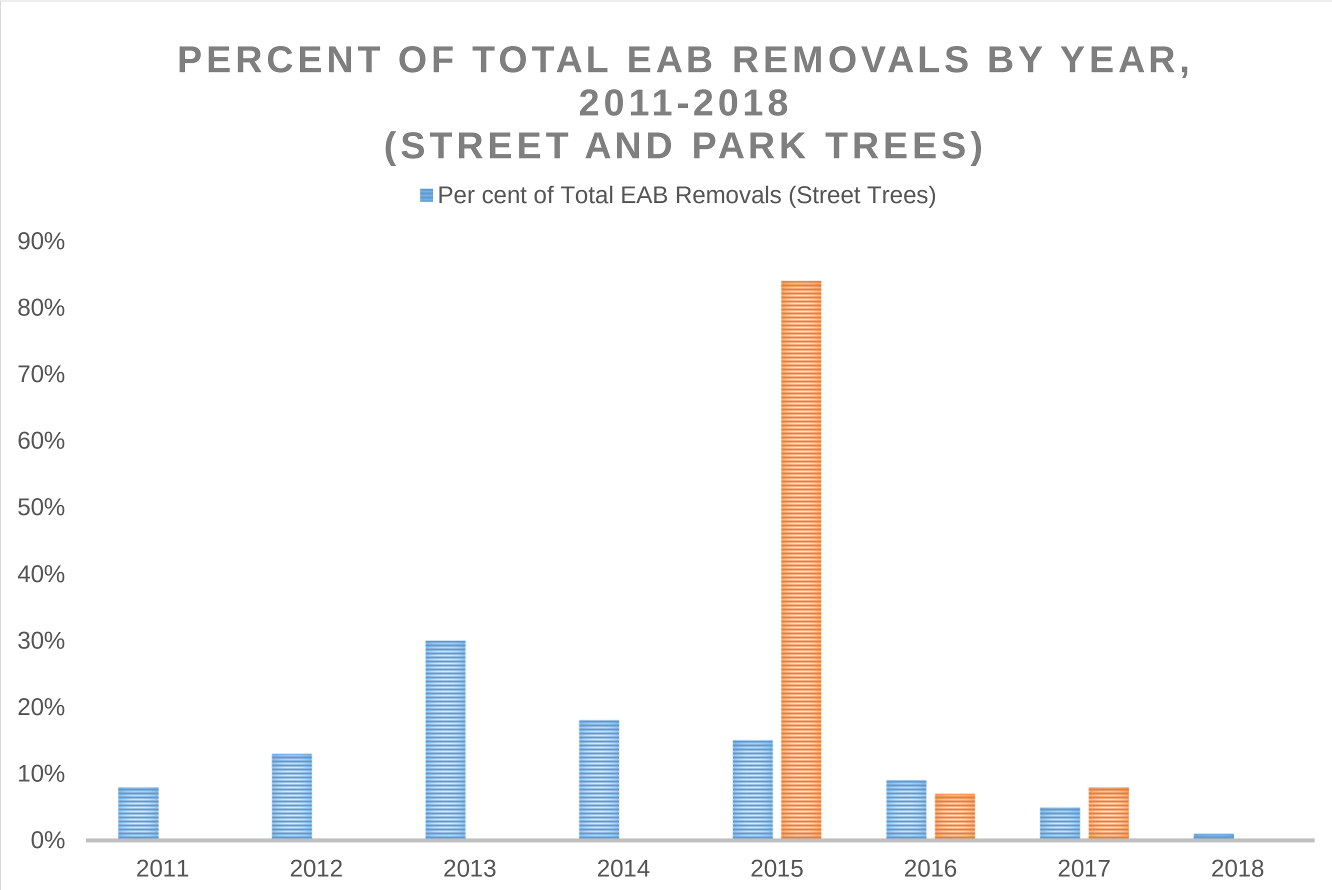


Figure 9. Percent of total EAB removals by year, 2011-2018 (Source: EAB removal data, City of Toronto).

A third factor of interest is the potential impacts of development on the city's tree canopy over the study period. Data for all building permits issued between 2008 and 2018 were overlaid on the map of tree cover change (loss) to examine any possible correlations between tree cover loss and development in the city. The data shows that 85% of parcels with building permits were correlated with parcels showing tree cover loss (Figure 10).[34] This correlation is high enough to merit further investigation and is supported by the findings of a 2018 research study undertaken in a downtown Toronto neighbourhood.[35]

[34] Because there are instances where more than one permit is attached to a parcel, the percentage was calculated as follows: number of parcels with tree cover loss/the total number of parcels with building permits.

[35] Steenberg, J. W. N., Robinson, P. J., & Millward, A. A. (2018b). The influence of building renovation and rental housing on urban trees. Journal of Environmental Planning and Management, 61, 553-567.

That study linked building permits to higher rates of tree mortality at both the parcel and street-section scale. This is because “construction activities can be a significant factor in tree decline and mortality due to mechanical injuries to trees, excessive pruning, root severing due to trenching, and restricted root growth caused by soil compaction.” The study findings concluded that “where concentrated changes in housing stock are occurring, substantial losses of trees and associated ecosystem services are possible.”

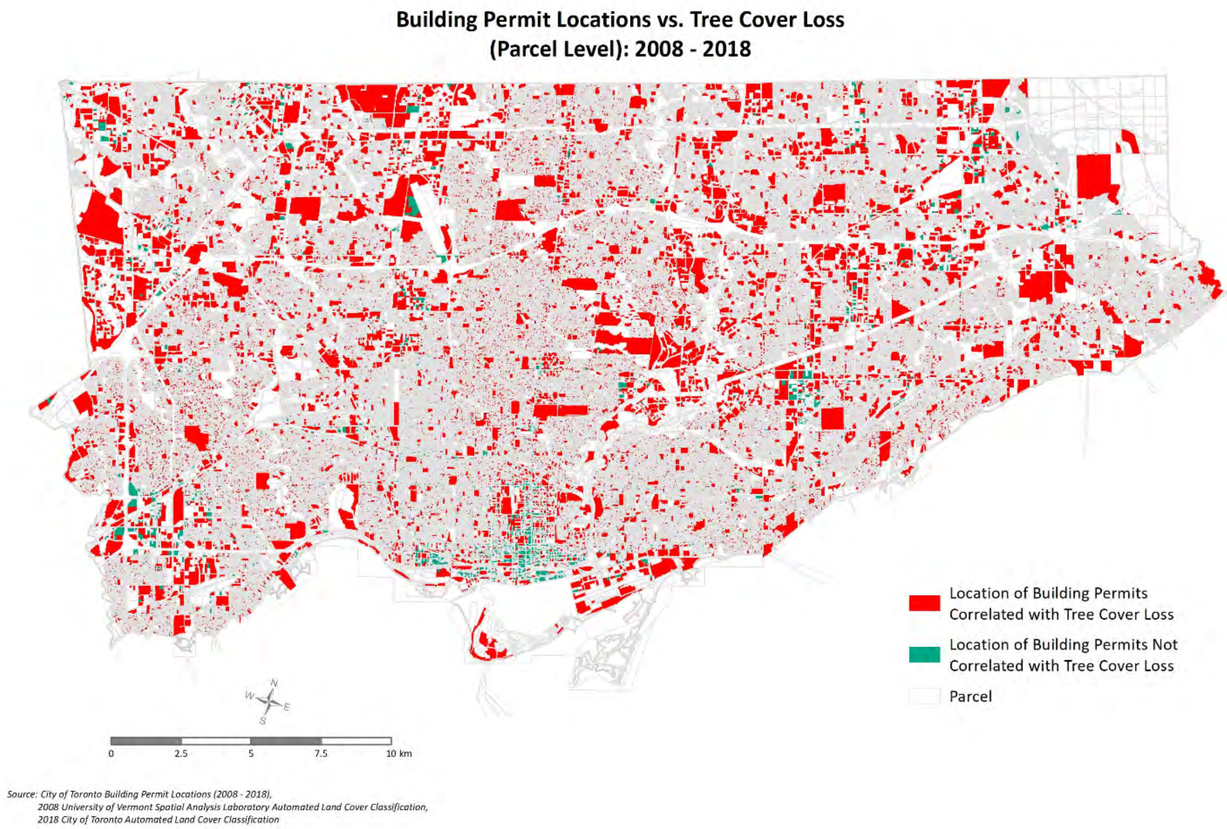


Figure 10. Location of building permits issued (2008-2018) compared to parcels with tree cover change (loss) (Source: Land cover classification 2008-2018 change assessment overlay with Building Permit location data from City database).

Finally, the data for EAB removals, ice storm calls and building permits were all overlaid on the map of tree cover change for Toronto, to assess whether tree cover loss might be the effect of cumulative stresses in some areas of the city (Figure 11). There was lower correlation between overlapping impacts and areas of tree cover loss, suggesting that each of these factors is independently affecting tree cover change in the city. Determining to what degree each factor has impacted the tree canopy would require more detailed study. The currently available data does not permit an assessment of area (e.g., in square metres or hectares) of tree canopy lost, but rather is linked at the parcel level to tree cover change.

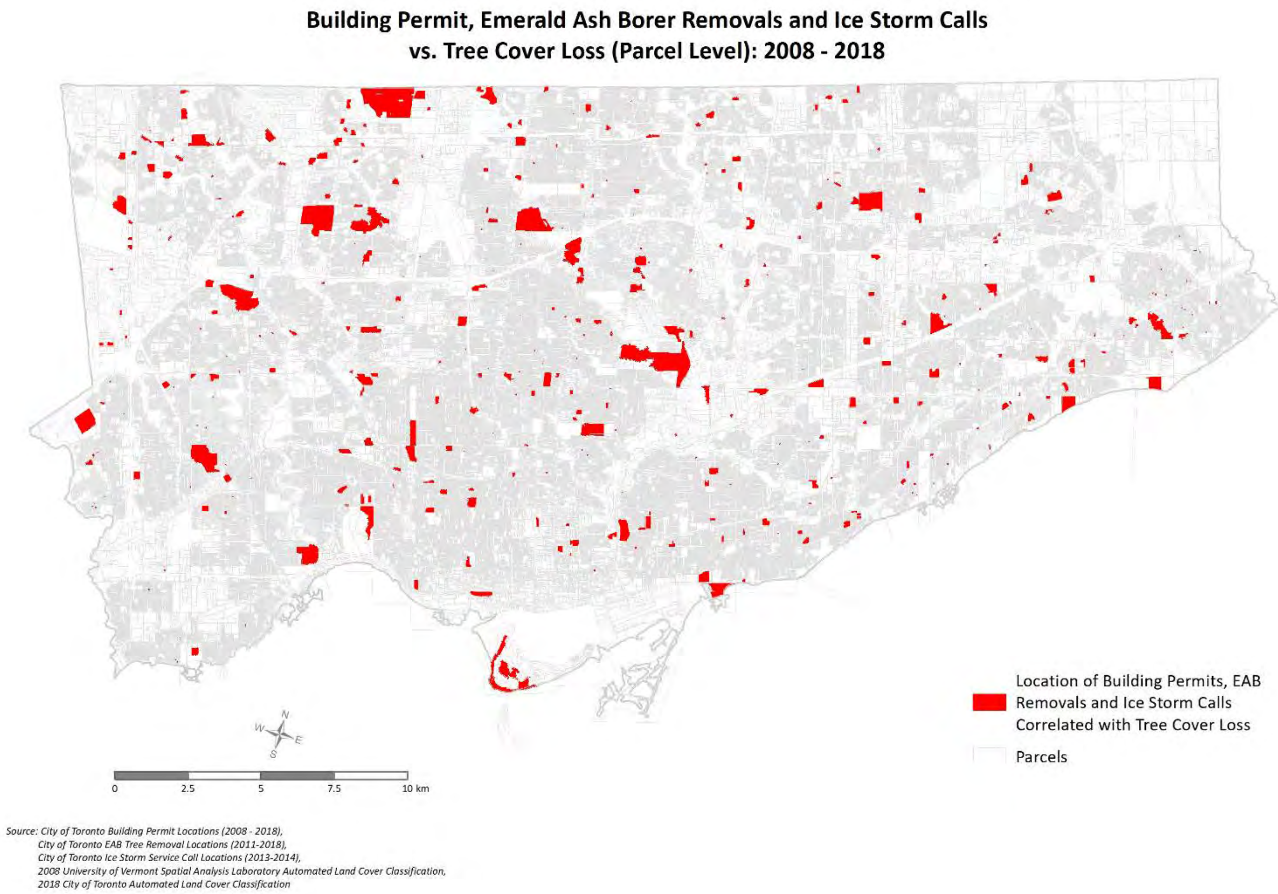
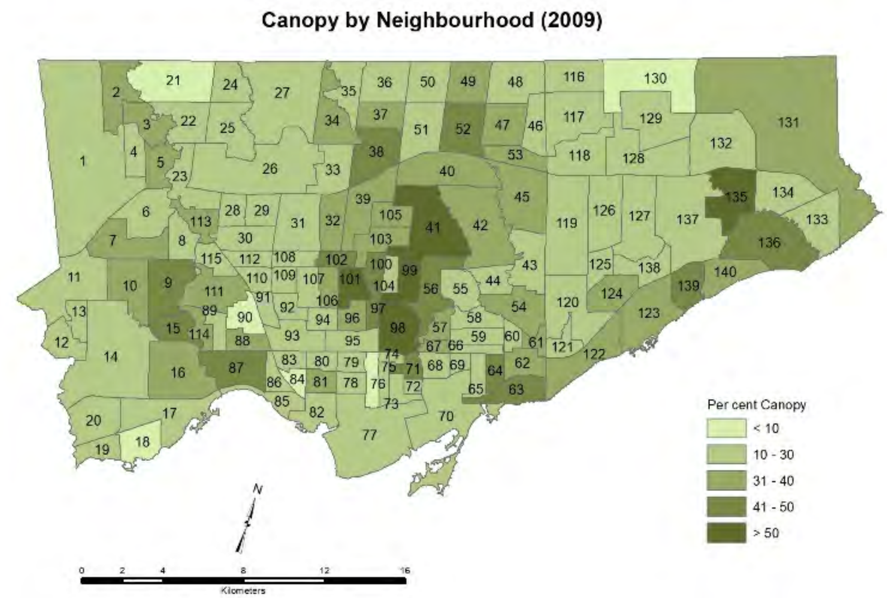
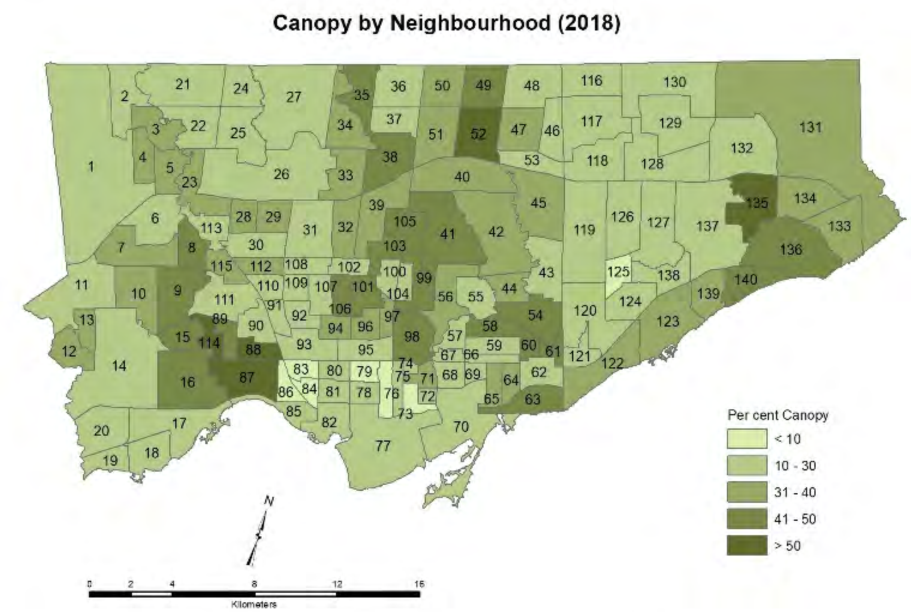


Figure 11. Ice storm service call locations, EAB tree removal locations and building permit locations overlaid with areas of tree cover loss (Source: City Forestry data, 2008 and 2018 land cover maps).



Data source: Point sample (tree and shrub) of 2018 leaf-on satellite imagery, City of Toronto Tree Canopy Study

Note: Samples at the neighbourhood level may have high standard error due to small sample size - see Appendix C



Data source: Point sample (tree and shrub) of 2018 leaf-on satellite imagery, City of Toronto Tree Canopy Study

Note: Samples at the neighbourhood level may have high standard error due to small sample size - see Appendix C

Figure 12. Canopy by neighbourhood 2009-2018 (Source: 2009 leaf-on point sample from 2013 Assessing Urban Forest Effects and Values, 2018 point sample).

5.2.2 | Canopy Change by Neighbourhood

The change in canopy is variable across the city. Out of 140 neighbourhoods, 22 showed statistically significant changes in canopy. Of these, fourteen (64%) showed a gain in canopy and eight (36%) showed a loss.[36] This is consistent with the overall increase in canopy across the City noted between 2009 and 2018.

The most canopy gain was seen in Lambton-Baby Point, and the most canopy loss seen in the Playter Estates-Danforth and University neighbourhoods (**Table 9**).[37] The change noted in the ten neighbourhoods with the highest gain and loss was statistically significant. While the study measures changes in canopy, it does not provide information on the cause of change. Further investigation would be needed to gain a better understanding of the reasons for canopy change (both positive and negative) in Toronto neighbourhoods.

Table 9: Toronto neighbourhoods with most gain and loss of canopy cover (Source: 2009 leaf-on point sample from 2013 Assessing Urban Forest Effects and Values, 2018 point sample data).

Most Canopy Gain	**Change (percentage points)**
Lambton-Baby Point	29.7
Woodbine-Lumsden	24.1
Old East York	22.4
Runnymede-Bloor Village	21.9
Clanton Park (33)	20.6
Most Canopy Loss	
Playter Estates-Danforth	-24.9
University	-22.3
Kennedy Park	-22.1
Dufferin Grove	-20.6
Forest Hill North	-20

[36] As per change detection using 2009 leaf-on (2013 Assessing Urban Forest Effects and Values, Appendix III) and 2018 leaf-on point sample (2018 Tree Canopy Study)

[37] Ibid.

Key finding: Out of 140 neighbourhoods in Toronto, 83 had an increase in canopy while 57 had a decrease. Of these, 22 showed statistically significant change. Fourteen of those showed an increase and eight neighbourhoods showed a decrease. This is consistent with the finding of overall positive canopy change across the City.

By aggregating the neighbourhood data, there are patterns that become apparent in terms of overall trends across the city. In general, the north and west areas of Toronto are seeing negative change in canopy, while south and east parts of the city are seeing positive change (Figure 13).

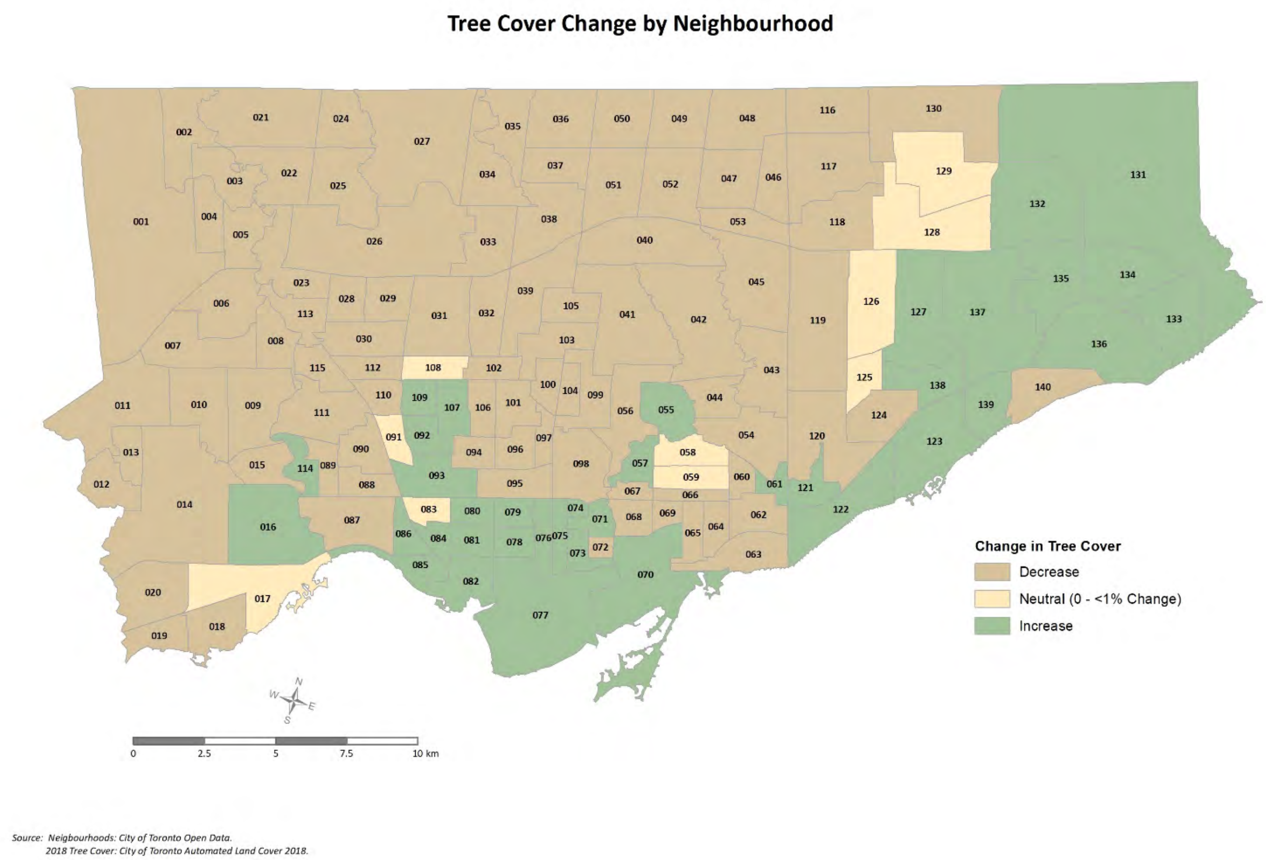


Figure 13. Tree cover change by neighbourhood (gain, loss, neutral). (Source: Change detection using 2008 and 2018 land cover data, City of Toronto)

This finding appears to contradict the predicted effect of high rates of street tree removal for EAB in some areas that saw an increase in tree cover. This suggests that EAB may not have had as significant an effect on overall tree cover as other factors affecting the urban forest in those areas. It could also mean that replacement tree planting and growth of existing trees mitigated the effects of EAB in those areas of Scarborough.

5.2.3 | Canopy Change by Land Use

Different land use areas tend to have different levels of canopy based on the intensity and character of development in those areas. For example, areas of Single Family Residential land use tend to have a lower intensity form of development than Commercial or Industrial lands. The ten land use areas used in the study are derived from the City of Toronto zoning and their relative land areas in the city are shown in **Table 10.**

The Single Family Residential land use makes up a significant portion of the city's land area, at 41.4% of Toronto's total land area, followed by the Industrial and Open Space 1 (Parks) land uses at 13.9% and 11.1%, respectively.

Table 10. Land use areas in Toronto. (Source: 2018 zoning/land use data, City of Toronto)

Land Use	Total Land Area (hectares)	% of Total Land Area
Commercial	3,447.7	5.4
Industrial	8,948.1	13.9
Institutional	1,352.8	2.1
*No Data	3,482.7	5.4
Open Space 1 (Parks/TRCA lands)	7,139.6	11.1
Open Space 2 (Commercial/Recreation/Agriculture)	4,329.2	6.7
Other (mainly vacant and marinas)	42.3	0.1
Multifamily Residential	5,575.1	8.7
Single Family Residential	26,574.2	41.4
Utilities & Transportation	3,275.5	5.1
Total	64,167.2	100.0

*No data represents areas of the City in transition, e.g., waterfront

As per Figure 14, canopy appeared to increase in all land uses, with the exception of the Commercial land use (which showed a decrease of 0.9%, not statistically significant). The largest increase in canopy was in the Utilities and Transportation land use (2.8 percentage point increase, not statistically significant), followed by Industrial areas (2.4 percentage point increase, statistically significant).

The increase in canopy on public lands (e.g., Open Space 1 land use) could potentially be related to tree planting efforts by the City in parks and natural areas, as well as some natural ingrowth of trees and shrubs. However, it is possible that invasive shrub species could also be contributing to this expansion since the point sampling approach captures both trees and shrubs in the estimates.

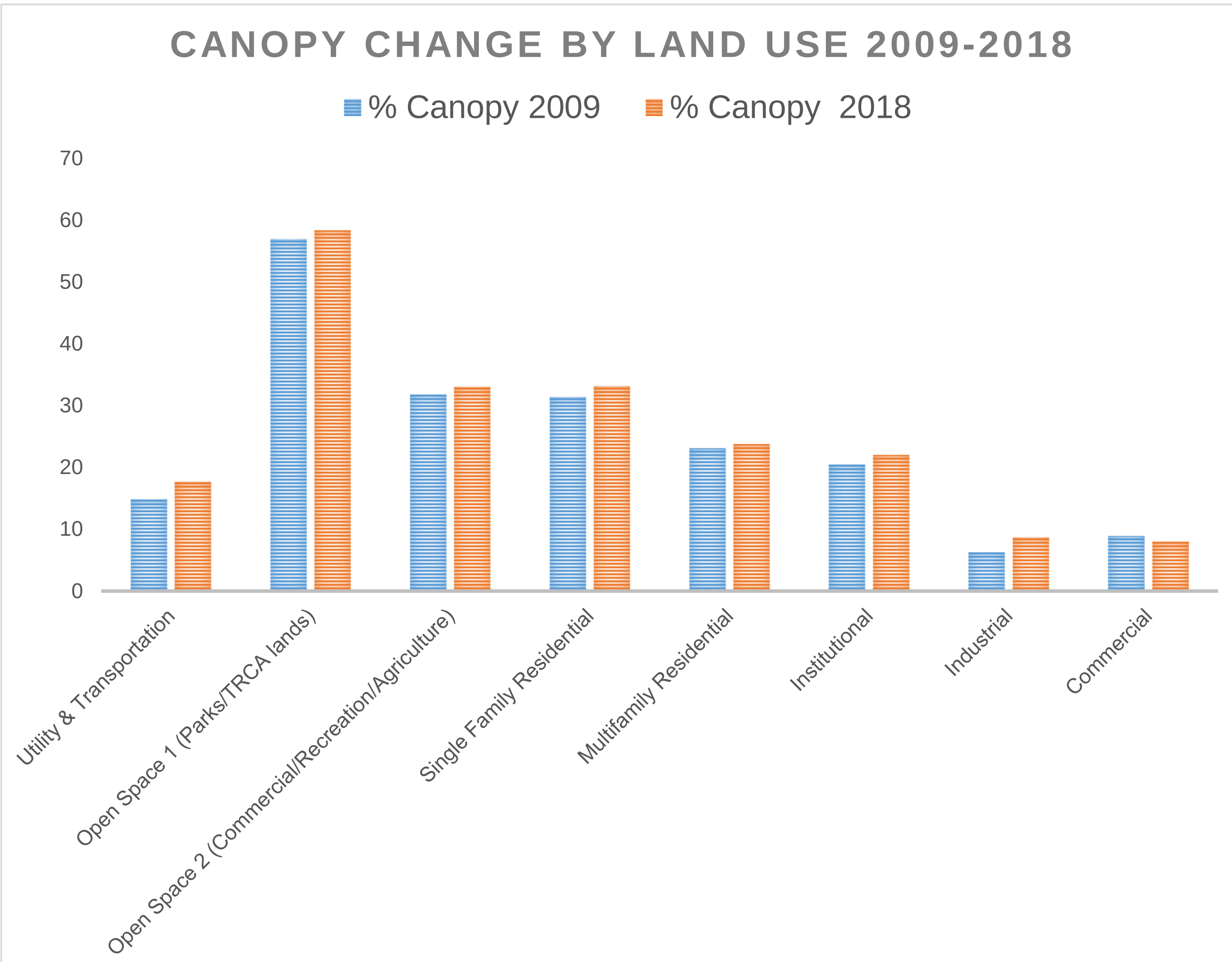


Figure 14. Canopy change by land use (Source: 2009 leaf-on point sample (2013 Assessing Urban Forest Effects and Values, Appendix III) and 2018 leaf-on point sample, 2008 land use layer).

It is important to note that the land use layer used for the first canopy study (2008) was used to complete this change assessment. In future studies, the City will use an updated zoning layer to define land use. (The baseline data to assess future land use change is included in Appendix K and shows land cover by 2018 land use for future comparisons.)

Key findings: Canopy increased in all land uses, with the exception of the Commercial (-0.9 percentage points, not statistically significant). The largest increase in canopy was in the Utilities and Transportation land use (2.8 percentage point increase, not statistically significant), followed by Industrial areas (2.4 percentage point increase, statistically significant).

Canopy is lowest (< 10%) in Commercial and Industrial land uses compared to other land uses in the city (all other land uses range between approximately 17-58%).

Understanding the root causes of tree mortality is fundamental to carrying out relevant improvements to forest management and other City policies and regulations that will better support canopy growth.

In urban areas, the loss of canopy is due to many factors such as tree removals due to development, end of tree life span, storms, insects and diseases, and unregulated tree removal by land owners. On the other hand, canopy in urban areas may expand through factors like tree growth, planting and natural regeneration. Recent planting efforts in Toronto will see greater gains in canopy in the future as newly planted trees grow, assuming these trees live to maturity. Proper early tree care can help increase young tree survival.[38]

In this context, positive gains in canopy in some land uses in Toronto could be attributed to factors such as:

- Success of afforestation efforts in parks and open space areas as well as residential and street tree planting programs;
- Colonization/expansion of invasive species cover in natural areas, in formerly grass or other open area; and/or,
- Expansion of tree cover from past plantings and existing tree cover.

Canopy studies can provide measures of change, but more detailed investigations beyond the scope of this study would need to be undertaken to link specific cause and effect. For example, tree planting data could be cross-referenced with areas of canopy gain to assess the success of planting programs toward contributing to increasing the city's canopy.

[38] Roman, L.A., Battles, J.J. and J.R. McBride. 2014. Determinants of establishment survival for residential trees in Sacramento County, CA. Landscape and Urban Planning 129: 22-31; Nowak, D.J. and E.J. Greenfield. 2018. Declining urban and community tree cover in the United States. Urban Forestry & Urban Greening 32: 32-55.

Regarding canopy loss, a recommendation to examine causes of tree mortality was made in the first 2008 canopy study but was not completed. The recommendation is carried forward, as this information underlies decisions about which program areas to target for improvements. For example, the solution to address development impacts on trees would be quite different from trying to mitigate losses to diseases and pests. A better understanding of what is driving tree mortality in Toronto would ultimately inform appropriate program decisions.

5.3 | Distribution and change in Tree Cover by Watershed

Toronto has set a canopy target of 40%. This goal has been informed in part by the City's environmental objectives and research[39] that identifies varying levels of forest cover necessary to maintain varying degrees of ecosystem functionality in watersheds. The Environment Canada report from which these targets originate also notes that while there is a high degree of interest in identifying minimum thresholds for canopy to support native flora and fauna, there are still science gaps to describe these. Nonetheless, having targets can help natural heritage and urban forest planning as well as initiatives to protect and expand canopy in the city.[40]

- 30% canopy cover at the watershed scale is the minimum threshold for supporting ecosystem function. This is a high-risk approach that may only support less than one-half of the potential species richness, and somewhat healthy aquatic systems.
- 40% canopy cover at the watershed scale represents a medium-risk approach that is likely to support more than one-half of the potential species richness, and moderately healthy aquatic systems.
- 50% canopy cover or more at the watershed scale is a lower-risk approach that is likely to support most of the potential species, and healthy aquatic systems.

Looking at a watershed and sub-watershed scale, three of Toronto's watersheds meet the minimum level in tree cover alone to sustain some species and aquatic ecosystems – The Petticoat, Rouge and Don are currently at or above 30% tree cover (Figure 15). This may improve if shrubs were included in a canopy cover estimate by watershed.

[39] 2013. How much habitat is enough? Environment Canada, Canadian Wildlife Service.

[40] 2013. How much habitat is enough? Environment Canada, Canadian Wildlife Service.

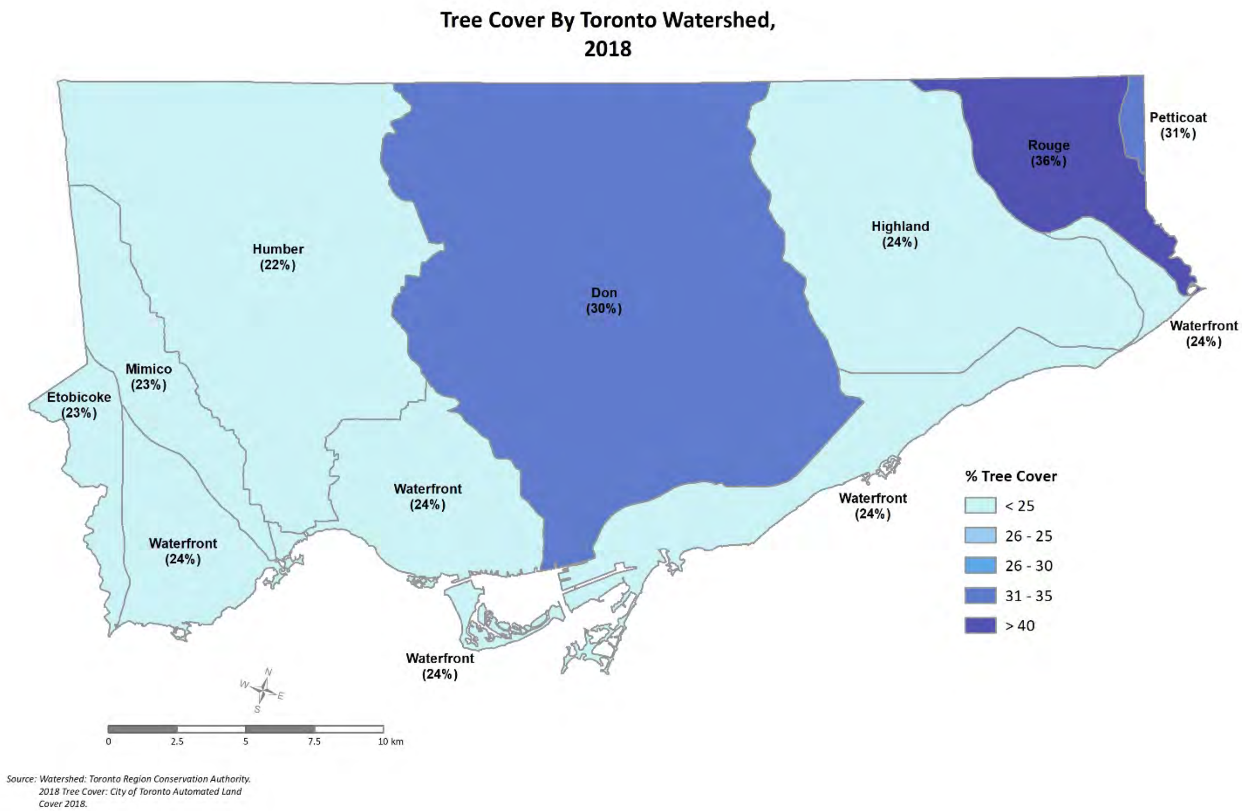
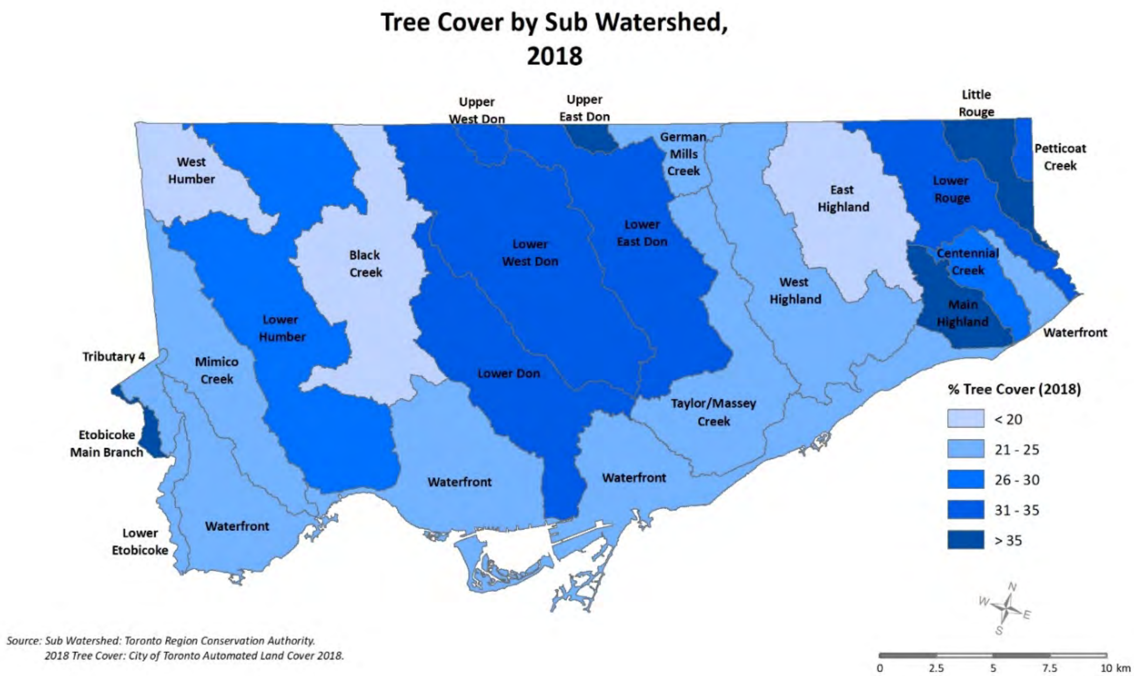


Figure 15. Tree cover by Toronto watershed, 2018. (Source: City of Toronto land cover classification, 2018).

At a sub watershed scale, the East Highland Creek, Black Creek and West Humber River sub watersheds have the lowest tree cover in the city (less than 20%). The highest percentage of tree cover is found in the Upper East Don (40%) and the Little Rouge River (43%) and the Main Highland Creek (43%) and Etobicoke Main Branch (37%) (Figure 16).



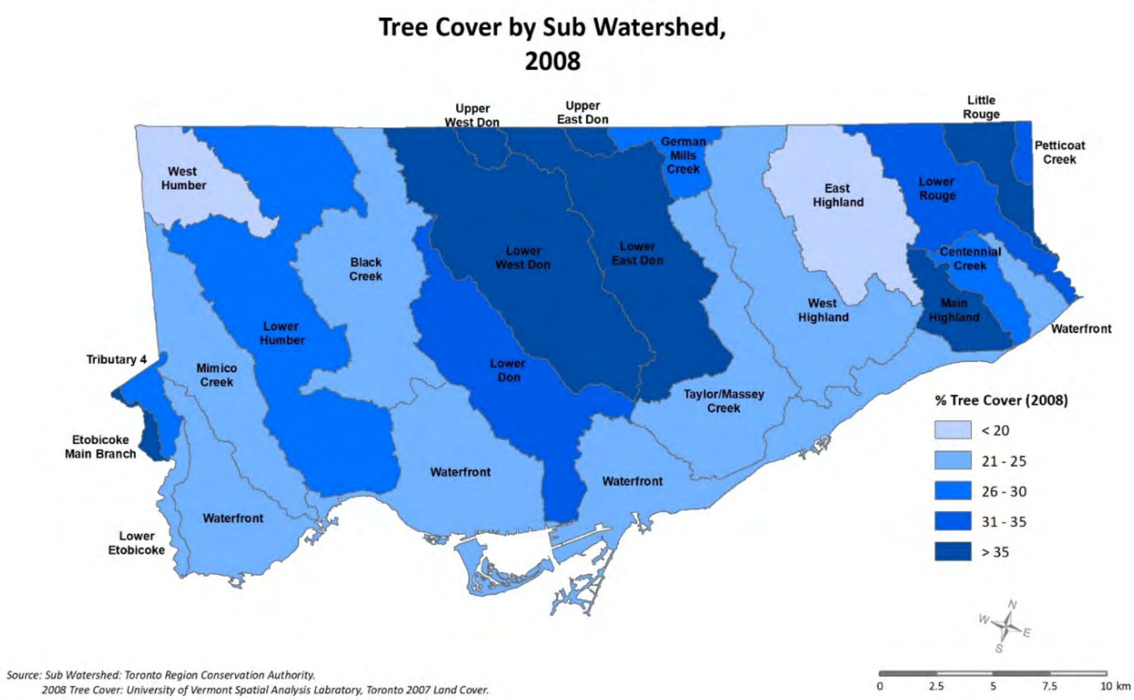


Figure 16. Tree cover by subwatershed, 2008 and 2018 (Source: Toronto land cover data, 2008 and 2018).

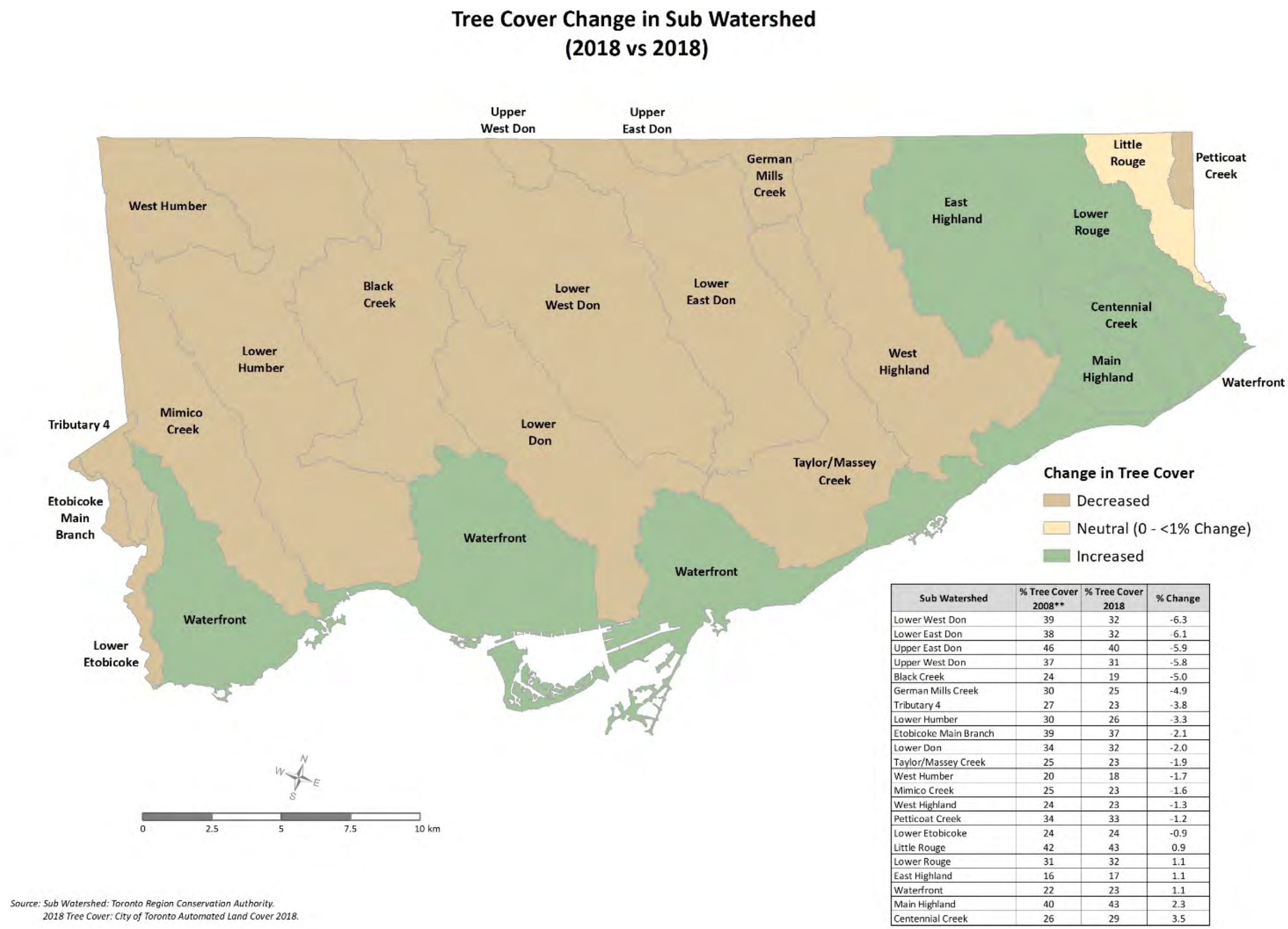
In terms of change, the greatest tree cover loss has occurred in the Lower and Upper Don subwatersheds (Figure 17). There were some possible minor gains in some subwatersheds in the eastern part of the City (e.g., Centennial and Main Highland), as well as the Waterfront. In total, 16 of 22 sub watersheds have experienced a decline in tree cover. Because these change estimates are derived from the land cover data, they are not associated with a level of statistical accuracy.

Having information on tree cover by watershed is a valuable input to help prioritize areas of focus in order to increase canopy in the future. Using watershed and sub watershed information to inform tree planting priority areas has the benefit of potentially supporting TRCA's watershed management priorities and complements 2016 research by the TRCA[41] that identified restoration priorities for increasing natural cover, among other things, in identified catchment areas.

Key finding: Only three of Toronto's seven watersheds (Petticoat, Rouge and Don) currently have the 30% tree cover required to maintain minimum watershed function (e.g., will support less than one-half of the potential species richness, and somewhat healthy aquatic systems[42]).

[41] Integrated Restoration Prioritization: A Multiple Benefit Approach to Restoration Planning. Toronto and Region Conservation Authority. 2016. URL: https://trca.ca/app/uploads/2016/12/2894_TRCA_IntegratedRestorationPrioritizationReport2015_Feb2016-FA-singlepgs-WEB-Mar3.pdf

[42] 2013. How much habitat is enough? Environment Canada, Canadian Wildlife Service.



Sub Watershed	% Tree Cover 2008**	% Tree Cover 2018	% Change
Lower West Don	39	32	-6.3
Lower East Don	38	32	-6.1
Upper East Don	46	40	-5.9
Upper West Don	37	31	-5.8
Black Creek	24	19	-5.0
German Mills Creek	30	25	-4.9
Tributary 4	27	23	-3.8
Lower Humber	30	26	-3.3
Etobicoke Main Branch	39	37	-2.1
Lower Don	34	32	-2.0
Taylor/Massey Creek	25	23	-1.9
West Humber	20	18	-1.7
Mimico Creek	25	23	-1.6
West Highland	24	23	-1.3
Petticoat Creek	34	33	-1.2
Lower Etobicoke	24	24	-0.9
Little Rouge	42	43	0.9
Lower Rouge	31	32	1.1
East Highland	16	17	1.1
Waterfront	22	23	1.1
Main Highland	40	43	2.3
Centennial Creek	26	29	3.5

Figure 17. Change in tree cover by sub watershed (Source: City of Toronto land cover data, 2008 and 2018).

6 | Land Cover Change in Toronto (2008-2018)

Along with change in canopy, other types of land cover change have occurred across the city of Toronto. Point sampling data with known statistical accuracy were used to carry out change detection, which identifies trends in other land as well as canopy change.

On the positive side, the city saw an overall increase in canopy. However, there has also been a 6.9 percentage point loss of pervious area from 1999-2018 (soil, grass, and agriculture land cover types) that represents a loss of quality growing space for trees. At the same time, there has been a 3.6 percentage point increase in impervious area in the city (buildings, roads, and other impervious surfaces) over that 19-year period. Breaking it down in more detail, there was no significant increase in roads or buildings measured over the last 10 year period (Figure 18). The greatest source of increase in impervious surface came from the “impervious other” category, representing any hard surface other than buildings or roads (e.g., parking lots, driveways, patios, etc.).

Table 11 shows the 19 year trend in land cover change across the city (2009-2018).

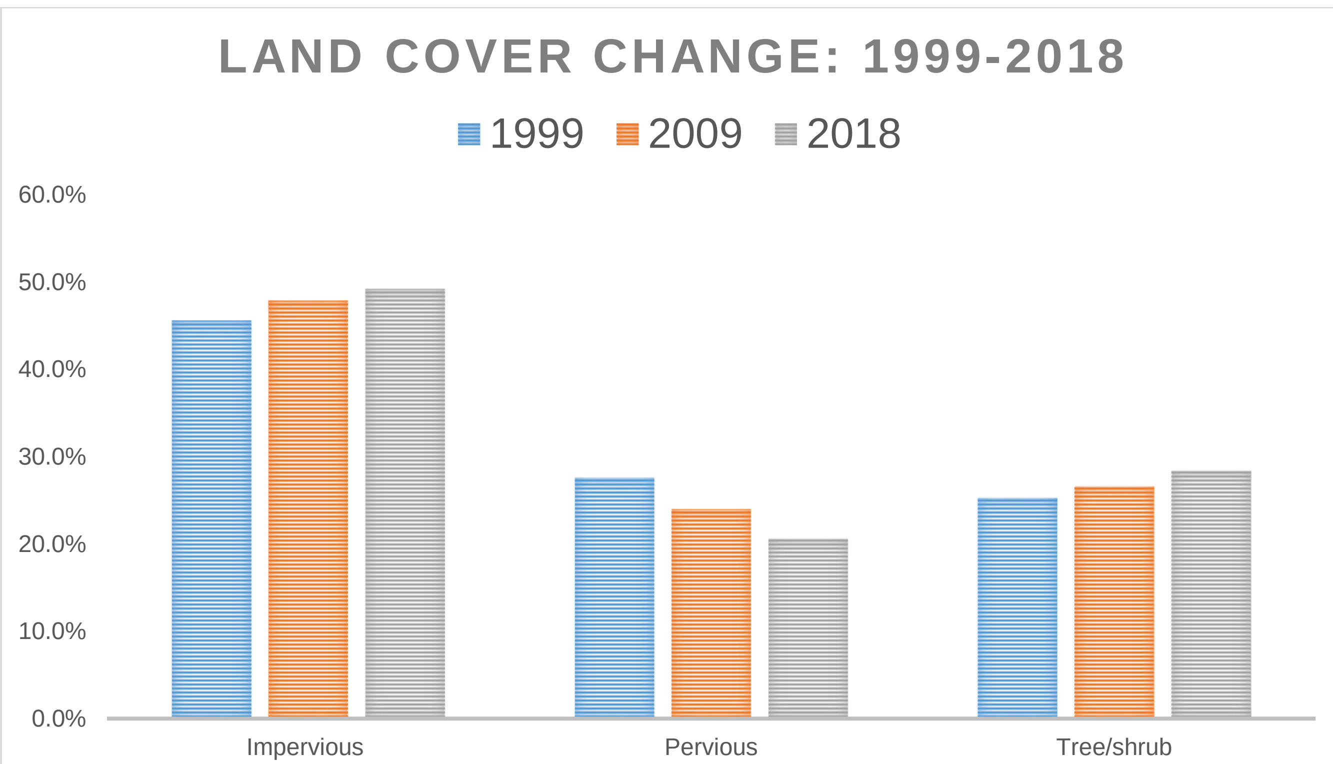


Figure 18. Land cover change – impervious and pervious surfaces with canopy cover. (Source: 1999 and 2009 leaf-on point sampling data (2013 Assessing Urban Forest Effects and Values report), 2018 leaf-on point sampling data.

While the changes seem small over a 10 year span (e.g., 1.4 percentage points increase in impervious surfaces), the effect is magnified over a 20 year period (e.g., 3.6 percentage point increase in impervious surfaces). On an area basis, this represents a total increase of 2,294 hectares of hard surface in the City since 1999.[43]

Table 11.Summary of land cover change between 1999 and 2018 (Source: 1999 & 2009 point sampling data (from 2013 Assessing Urban Forest Effects and Values), 2018 point sampling data.

*Land Cover	1999	2009	2018	9 year Change (2009-2018)	19 year Change (1999-2018)
Impervious	45.6%	47.9%	49.2%	1.3%	3.6%
Pervious	27.6%	24.0%	20.7%	-3.3%	-6.9%
Canopy	25.3%	26.6%	28.4%	1.8%	3.1%

Because the pervious and impervious land cover estimates are aggregated here, there is no associated measure of standard error. However, there were statistically significant changes in impervious cover noted between 1999 and 2009 where α = < 0.01, as well as in the "Impervious Other" land cover class between 2009 and 2018.

The loss of pervious area in the city has potential negative implications for stormwater management, water quality, loss of healthy soils, biodiversity, urban heat island effect, and the reduction of pervious growing space for potential tree planting. Figure 19 uses the 2007 and 2018 land cover data to identify the location of changes (increase) in impervious surfaces across the City. The data shows the change dispersed broadly across all areas of the City, with some concentrations in some areas that may be linked to specific types of development. This would require further investigation at the site level with other City datasets to confirm

[43] Total land area of Toronto is 63,736 hectares.

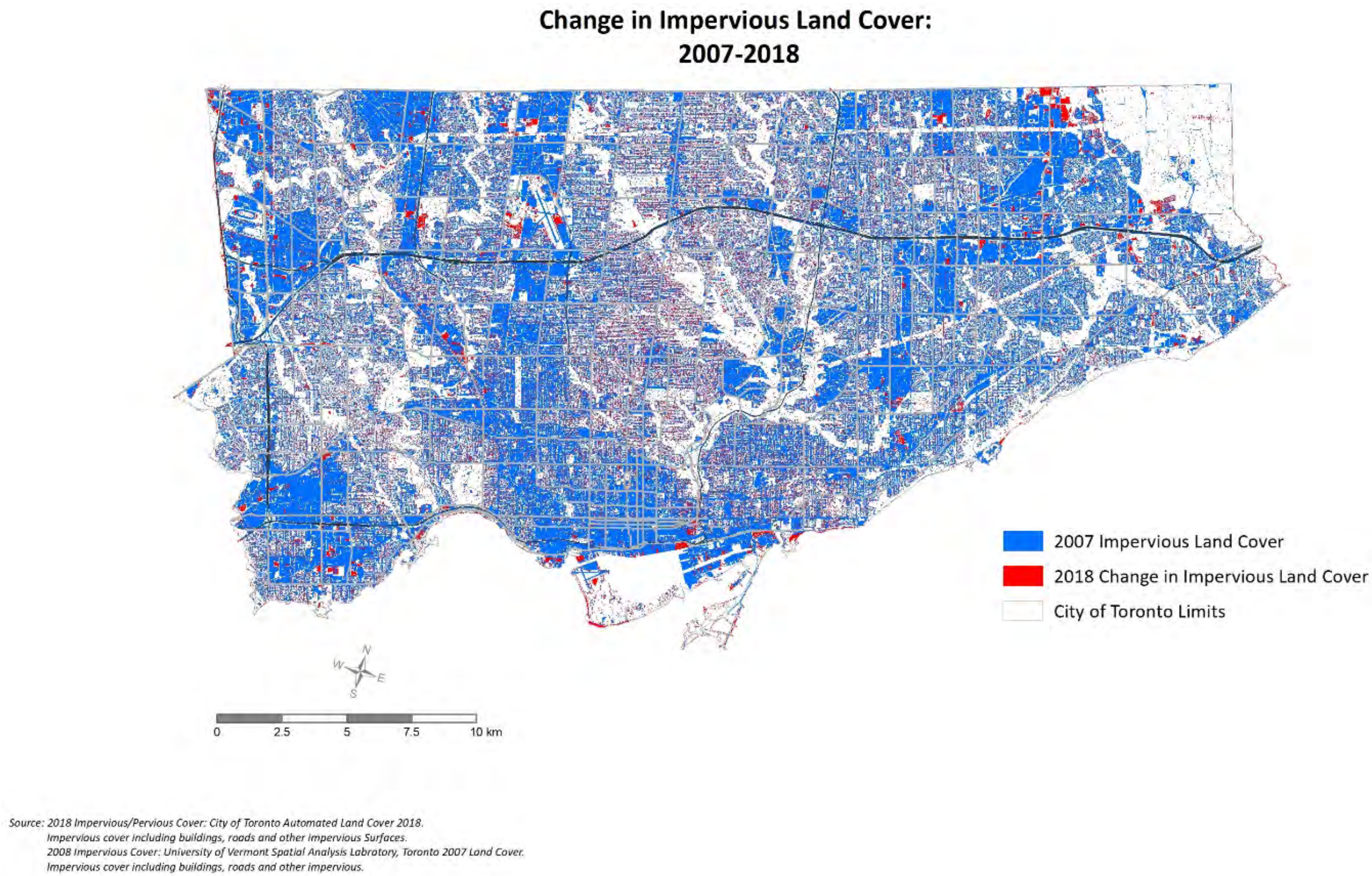


Figure 19. Location of increase in impervious land cover, 2007-2018 (Source: Change detection using 2007 and 2018 land cover data, City of Toronto).

A closer look at land cover change by land use offers more information on where land cover change is occurring. The highest rate of change has occurred in the Utility and Transportation land use, which showed an increase in hard surfaces of 4.8 percentage points from 2009 to 2018 (mainly from buildings and 'impervious other' category).

Change to impervious surfaces was also detected on Commercial (2.6 percentage points increase), Open Space 1 (1.8 percentage points increase), and Open Space 2 (0.8 percentage points increase) lands. Single Family Residential lands saw an increase in impervious area of 1.3 percentage points over the ten year period (Figure 20). Multifamily Residential lands, unlike the Single Family Residential lands, saw an increase in pervious area. This is unlikely to be an actual increase, but rather could be an artefact of sampling. It could also be related to redevelopment of higher density housing in that land use, where construction sites may be classified as soil while they transition from one building type to the next.

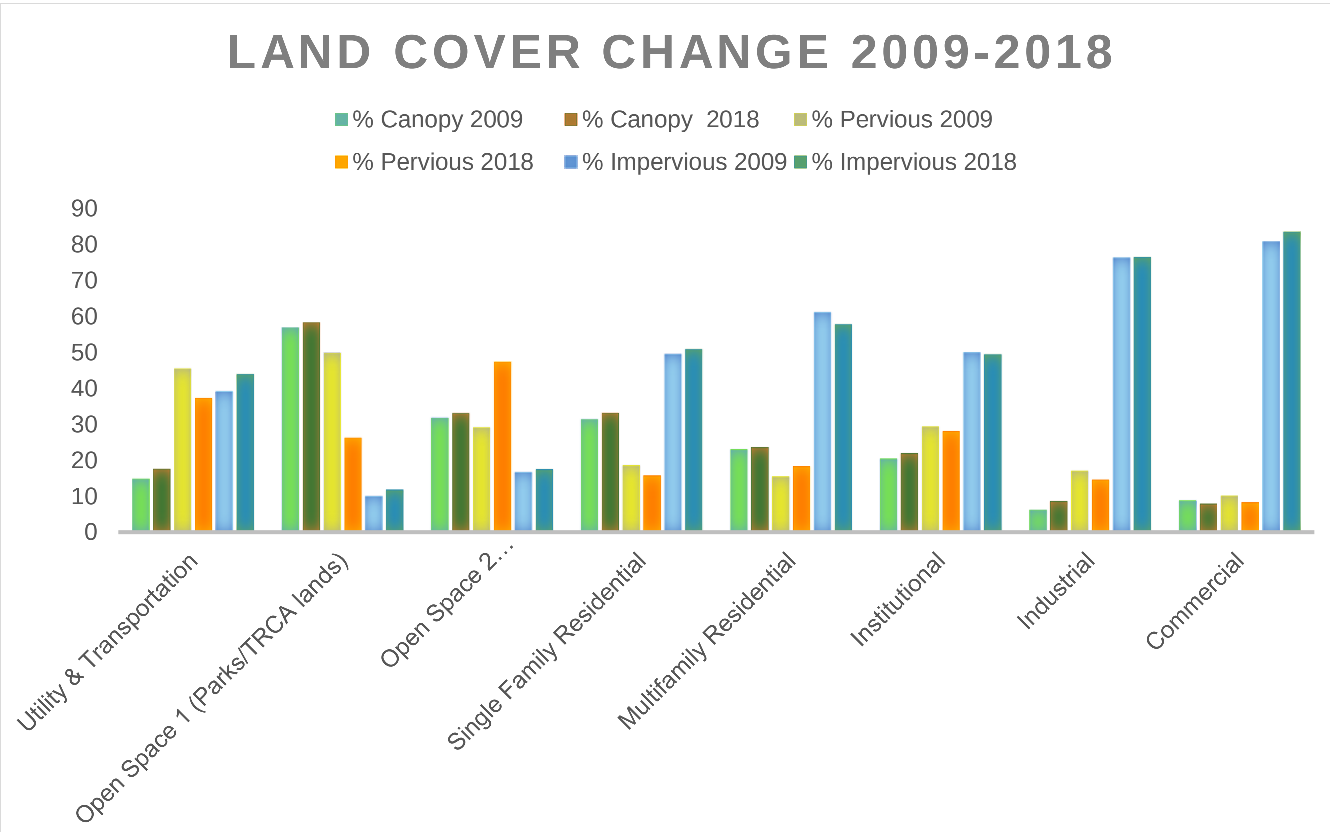


Figure 20. Percent land cover change: canopy cover, pervious and impervious by land use. (Source: 2009 leaf-on point sample data from USDA Report Assessing Urban Forest Effects and Values (2013), 2018 from 10,000 point sample of high resolution orthoimagery)

However, when considering the relative land area in each land use, the actual area of conversion in hectares was highest on Single Family Residential lands (349 ha), followed by Utility and Transportation and Commercial lands, at 114 and 112 ha respectively. Open Space

1 lands were close behind, showing an increase in 107 ha of hard surface from 2009-2018 (Figure 21). [44]

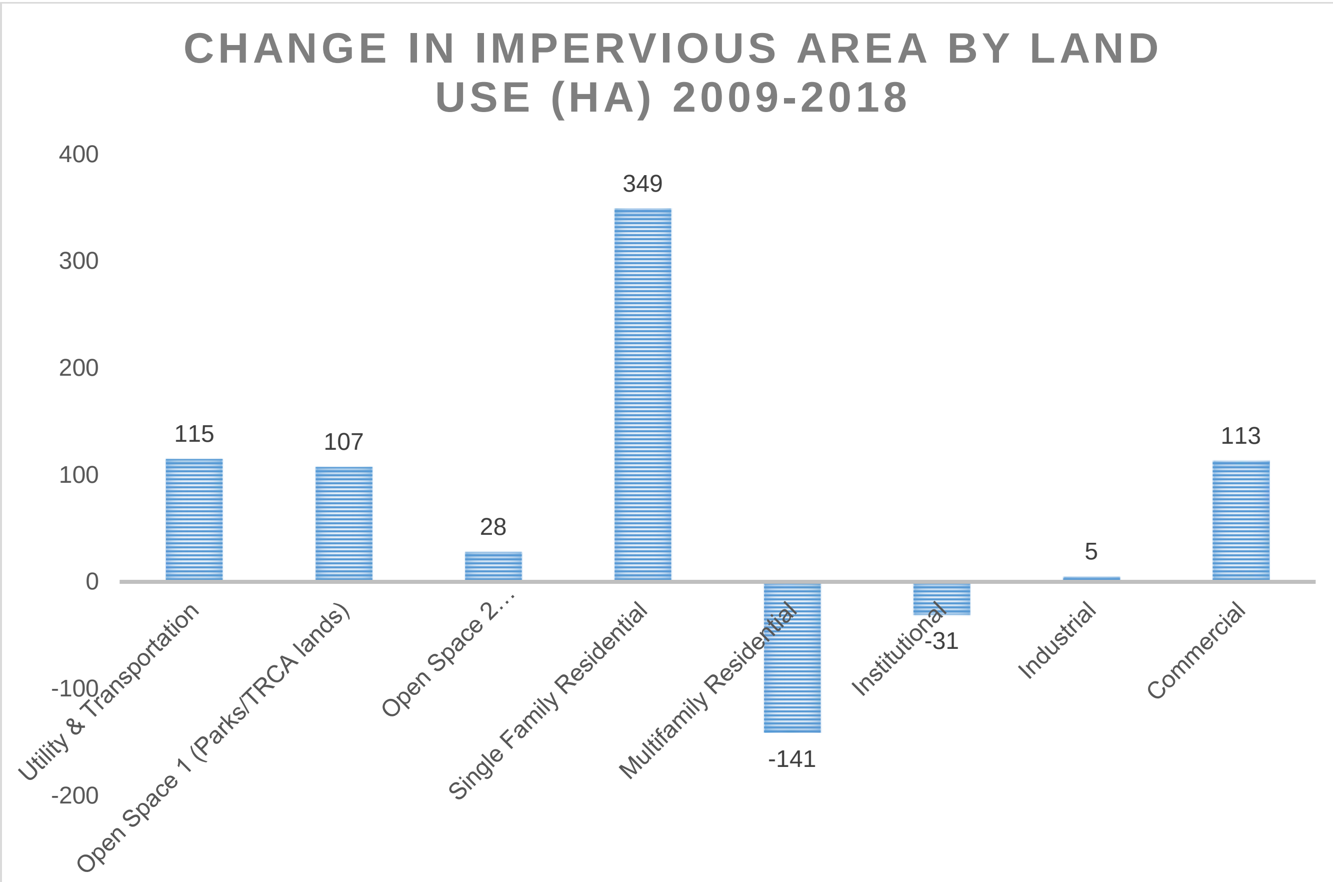


Figure 21. Pervious to impervious land cover change by land use (in hectares). (Source: 2009 leaf-on point sample from USDA Report Assessing Urban Forest Effects and Values (2013), 2018 from 10,000 point sample of high resolution orthoimagery, 2008 land use layer)

The conversion of land from pervious to impervious cover has future cost implications for the city, assuming Toronto wants to continue to maintain and increase canopy. It is more cost effective to increase tree cover in existing pervious cover than planting trees in hard surfaces. Technologies such as soil cells and continuous trenches can be more expensive than traditional approaches to planting trees. For example, it can cost anywhere between $6,300 (curb wall planted) and $21,000 per tree (T-2 Soil Cell System with unit paving) to plant in hard

[44] Results of 2009 leaf-on point sampling data (from 2013 Assessing Urban Forest Effects and Values report) and 2018 leaf-on point sampling data (2018 Tree Canopy Study). For comparison purposes, the 2008 land use layer from the first study was used to assess change by land use. A baseline measure for future comparison that uses the updated 2018 land use (zoning layer) for the City is included in Appendix K.

surfaces, depending on which technique is applied.[45] By comparison, conventional tree planting in soil requires investments in the low hundreds of dollars.

Key finding: The amount of impervious surface in Toronto has increased 1.4 percentage points, from 47.9% to 49.2% between 2009 and 2018. The highest rate of change is in the Utility & Transportation land use (4.8 percentage points increase in hard surface). However, the most area converted from pervious to impervious is found in the Single Family Residential land use, which saw a 349 ha increase in hard surface from 2009-2018.

7 | Key Findings from the 2018 i-Tree Eco Studies

There were two separate i-Tree studies completed in 2018, one for the city's entire forest and the other for street trees. In the former study, the same set of sample plots from 2008 was re-measured and provides information on high-level change across Toronto's entire urban forest.

In the latter study, the City's street tree database was used to conduct a more in-depth i-Tree analysis of the status of Toronto's street trees. This included approximately 614,000 records, with the results compared against the findings from the 2008 street tree study. Highlights from each analysis are summarized in the following sections, with detailed reports included in Appendices A and B.

7.1 | 2018 i-Tree Eco Urban Forest Results – Highlights

7.1.1 | Population and Leaf Area of the Urban Forest

Toronto's urban forest increased in population from 10.2 million trees in 2008 to 11.47 million trees in 2018. Despite this gain, the total leaf area declined from about 101,500 hectares in 2008 to 90,516 hectares in 2018. Leaf area is the two-dimensional measurement of the amount of area composed of all the leaves contained in the urban forest. Healthy large trees have relatively more leaf area than small trees as they contain more leaves. A tree population made up of predominantly small trees will generally have less total leaf area than a population of the same size made up of large trees of similar species, assuming they are healthy trees with full crowns.

Key finding: Despite an increase in canopy cover and tree population, the total leaf area of the urban forest decreased by about 11% (from 101,500 in 2008 to 90,516 hectares in 2018).

[45] Growing Trees in City Sidewalks. DTAH. URL: https://www.csla-aapc.ca/sites/csla-aapc.ca/files/CONGRESS2014/Clara%20Kwon%20-%20FINAL.pdf

7.1.2 | Size Class Distribution

Average tree diameter size decreased between 2008 and 2018, with fewer medium- to large-diameter trees and more small-diameter trees in the tree population (Figure 22). In 2008, about 68.6% of trees measured less than 15.2 cm diameter at breast height (DBH), while in 2018 about 73% of trees belonged to this diameter class. By land use, Utilities & Transportation lands have the highest proportion of small diameter trees, at 86%, and the lowest proportion of large diameter trees, at 2%. Multifamily Residential lands have the lowest proportion of small diameter trees, at 57%, and the highest proportion of large diameter trees, at 22.5%.

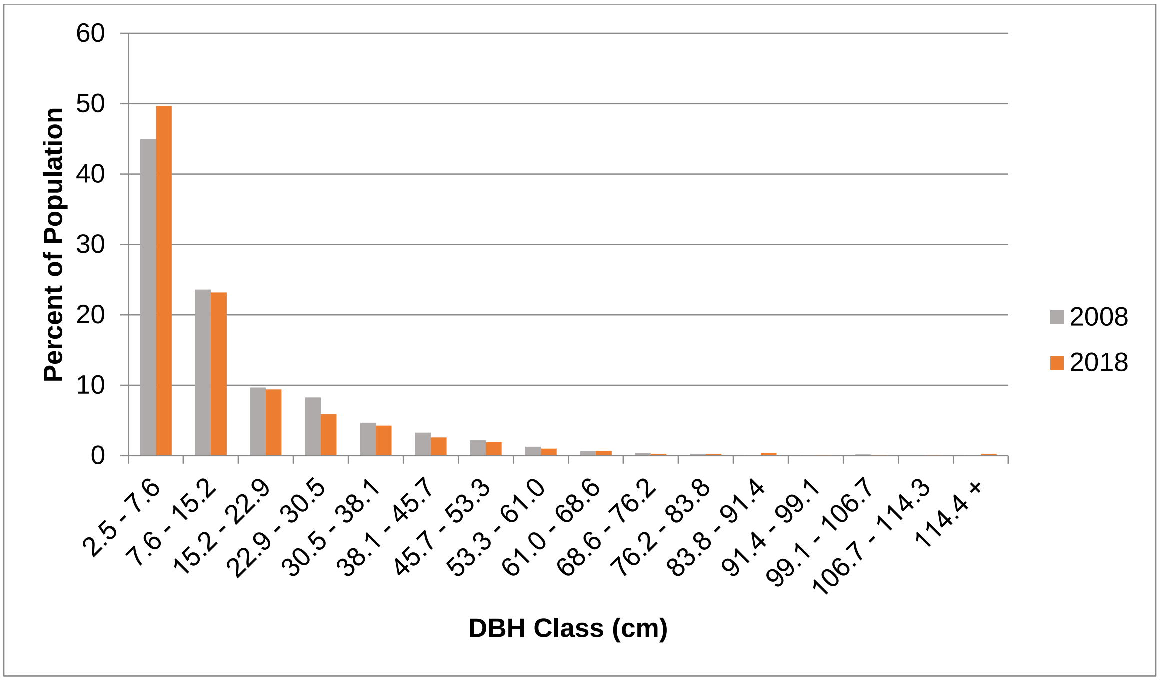


Figure 22: Distribution of Toronto's tree population by diameter class, 2008-2018. (Source: 2008 and 2018 i-Tree Eco data.)

The proportion of trees with a DBH of 15.2 cm and under has increased, with about 68.6% in 2008 compared to 73% in 2018. This is likely a result of two factors: a) the loss of mature trees to EAB and other factors and b) an increase in the population of young trees through recent planting.

Taken together with the decline in leaf area, a decrease in average tree diameter size across the city suggests that, while Toronto's urban forest has more trees than in 2008, the tree population is characterized by a larger proportion of smaller trees with lower structural value in 2018. These trees represent both young specimens of species that will grow into large trees when mature and small-stature species. This shift helps to explain the slight decline in structural value, from about $7.1 billion in 2008 to about $7.04 billion in 2018. Although there is no definitive explanation for this decrease, it is likely related to an increase in the proportion of young trees in the population (as a result of planting) with a simultaneous loss of thousands of mature ash from EAB, as well as from other causes like development.

7.1.3 | Tree Canopy and Land Ownership

The majority of Toronto's trees are located on private property (54.4%). This represents a slightly reduced proportion from 2008, when about 60% of trees were located on private property. However, the tree population has increased on public property since 2008, which suggests that the net rate of tree planting and ingrowth on public property has outpaced the rate of planting and ingrowth on private property in the last ten years. About 40.1% of trees are found in parks and natural areas with an additional 5.4% along streets in the City's right-of-ways (Figure 23). These trees, which make up 45.5% of the population are located on City property and managed by municipal departments.

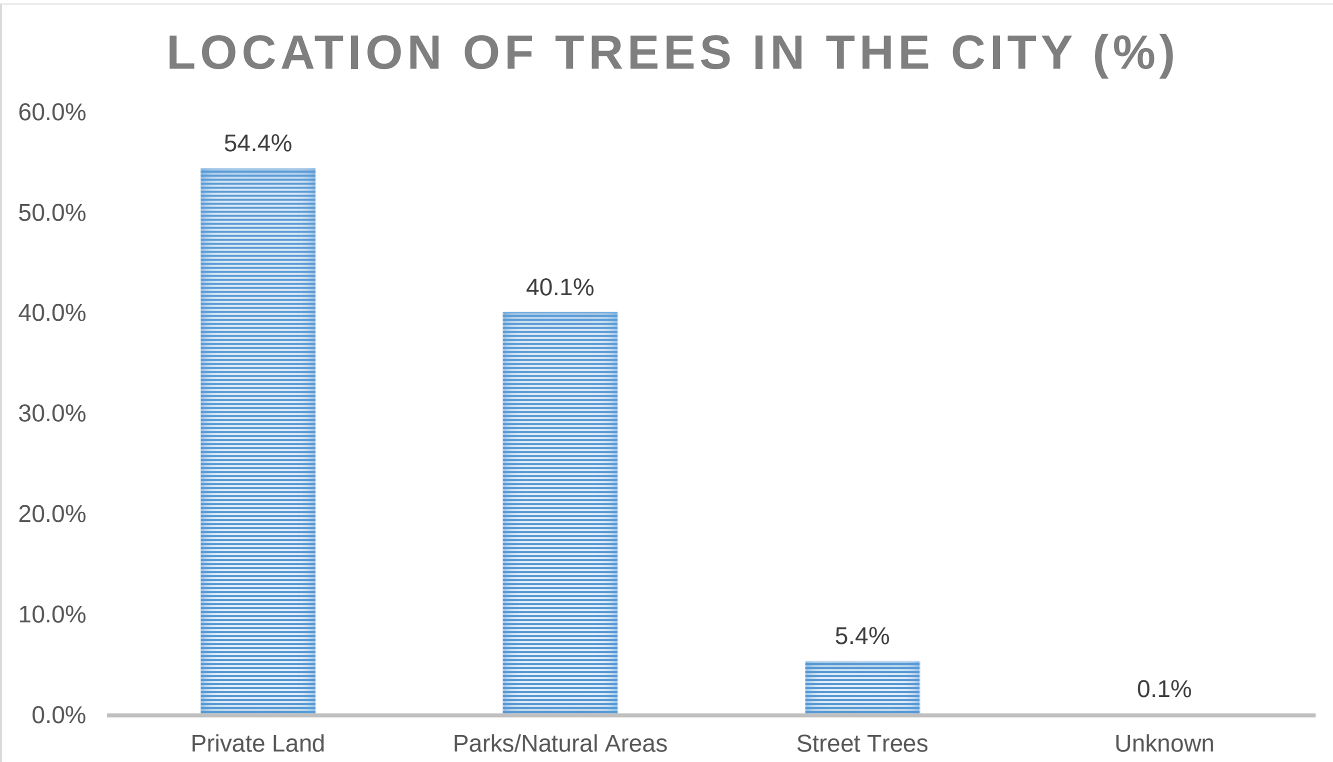


Figure 23. Tree ownership in Toronto. (Source: 2018 i-Tree study data).

Key finding: The proportion of trees on public property has increased by 5.6 percentage points, while the proportion of private trees has decreased from 60% in 2008 to 54.4% in 2018. This is likely because the rate of planting and natural ingrowth on public lands has outpaced that on private lands. One factor in this shift may be the success of public tree planting programs.

7.1.4 | Species Composition and Diversity

In 2008, a total of 116 tree species were recorded; in 2018, a total of 179 species and varieties were recorded. Approximately 50% of these species are native to southern Ontario, while about 26% of Toronto's urban forest population is composed of invasive[46] tree species, including Norway maple. The remainder consists of non-invasive, exotic species (i.e., not native to Ontario).

Biodiversity is often upheld as a measure of healthy ecosystems. It is defined as "the variety of life on Earth ... including diversity within species, between species and of ecosystems."[47] The number of species in the City alone is not a measure of biodiversity, as urban forests may have higher species richness than natural forests. Urban forests may be characterized by an inconsistent distribution of species diversity, as residential and other highly cultivated landscapes may contain a relatively diverse mix of native and non-native species, while rural areas (assumed to be more natural) may be relatively less diverse in species mix.

Single Family Residential lands had the highest number of species, with 138 species recorded. However, the Open Space 1 land use had the highest amount of species per unit area. The lowest number of species was found in the Institutional land use, with only 12 species recorded. Commercial lands are characterized by the lowest level of native trees, at about 21%, and the highest level of invasive trees, at about 54%.

The top three species in Toronto's urban forest by population remain the same in 2018 as they were in 2008. Eastern white cedar (*Thuja occidentalis*) is still the most abundant species in Toronto, and its population grew significantly since 2008. Sugar maple (*Acer saccharum*) remains the second most abundant species and Norway maple remains the third most abundant. Norway maple continues to be the dominant species in terms of leaf area due to its large population, average size, and dense leafy crown.

Ash species have experienced a dramatic decline in Toronto's urban forest, due to the effects of the emerald ash borer infestation. Green ash (*Fraxinus pennsylvanica*) and white ash (*Fraxinus americana*) were the fourth and tenth most abundant trees by leaf area in 2008. By 2018, no species of ash ranked in the top 25 species by leaf area. At the same time, green and white ash still ranked in the top 10 by population in 2018, albeit at lower levels than in 2008. This points to a dramatic loss of large specimen ash trees over ten years and their attendant benefits, and a remnant population largely made up of numerous smaller specimen ash trees with low structural value.

[46] A species introduced to areas outside its natural range that has a tendency to spread to a degree believed to cause damage to the environment, human economy or human health. Ontario Invasive Plant Council. URL: https://www.ontarioinvasiveplants.ca

[47] Biodiversity: It's In Our Nature. Government of Ontario. URL: https://www.ontario.ca

Key findings:

Overall tree species richness has increased in the urban forest, from 116 species recorded in 2008 to 179 species recorded in 2018.

There was no change in the ranking of the top three species by population in the urban forest – eastern white cedar, sugar maple and Norway maple. Norway maple is still the most abundant species by leaf area.

26% of Toronto's urban forest leaf area is composed of invasive tree species, including Norway maple.

The status of ash in the tree canopy has dramatically declined, although they are still ranked in the top ten species by population in 2018 at 541,000 trees. Remaining ash are small trees with low structural value.

Commercial lands have the lowest proportion of native species (21%) and the highest proportion of invasive species (54%) by leaf area.

7.1.5 | Invasive Species

Overall Change in Invasive Species

Overall, the amount of understory invasive species increased from 2008 to 2018. The highest proportion of invasive shrub species is found in Commercial lands, with Open Space 1 (natural areas) following in second place. Institutional lands have the lowest proportion of invasive shrub species (Figure 24).

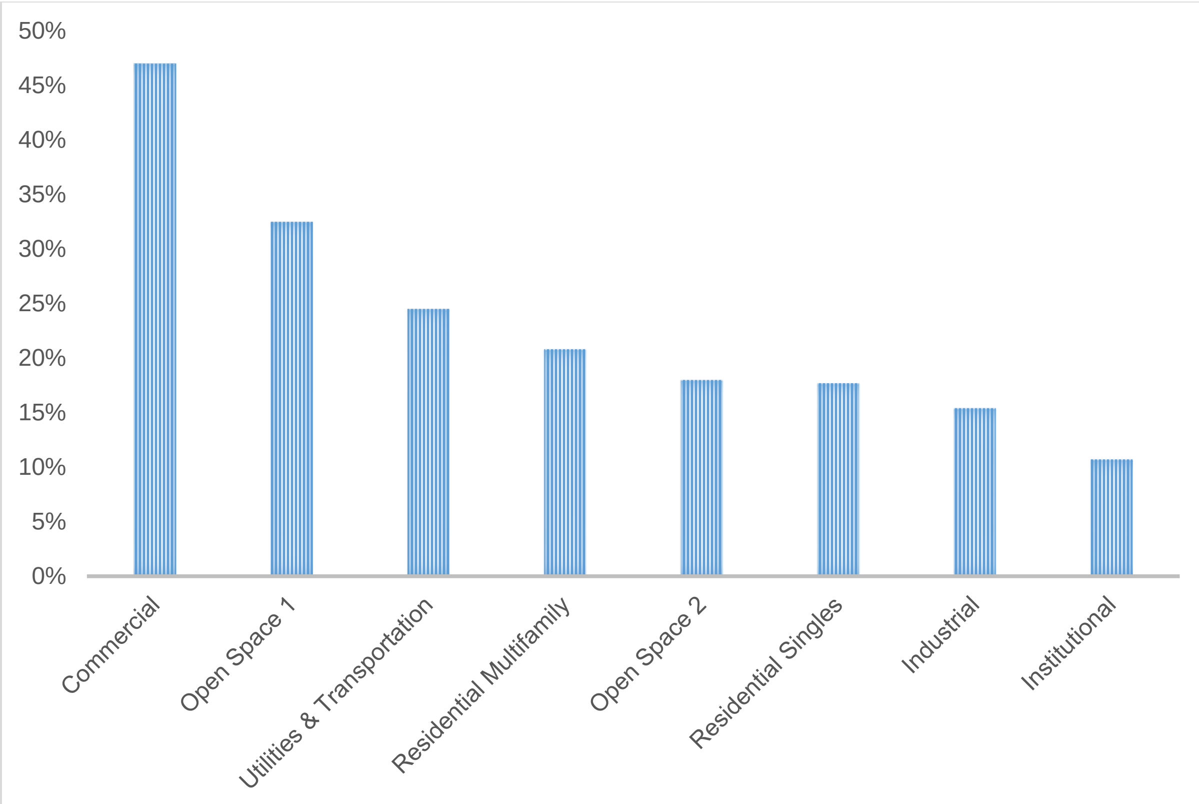


Figure 24. Proportion of invasive shrubs by land use (as percent of leaf area of total shrub population), 2018. (Source: 2018 i-Tree Eco data)

Eastern white cedar continues to be the dominant species in the shrub layer of Toronto's urban forest, comprising about 10.8% of the shrub leaf area in 2018. The invasive common buckthorn increased from 1.8% of the shrub layer in 2008 to 5% in 2018, assuming a more prominent place in the understory of Toronto's urban forest.

Increases of invasive shrubs in natural areas are particularly concerning because these species can inhibit regeneration of native species and affect forest succession. Indeed, common buckthorn was abundant on Open Space 1 and Open Space 2 lands, comprising 17.6% and 9% of the shrub layer, respectively. The Utilities & Transportation lands also contained a significant amount of buckthorn, where it made up about 12.6% of the shrub layer.

Invasive Species in Natural Areas

During the 2018 i-Tree Eco survey, field crews recorded the presence and extent of invasive plants in all plots located in ravines and natural areas. This set of data helps to provide additional insight into the nature of invasive plant distributions in Toronto's ravines and natural areas and may assist with any potential operational activities aimed at managing local invasive plant populations. The list of plants included in this portion of the survey was focused on 23 non-native invasive species and two native noxious species (See Appendix B for the full list of species).

Out of the list of 25 species, field crews detected 14 species of invasive and noxious plants. Based on the findings of these assessments, the three most common invasive plants in Toronto's natural areas and ravines are dog-strangling vine (with 35 detections), common buckthorn (with 28 detections), and garlic mustard (with 20 detections). Dog-strangling vine was also detected most frequently (in four plots) as a species that blanketed the understory of the plot and the surrounding area. A total of 47 plots (8% of the total number of plots) were found to contain at least one invasive plant species.

Invasive tree cover has increased somewhat in the city's natural areas (Open Space 1 lands) from about 10% of leaf area in 2008 to 14% in 2018. However, these areas also still have the highest proportion of native tree cover at about 70% of leaf area, which is similar to the level recorded in 2008.

About 32.5% of the shrub layer leaf area in Open Space 1 lands is made up of invasive species. Given that this land use consists of natural areas and woodland parks, this is a concerning increase from 2008 when approximately 15% of the shrub layer leaf area was defined as invasive. In fact, Open Space 1 lands had the third lowest percentage of invasive shrubs in 2008. By 2018, invasive shrub leaf area in this land use had doubled and now represents the second highest percentage of invasive shrubs (Figure 24).

Key findings:

Native tree cover (leaf area) in the Open Space 1 lands remained relatively stable between 2008 and 2018, at around 70%.

The leaf area of invasive tree species in Open Space 1 lands increased from 10% in 2008 to 14% in 2018.

The leaf area of invasive shrubs in natural areas (Open Space 1 land use) more than doubled in ten years, from 15% in 2008 to 32.5% in 2018.

Commercial lands have the lowest proportion of tree leaf area composed of native species (21%) and the highest proportion of tree leaf area composed of invasive species (54%).

Prioritize outreach to commercial land owners adjacent to natural areas with information about invasive species.

This i-Tree study data along with local expertise of PFR and TRCA staff identify invasive species as a high priority management issue for the city's urban forest, especially in ravines and natural areas. However, detailed information on forest structure to develop targeted management approaches is needed.

A forest condition monitoring program has been developed by the City to help to address this need. In 2019, a network of 200 permanent sample plots has been proposed in partnership with the University of Toronto to monitor forest condition in ravine forests and natural areas.

The purpose of the proposed forest condition monitoring program in ravines and natural areas is to:

- Develop a permanent terrestrial ecological monitoring strategy for the City of Toronto to complement monitoring that is done by the Toronto and Region Conservation Authority (TRCA)
- Establish 200 permanent sample plots throughout Toronto's ravine forests and natural areas, and collect initial baseline data
- Analyze data to define baseline ecological conditions and derive indicators of ecological quality
- Develop a tool that can be used by citizen volunteers, allowing additional data collection through their programs

These data will be invaluable for developing appropriate strategies for natural areas, including invasive species management.

7.1.6 | Tree Condition

Average tree condition has declined since 2008, when 81.6% of trees were rated as being in excellent or good condition based on the amount of dieback in the crown. In 2018, only 70% of trees were rated as being in excellent or good condition. There were also more standing dead trees observed in 2018 (7%) than in 2008 (4%). Trees on Single Family Residential lands are in relatively good condition compared to the average tree condition, with about 79% of trees rated as being in excellent or good condition. Trees in the Open Space 1 land use, which includes parks and natural areas, were below average in tree condition, with only about 61% of trees rated as being in excellent or good condition. The Open Space 1 land use also had a higher proportion of standing dead trees than the average, with 8.5%. However, the land use with the highest proportion of standing dead trees was Institutional, at 29.3%. The reasons for the decline in average tree condition rating are not clear.

The decline in overall tree condition may be related to the effects of emerald ash borer pest which continues to affect the health of remaining ash trees in the city. It could also be related to other pest cycles (e.g., gypsy moth), which can affect tree condition in the short term with recovery seen later, assuming proper treatments are applied or depending on the cycle and intensity of infestation. Other possible factors affecting tree condition could include: climate conditions (e.g., drought and/or heat stress), variable freeze/thaw cycles as well as a lack of tree maintenance contributing to the decline in tree condition.

Key Finding: Average tree condition across the urban forest has declined – in 2008, 82% of trees were rated in excellent or good condition. In 2018, that number declined to 70%, with an increase in standing dead trees also observed (7% in 2018 vs. 4% in 2008).

7.1.7 | Carbon Storage and Sequestration

During each growing season, trees sequester atmospheric carbon through their leaves during photosynthesis. Large trees with large leaf areas sequester more carbon compared to small trees and healthy trees tend to sequester more carbon than unhealthy trees of a similar size. Thus, carbon sequestration is a reflection of both leaf area and tree function. As the tree grows, carbon is stored for the long term in woody tissue. As a result, large trees on average store more carbon in their trunks and branches compared to small trees, due to the larger amount of woody tissue in large trees. Stored carbon is gradually released when trees die and decay naturally. If a population of trees is in particularly poor health, or there is high mortality, it can release more carbon than it sequesters, resulting in a net source of atmospheric carbon.

There was a very small decline in the amount of carbon stored by Toronto’s trees since 2008. However, trees currently store an estimated 1.1 million tonnes of carbon, which is approximately equivalent to the amount stored in 2008. As in 2008, Norway maple trees store more carbon than any other species in Toronto’s urban forest. About 59% of the carbon stored in Toronto’s urban forest is stored by trees in the Single Family Residential land use.

Compared to the levels reported in 2008, annual carbon sequestration rates performed by Toronto’s trees have declined. In 2008, trees sequestered about 46,740 gross tonnes of carbon per year while in 2018 this number had declined to 35,165 annual gross tonnes. The annual value of carbon sequestration performed by Toronto’s trees is about $4.04 million. This decline in annual carbon sequestration aligns with the decline in total leaf area, as carbon sequestration is a partly function of a tree’s leaf area. Norway maple and sugar maple continue to sequester the most carbon each year. About 65% of the net annual amounts of carbon sequestered by Toronto’s urban forest is due to trees on Single Family Residential lands.

7.1.8 | Pollution Removal

Like atmospheric carbon, trees remove atmospheric air pollution through the regular function of their leaves. Increases in leaf area can translate to increases in pollution removal, while decreases in leaf area can have the opposite effect. Toronto’s trees are estimated to remove about 972 tonnes of pollution from the air each year, which carries an estimated annual value of $37.9 million. This represents a decline in pollution removal from the level reported in 2008, but this is in part due to differences in the criteria pollutants that are measured using the i-Tree Eco software. For example, large particulate matter, which formerly accounted for 357 tonnes of annual pollution mitigation, was removed from analysis in favour of small particulate matter, which has more serious implications for human health, but only accounts for 32.7 annual tonnes of mitigated pollution. Nevertheless, a decline in pollution removal aligns with a decline in overall leaf area.

7.1.9 | Energy Savings

When properly located, trees help to reduce home energy costs, particularly as trees grow larger. They do this mainly by shading and cooling in summer (reducing the need for air conditioning) and reducing wind speeds in winter that can cut down on heating costs. Toronto's trees are saving homeowners an estimated $8.3 million annually. Through energy savings, trees also prevent 23,081 tonnes of carbon emissions each year that result from energy use, which carries an additional annual value of $2.6 million. This represents a positive change from 2008 when trees prevented about 17,000 tonnes of annual carbon emissions.

Key Finding: The amount and value of some key ecological services provided by the urban forest has declined, as a result of less total leaf area of the urban tree canopy despite an increase in the number of trees.

7.2 | Status Report on Toronto's Street Trees

7.2.1 | The Role of Street Trees in the Urban Forest

The i-Tree Eco version 6 software was used to process each ward's street tree inventory data and produce the following benefits analysis. i-Tree Streets was originally proposed for the benefits analysis, but consultations between BioForest and City of Toronto staff led to the use of the more updated i-Tree Eco version 6 for this portion of the project. See Appendix A for a detailed methodology.

Street trees represent an important component of a city's urban forest. Street trees enhance the aesthetics of neighbourhoods, provide valuable ecosystem services and make up a significant portion of a city's urban forest cover. In some densely built neighbourhoods, street trees can represent most of the urban forest cover and thus make valuable contributions to neighbourhood character and livability.

Street trees play an important role in improving urban environmental equity in low income and underserviced communities. For example, street trees have been linked to positive effects on physical and mental health[48]. Their location adjacent to the road allowance helps to reduce

[48] Lovasi et al. 2008. Children living in areas with more street trees have lower prevalence of asthma. Journal of Epidemiology & Community Health 62: 647-649; Taylor et al. 2015. Research note: Urban street tree density and antidepressant prescription rates – A cross-sectional study in London, UK. Landscape and Urban Planning 136-174-179; Salmond et al. 2016. Health and climate related ecosystem services provided by street trees in the urban environment. Environmental Health 15 (Suppl. 1): S36.

runoff from asphalt during rain storms, thereby helping to reduce their burden on municipal infrastructure[49].

Since street trees are located adjacent to roadways, they are predisposed to a variety of stress factors that trees in woodlands and rear yards are unlikely to face. Street trees are often subject to salt during the winter, which has been shown to affect their performance.[50] Street trees may be planted in confined growing spaces with inadequate soil volume and poor soil quality. When planted along heavily trafficked streets, this soil can become compacted by repeated pedestrian trampling contributing to restricted fine root growth. Conflicts with utilities, pedestrian clearways, patios and other encroachments into potential growing space minimize opportunities for tree planting in the right-of-way.

Street trees may also be injured by snow removal or construction equipment, vehicles, and vandals. Street trees growing in areas with abundant impervious ground cover and reflective building surfaces can suffer heat stress during the summer months. Injuries and increased stress can predispose trees to insect and disease infestation, further endangering their longevity and preempting the benefits provided by mature trees.

Some innovations, such as “modular structural soil cell systems" or "modular suspended pavement systems" are methods used to modify urban infrastructure so that street trees can have adequate space for root growth, water infiltration, and access to oxygen and nutrients. These modular systems are used in paved environments and can allow for trees to be planted where there is otherwise very limited soil. By creating or enhancing soil volume, these systems can help to prevent negative impacts to trees from grey infrastructure, such as pipes and sidewalks, which can restrict root growth. However, widespread application of these solutions may not be possible due to high costs, approvals, above grade clearance requirements and logistics.

An analysis of the benefits provided by Toronto’s street trees complements the assessment of the city’s entire urban forest by highlighting the value provided by the street tree population. The value of a street tree resource is in many ways contingent on the health of the trees and the extent of leaf area they collectively represent. As the City is responsible for planting, maintaining and removing street trees, an overview of the benefits provided by street trees can provide insights into the outcomes of the City’s investments in the resource and help to inform management decisions.

[49] Armson et al. 2013. The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. Urban Forestry & Urban Greening 12(3): 282-286.

[50] Camilo Ordóñez-Baronaa, Vadim Sabetski, Andrew A. Millward, James Steenberg. De-icing salt contamination reduces urban tree performance in structural soil cell. Environmental Pollution, Volume 234, March 2018, Pages 562-571. URL: https://www.sciencedirect.com/science/article/pii/S0269749117339891

7.2.2 | Highlights of the Street Tree Benefits Analysis

Street trees provide a proportionately greater amount of urban forest benefits than the urban forest as a whole, representing 19.4% of the total structural value of the urban forest, while accounting for only 5.4% of the total tree population.

Table 12. Benefits provided by Toronto's street trees (Source: Street Tree Benefits Analysis, 2018).

Category	Data
Number of street trees	**614,227**[51]
% of the Toronto's total tree population	5.4%
Structural Value of Street Trees[52]	$1.363 billion 19.4% of total structural value
Carbon storage	173,355 tonnes Associated value of $19,882,000 15.8% of total carbon stored
Annual Carbon Sequestration	2,877.9 tonnes Associated value of $330,750 8% of annual carbon sequestration
Annual Pollution Removal	125.5 tonnes pollution removed Associated value of $175,450 12.9% of the total annual pollution removal
Annual Avoided Runoff	331,745 m^3 avoided runoff Associated value of $771,300 29% of the total annual avoided runoff
Total Value of Annual Ecosystem Services Performed by Street Trees	$1,277,500

[51] This figure represents an edited version of the City of Toronto's street tree population as of June 5, 2018. The full population of 620,221 was edited to remove erroneous records such as trees with DBH recorded as 0.

[52] Structural value is based on the CTLA trunk formula method, which is used to calculate the economic value of the physical tree based on its relative size. Additional factors that can influence value include the tree's species, condition, and location.

These results indicate that the benefits provided by Toronto's street trees are outsized compared to the portion of the total tree population they represent. This may be attributed in part to the relatively good condition and health of the street tree population as well as their large crown sizes (not always achieved by trees in a woodland setting), which the City manages directly.

The results also speak to the importance of investing in other municipal green infrastructure (e.g., ravines) as the City of Toronto's management of its street trees has clearly resulted in substantial environmental benefits. Urban Forestry should work with other City Divisions in developing this infrastructure to increase the overall percentage of street trees in recognition of the benefits street trees provide the urban landscape. The City's role in improving neighbourhoods by maintaining tree canopy and delivering the benefits to the city's residents that flow from street trees is significant.

7.2.3 | Street Tree Condition/Health

The health of Toronto's street trees is relatively good, according to the condition ratings recorded in the city's tree inventory (Figure 25). The overall condition of Toronto's street trees has improved since the previous urban forest study was completed in 2008.

74.4% of Toronto's street trees are in excellent or good condition compared to 49% in 2008. Dead trees made up about 0.5% of the street tree population in 2018 but were not reported in the previous study. The improvement in average tree condition is mostly likely an outcome of regular tree maintenance and the removal of trees in poor condition.

Key finding: Street tree condition has improved, with 74.4% of street trees in excellent or good condition compared to 49% in 2008. This shows the effects of regular tree maintenance.

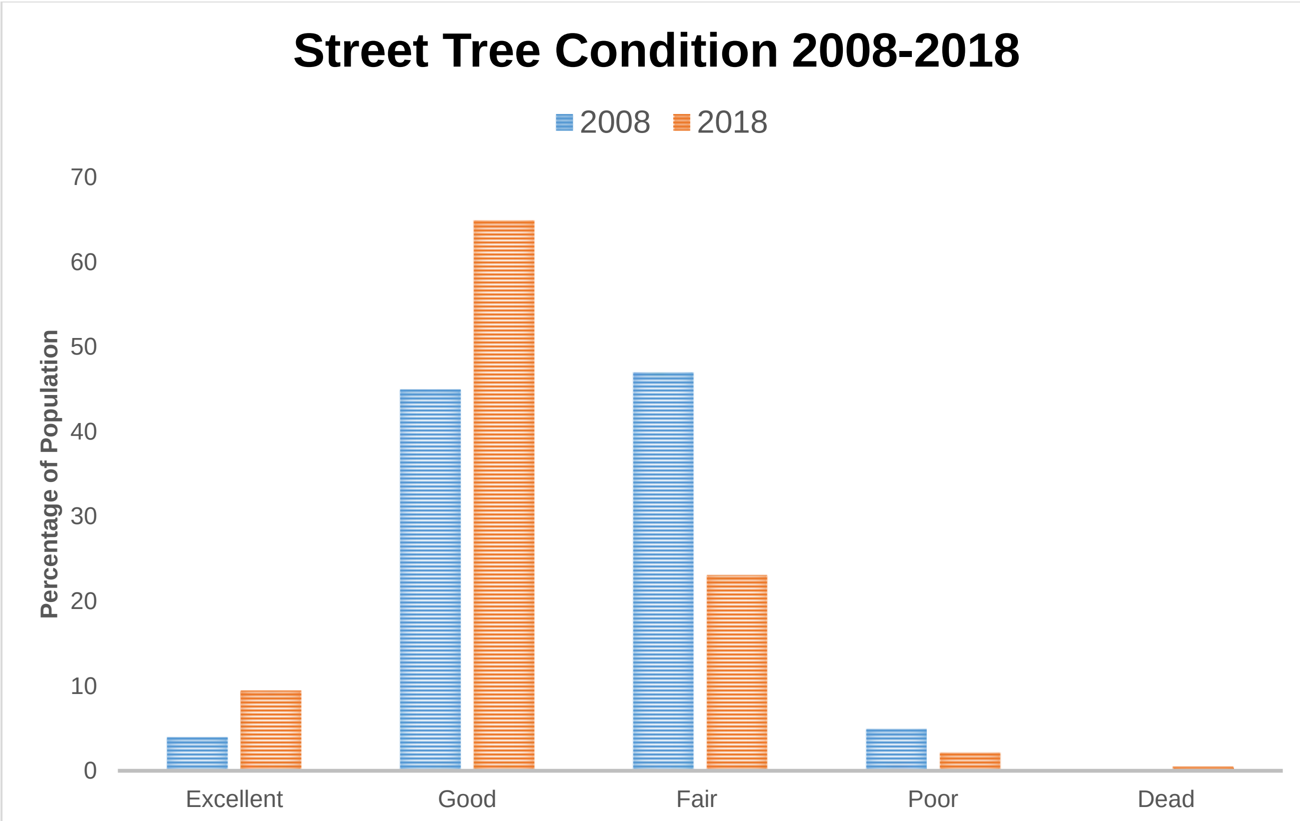


Figure 25. Average street tree condition as percent of population, 2008-2018. (Source: Every Tree Counts and 2018 i-Tree Eco analysis of street tree population)

7.2.4 | Species Composition & Diversity

Norway maple is the most abundant street tree, comprising about 13.5% of the total street tree population in 2018, compared to 22% in 2008 (Figure 26). It is also the most abundant species in all but two of the 25 wards, typically comprising between 9 and 20% of a ward's tree population. Norway maple has by far more leaf area than any other species of street tree, contributing about 28% of the leaf area of all street trees (Figure 26). This is partly due to Norway maple's abundant population but is also due to its naturally dense and leafy canopy and the relatively large size attained by mature Norway maple trees.

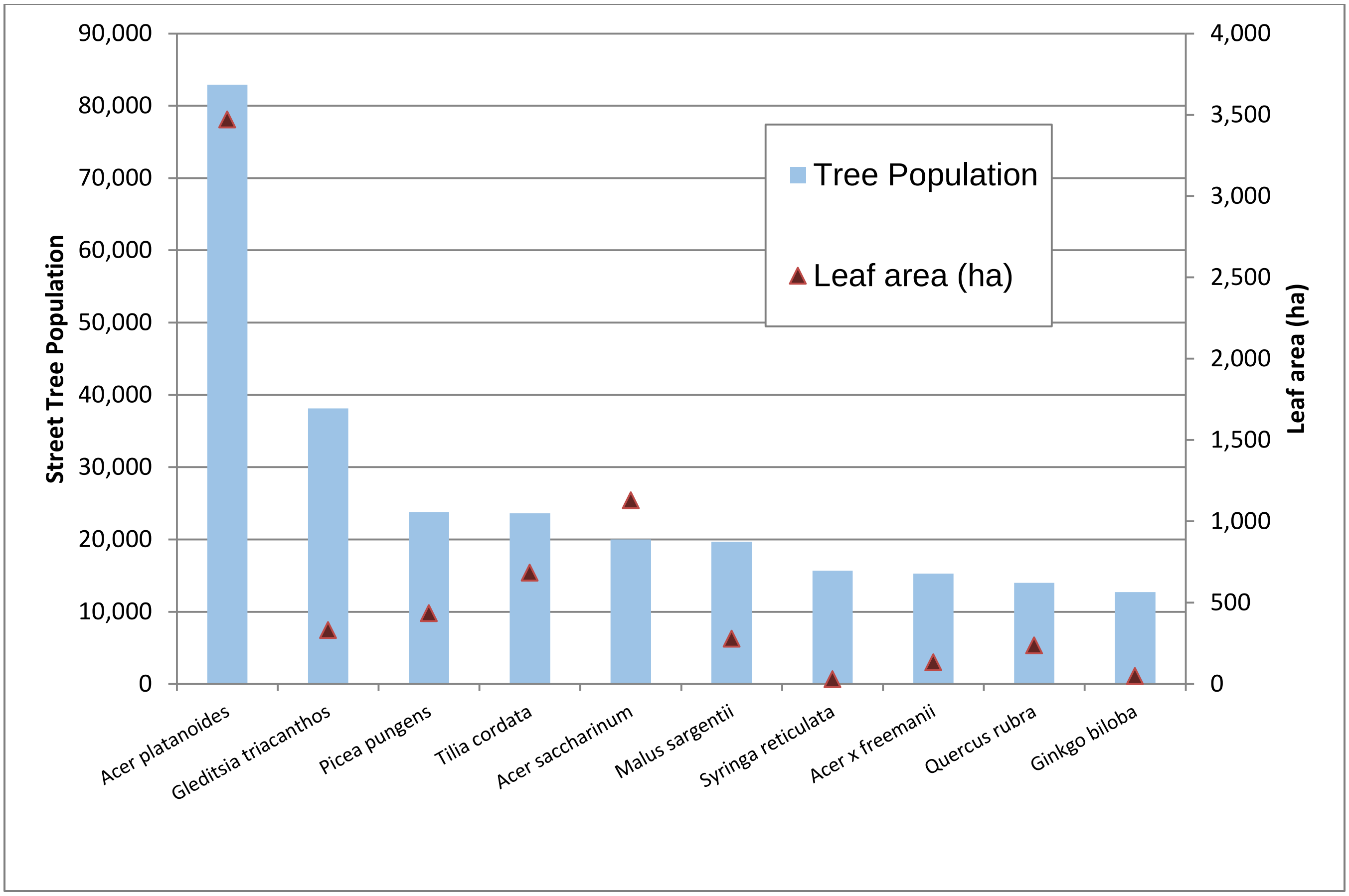


Figure 26. Top ten species of street tree by population and total leaf area, 2018. (Source: 2018 i-Tree Eco analysis of street tree population)

The decrease in population and leaf area of Norway maple is an improvement over the findings in 2008 since this species is highly invasive in forest and ravine habitats and degrades forest health. However, its contributions to ecosystem services are undeniable. Along with other species of maple, Norway maple trees are at risk from the Asian long-horned beetle (ALHB) pest as the maple is a preferred host genus. The vulnerability of such a large contingent of street trees to this pest threat is a concern for the long term resilience of the street tree resource.

Also of note is the downgrading of the rank of ash species in the street tree population since 2008. Red/green ash is now the fifteenth most abundant street tree (compared to 7th in 2008) and accounts for only 1.37% of Toronto’s street tree population (or 1.74% of total leaf area). The decline in population is due to removals related to decline and mortality as a result of the emerald ash borer (EAB) infestation that has devastated ash trees across the province.

Other changes in species composition include an increase in Freeman maple (*Acer × freemanii*), red oak (*Quercus rubra*), and ginkgo (*Ginkgo biloba*) since 2008. This increase, in terms of species diversity and in terms of long-term ecological services, is beneficial as all these species have the potential to grow into large stature trees.

Approximately 40.6% of Toronto's street trees are native to Europe and/or Asia. About 52.3% are native to North America though not necessarily native to Ontario (Figure 27). While the City strives to use native species in natural areas to support biodiversity objectives not all native species are suitable for street tree selection due to the harsh growing conditions. Increased species diversity in the street tree population promotes resilience to pests, disease and climate change effects. For this reason, exotic species (e.g., gingko) are acceptable choices for street tree planting.

Some of the effects of climate change such as temperature increases may exacerbate stresses on street trees, which often already contend with difficult growing environments. As a result, native species may not always be optimal choices for planting along city streets and resilient non-native species may be favoured if they have a higher likelihood of survival under the harsher conditions.

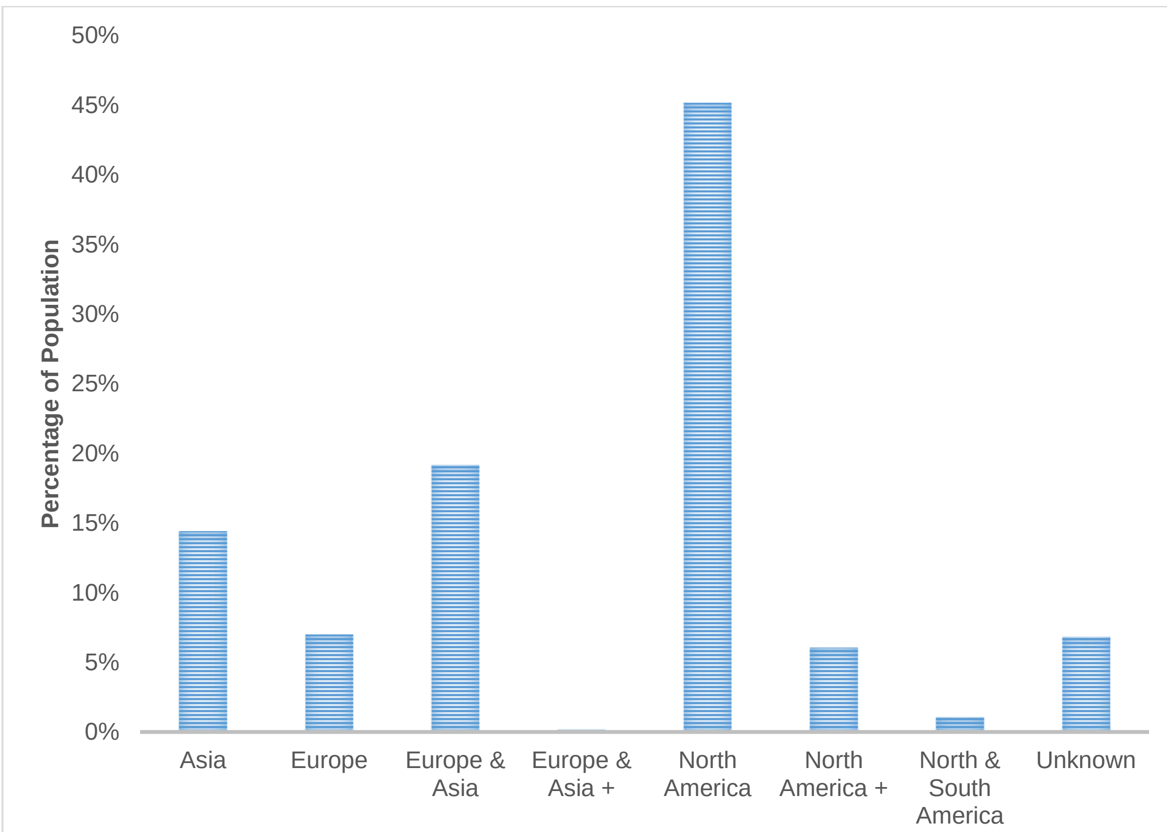


Figure 27: Toronto's street tree species by native place of origin, 2018. (Source: 2018 i-Tree Eco analysis of street tree population)

7.2.5 | Size Class Distribution

As of 2018, the average diameter size of street trees increased with only 43% of street trees measuring 15.2 cm or less in diameter compared to 47% in 2008. About 33.7% of street trees measured more than 30.6 cm in diameter compared to 25% in 2008 (Figure 28).

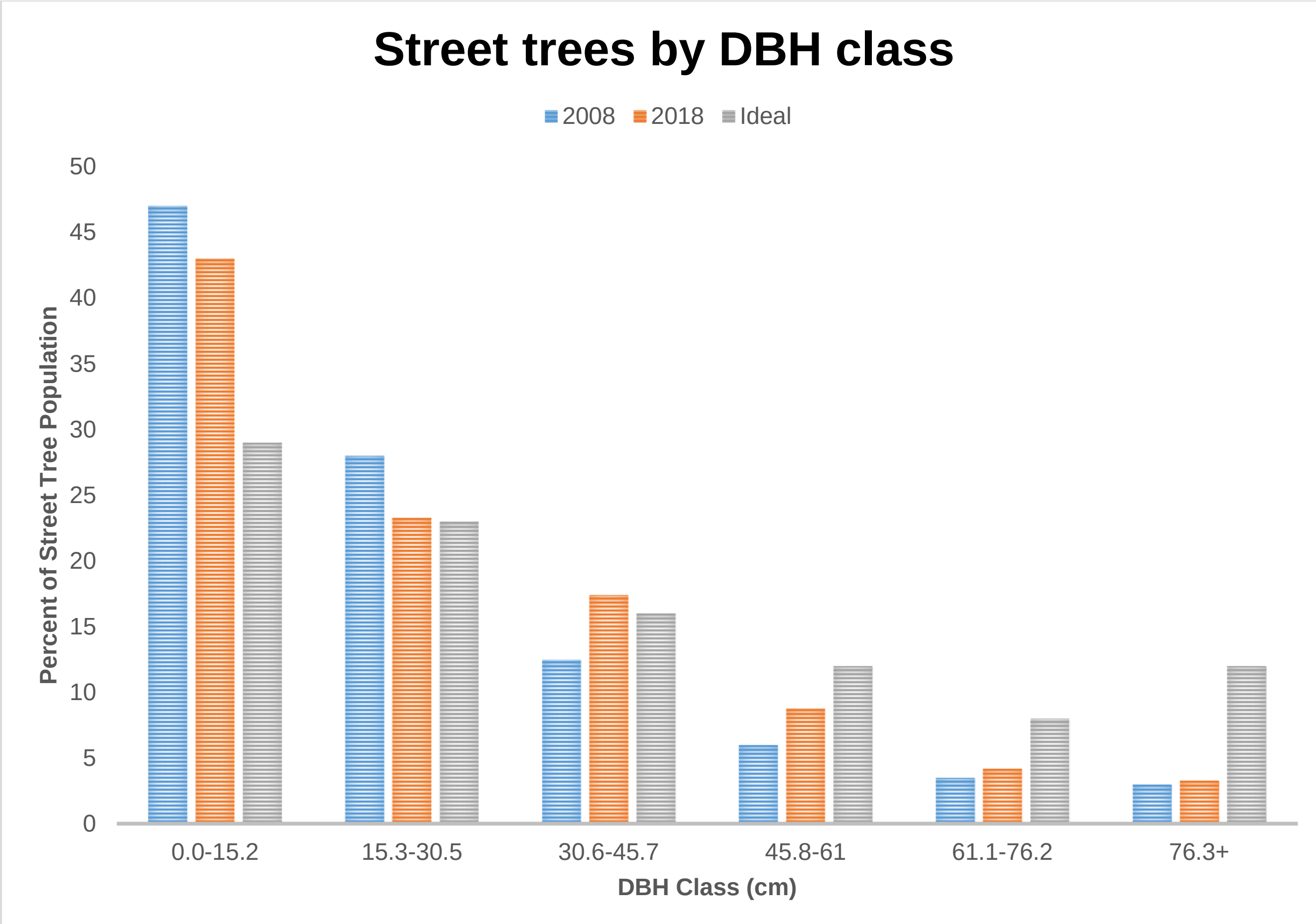


Figure 28: Distribution of Toronto's street tree population by DBH class (cm), 2008-2018, compared to suggested 'ideal' distribution. (Source: Every Tree Counts and 2018 i-Tree Eco analysis of street tree population)

Overall, the diameter distribution of street trees has improved. There is a better distribution across all size/age classes approaching the ideal in some of the size categories. While the 'ideal' size class distribution is an evolving science, it provides one benchmark against which the street tree size class distribution may be measured.

It is important for cities to maintain a good complement of larger street trees as they provide the most environmental and health benefits. This can be supported by strong protection and preservation of existing trees. Protecting and maintaining large trees allows them to continue to deliver benefits into the future and per-tree benefits will continue to increase as trees grow larger.

Key finding: The size class distribution of street trees has improved and includes an increased number of large trees (45cm DBH and up), which produce more urban forest benefits.

7.2.6 | Street Tree Planting

Since 2008, the City of Toronto has planted approximately 90,000 street trees, this includes new tree planting and replacement planting. It is a policy of the City of Toronto to replant all removed street trees. New street tree planting numbers are a factor of available space and funding priorities.

Key finding: Approximately 90,000 street trees were planted between 2008 and 2018, representing 9,000 trees of the 120,000 trees and shrubs planted on public land over the last 10 years.

Change in Toronto's street tree population indicators is provided in Table 13. Overall, proactive management and continued investments in this important City asset have led to improvements in their condition, diversity and size class distribution.

Table 13. Summary of change in selected street tree indicators 2008-2018. (Source: Street Trees Benefits Analysis)

Indicator	2008	2018	Trend
Population	~600,000	614,227	Positive
# of Street Tree Species	144	241*	Positive
# Small Trees (>30.6 cm DBH)	25%	33.7%	Positive (increase in average diameter of street trees = more benefits)
% Trees in Excellent or Good Condition	49%	74.4%	Positive
Norway maple as % of population (invasive)	22%	13.5%	Positive
% Maple Species (Vulnerability to Invasive Pests and Disease)	34%	28%	Positive

*There are more species of street trees recorded in the City's street tree inventory database than are captured by the 407 plot data, which represents a sample-based approach to tree inventory.

8 | Opportunities for Expanding Toronto's Tree Canopy

8.1 | Possible Planting Area (PPA)

A valuable outcome of completing land cover mapping for the City of Toronto is the opportunity to look at existing urban forest canopy but also possible planting areas (PPA). PPA is a high-level estimate of theoretical available planting space made up of two kinds of surfaces: pervious and impervious.

- Pervious PPA represents open areas composed of land covers including soil and grass.
- Impervious PPA represents open areas composed of impervious services with land covers other than buildings and roads, such as parking lots and sidewalks.

PPA does not provide precise estimates of available planting area because it does not consider in detail the many constraints that could be encountered on a particular site. In this study, sports fields and hydro corridors were extracted from the PPA total to reflect some of the main competing land uses (e.g. recreation and utilities) that would preclude the planting of trees. Nevertheless, PPA estimates could provide a starting point for understanding where potential opportunities to increase canopy might be found and the size of the areas available.

A more detailed planting prioritization exercise using the 2018 land cover data that applies other filters like land ownership, land use (e.g., agriculture), existing levels of canopy cover or other factors of interest (flood prone areas, high urban heat island effect, etc.) could help managers develop more detailed operational plans for tree planting.

Key finding: In total, there are approximately 28,668 hectares of possible planting area (PPA) across the city. Approximately 52% of this area, or 14,822 hectares, consist of pervious land cover types. By comparison, there are 64,167 hectares of existing tree cover across the City.

While it seems counterintuitive that impervious areas could be used to plant trees, they can represent opportunities to integrate tree cover into a landscape by using things like structural soils or cells, continuous planting trenches and/or permeable paving to create sub-surface growing space for trees in impervious landscapes, or even the simple creation of planting sites by removing impervious surfaces and exposing plantable soil, which may create less optimal planting sites but has a lower cost. The Toronto Design Guidelines for 'Greening' Surface Parking Lots, among other things, includes requirements to 'green' the surface parking lot by planting trees, providing good quality soil and generous landscaped areas.[53]

[53] Toronto Design Guidelines for 'Greening' Surface Parking Lots. 2013. URL: https://web.toronto.ca/wp-content/uploads/2017/08/9642-Design-Guidelines-for-Greening-Surface-Parking-Lots.pdf. Toronto Green Standard Version 3. URL: https://www.toronto.ca/city-government/planning-development/official-plan-guidelines/toronto-green-standard/toronto-green-standard-version-3/

Figure 29 shows the total available area in hectares of both pervious and impervious PPA in the city.

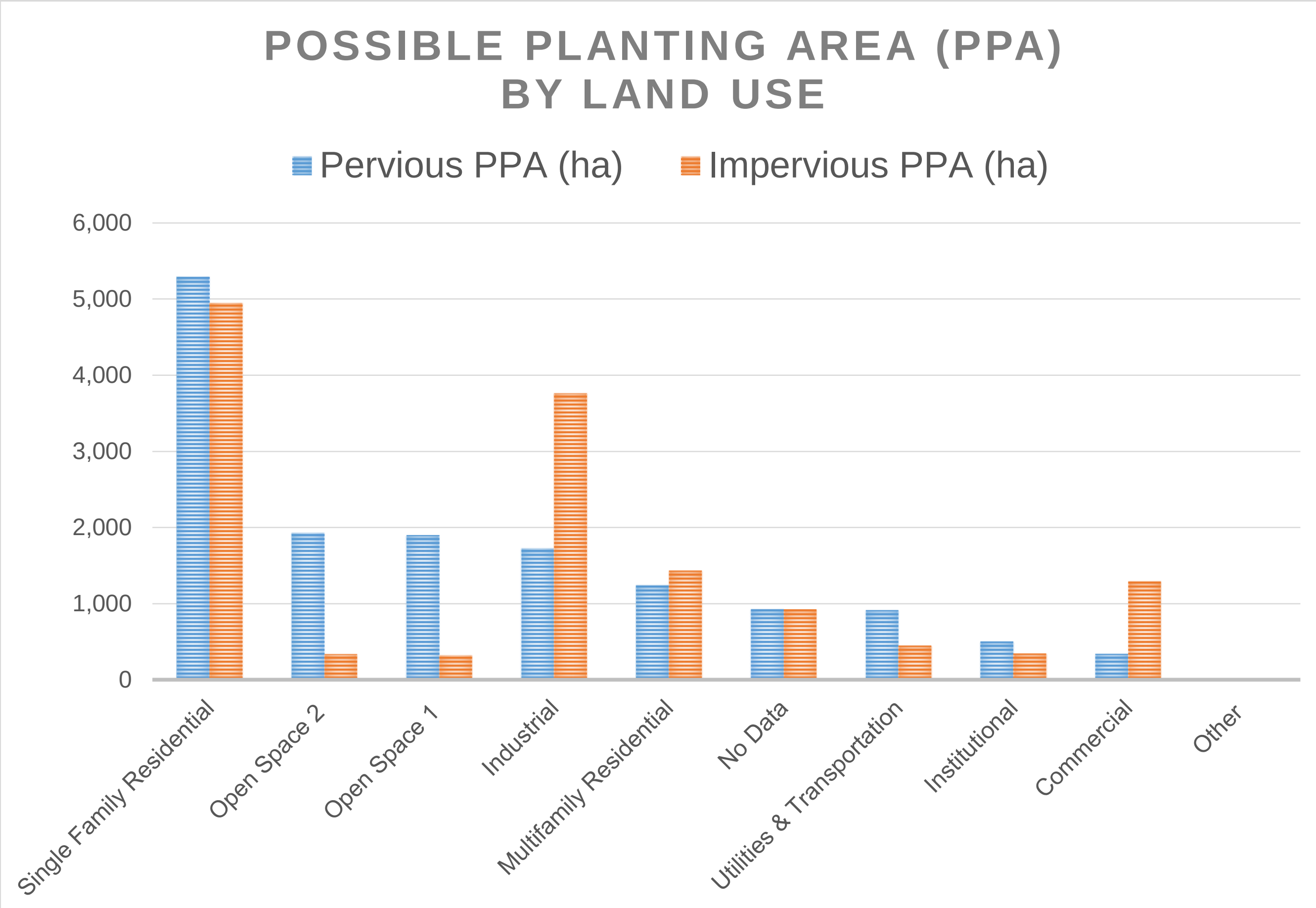


Figure 29. Possible pervious and impervious planting areas, by hectare, with sports fields and hydro corridors removed from available pervious PPA total (Source: 2018 land cover and land use (zoning) data, City of Toronto).

As the equitable distribution of tree canopy across the city is a strategic goal of the City's forest management plan, planting could be prioritized by looking at areas of low canopy and high possible planting area or neighbourhoods with marginalized populations with less access to proximal greenspace. Pervious land covers are a lower cost option than planting trees in impervious PPAs. However, impervious PPA should not be discounted on the basis of cost alone. Figure 30 shows the existing tree cover by land use relative to the possible pervious planting area in that same land use.

Logically, the level of existing tree cover will affect the available planting space for additional tree planting on lands where canopy levels are already high (e.g., Open Space categories). Figure 30 suggests that the greatest opportunities for improving canopy are on Industrial and Institutional lands, where existing tree cover is low and pervious PPA is relatively high.

Key findings:

The greatest amount of available pervious planting area by land use is on Single Family Residential lands (5,292 ha), followed by Open Space 1 (1,902 ha), Open Space 2 (1,935 ha) and Industrial (1,733 ha) lands

The greatest amount of impervious PPA is found on Single Family Residential (4,946 ha), Industrial (3,765 ha) and Multifamily Residential lands (1,425 ha).

8.1.1 | Pervious Possible Planting Area

The pervious PPA land cover classes are the most suitable for tree planting in Toronto. By land use type, Single Family Residential lands have by far the greatest amount of pervious PPA (5,292 hectares), relative to the City's total land area. This means that a majority of high-quality (requiring less intervention) planting sites are found on private lands in the City. The Open Space land uses (1 and 2) follow Single Family residential in terms of planting area, though competing interests for open areas may limit further tree planting in the Open Space 1 land use, and private land interests in the Open Space 2 land use may present similar constraints.

Industrial lands have the second highest total area of PPA (pervious and impervious at 5,498 hectares), suggesting there may be opportunities in both pervious and impervious planting area in that land use as well.

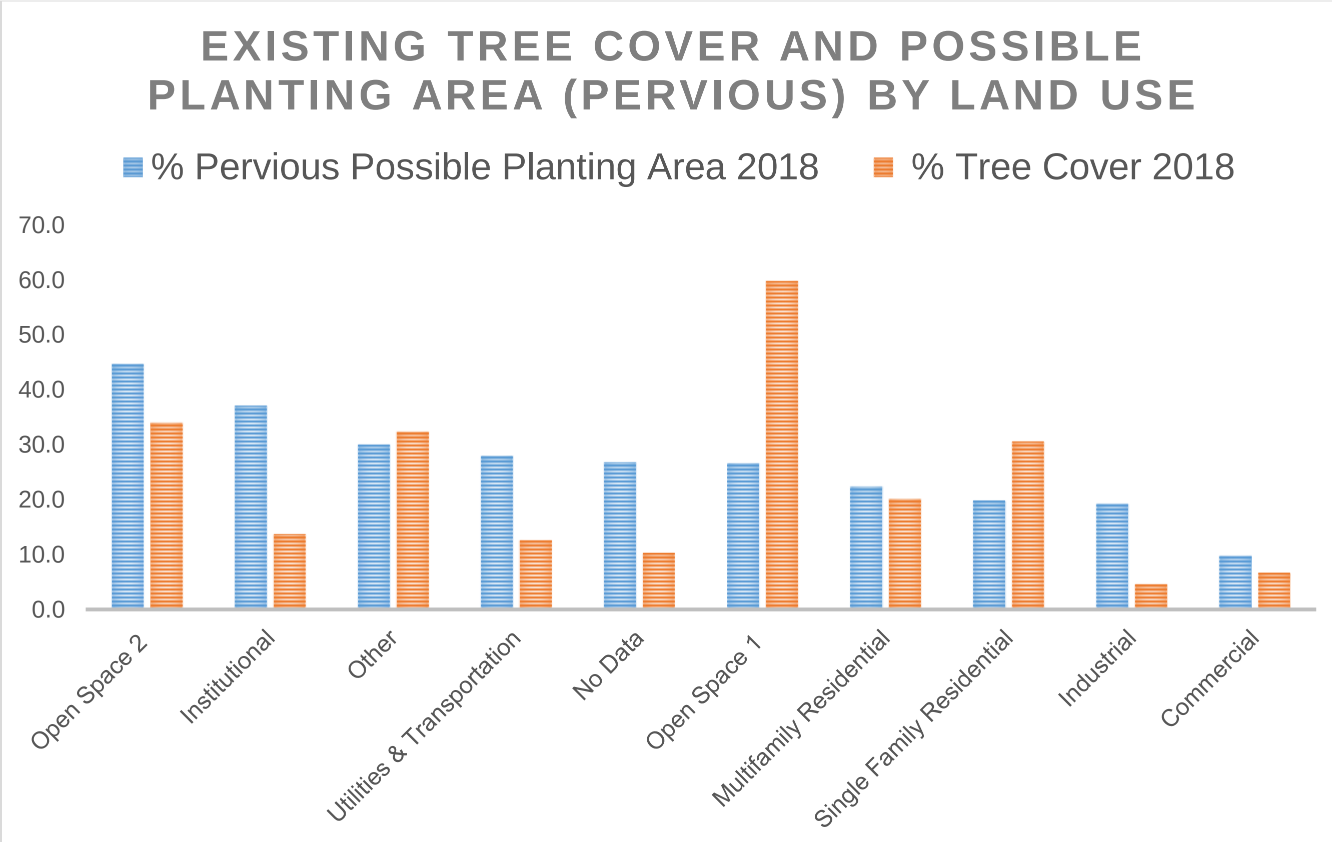


Figure 30. Pervious possible planting area (sports fields/hydro corridors excluded) and existing tree cover by land use. (Source: 2018 land cover and land use (zoning) data, City of Toronto)

Possible Planting Area can be mapped across the city to identify those areas with the highest and lowest PPA (Figure 31). Like tree cover distribution, available PPA is not evenly distributed across the city. The northeast and northwest corners of the city appear to have the greatest amount of pervious PPA.

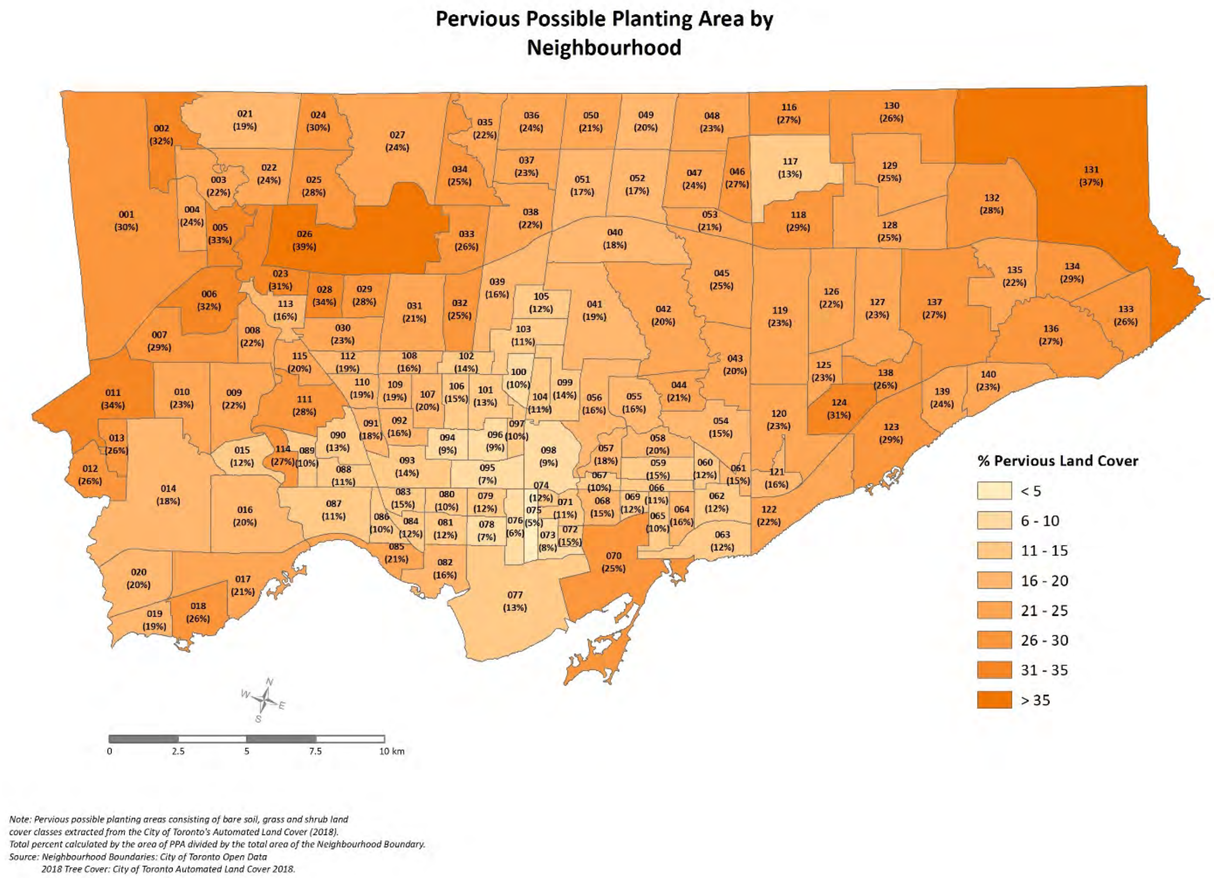


Figure 31. Pervious possible planting area by neighbourhood. (Source: 2018 land cover data with neighbourhoods, City of Toronto).

Looking more closely at pervious PPA in the top and bottom five neighbourhoods illustrates some of the limitations of this high-level mapping to inform the City's planting strategy at an operational level. Because the PPA estimates consist strictly of pervious land cover types, they capture areas in the City where competing land uses would limit planting in any practical sense.

For example, a high amount of pervious PPA in the Rouge may be attributed to agricultural lands that are likely not available for tree planting. Other identified high PPA neighbourhoods include locations with large open areas such as Woodbine Racetrack and Downsview Park. This supports the need for further investigations to narrow down the areas of best tree planting opportunity for operational planning. A more detailed prioritization exercise using the 2018 land cover data in concert with other City datasets will assist in this process.

Table 14. Top five neighbourhoods - pervious possible planting area (ha). (Source: 2018 land cover data, City of Toronto).

Neighbourhood	Pervious PPA (ha)
*Rouge (131)	1,406.3
*West Humber-Clairville (1)	893.9
*Downsview-Roding-CFB (26)	584.9
Woburn (137)	328.1
York University Heights (27)	317.1

The high amount of PPA in these neighbourhoods may be attributed to agricultural lands that are likely not available for tree planting and/or includes locations with large open areas such as Woodbine Racetrack and Downsview Park.

Table 15. Bottom five neighbourhoods - pervious possible planting area (ha). (Source: 2018 land cover data, City of Toronto).

Neighbourhood	Pervious PPA (ha)
Bay Street Corridor (76)	10.3
Regent Park (72)	9.6
Playter Estates-Danforth (67)	8.9
Church-Yonge Corridor (75)	6.2
North St. James Town (74)	4.9

There is a significant difference between the hundreds of hectares of planting space in some neighbourhoods versus neighbourhoods with less than 10 hectares available. This disparity can be attributed in part to the different size of some neighbourhoods but also by the intensity of land use. Neighbourhoods with lowest pervious PPA could be prioritized for further exploration of ways to expand canopy even in areas with high levels of impervious possible planting area. This includes land uses such as commercial and industrial areas, or high-density residential areas.

Key finding: Available pervious planting area is unevenly distributed across the city's 140 neighbourhoods. This is a result in part to the intensity of land uses in some neighbourhoods and reveals the inequitable benefits derived from the urban forest by some neighbourhoods.

8.1.2 | Impervious Possible Planting Area

Impervious PPA consists of impervious areas other than buildings or roads. Examples of impervious PPA are parking lots, schoolyards, parking pads or other paved surfaces that could in theory accommodate trees, if structural adjustments are made to incorporate growing space into these areas.

Levels of existing tree cover relative to impervious possible planting areas (PPA) are shown in Figure 32. The greatest area of impervious PPA, by available hectares, is found in Single Family Residential (4,946 hectares), Industrial (3,765 ha) and Multifamily Residential lands (1,435 ha). This would suggest that these areas have the most opportunity by area to incorporate tree cover into paved areas.

The lowest levels of canopy cover and greatest impervious PPA are found in the Industrial, Utilities and Transportation and Institutional lands. The fact that tree cover is low combined with high impervious surface areas would make these land uses potential candidates for implementing techniques for planting trees in hard surfaces. In 2013, the City developed a manual of best practices for “Tree Planting Solutions in Hard Boulevard Surfaces”. This outlines the various options and costs associated with different techniques for planting trees in hard surfaces.

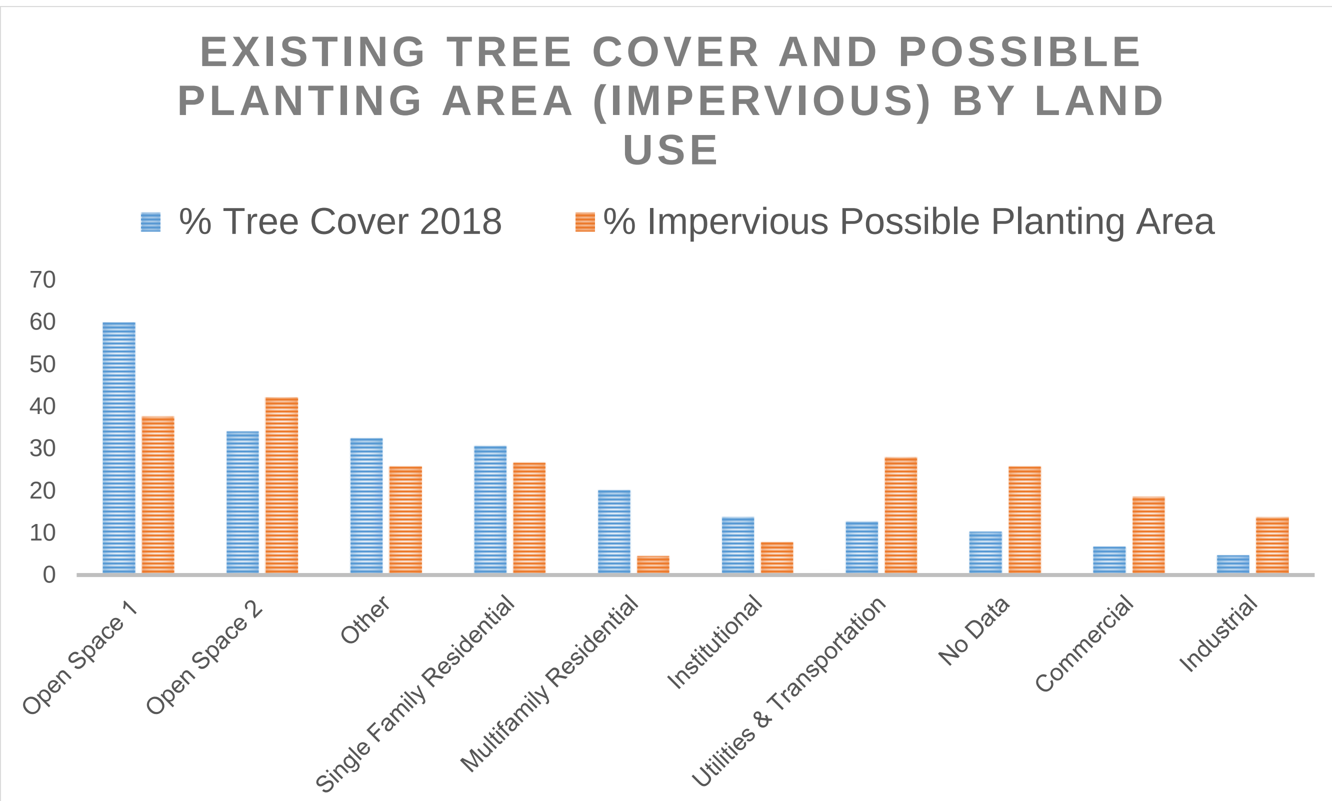


Figure 32. Impervious possible planting area and existing tree cover by land use. (2018 land cover and land use (zoning) data, City of Toronto).

Some neighbourhoods have high levels of impervious area and low levels of pervious PPA. These areas will likely be the most challenging and highest cost for increasing canopy cover in future tree planting efforts. However, if the City maintains a goal of achieving a more even distribution of canopy cover, further examination of opportunities and cost related to increasing tree cover in these areas will be needed.

Key findings: The greatest amount of impervious PPA, by available hectares, is found in Single Family Residential (4,946 hectares), Industrial (3,765 ha) and Multifamily Residential lands (1,435 ha).

9 | Conclusions

Over the course of ten years, the tree population of Toronto's urban forest has expanded. The city's canopy covers more area despite facing significant environmental stress factors. Challenges such as the emerald ash borer infestation, the 2013 ice storm, and intensive development – and crucially, the responses to these challenges by public and private landowners – have fundamentally altered the urban forest from the conditions reported in *Every Tree Counts*, the City's first comprehensive urban forest study.

Since 2008, Toronto's urban forest has become more species-rich overall. Canopy cover increased from 26.6% to 28.4%. Toronto's street trees are healthier and more abundant and deliver proportionately more environmental services than the small share of the total tree population they represent. These advancements are a testament to continuous improvement in the City's proactive maintenance programs and consistent investment in urban forest expansion. Furthermore, street trees contribute additional social-economic co-benefits contributing to the livability of the city.

While some characteristics of Toronto's urban forest have improved not all trends are positive which suggests the need for continued monitoring in ravine areas and increased investment in management activities. Total leaf area of the urban forest has declined since 2008 and the average tree size has become slightly smaller. Overall tree condition appears to have declined slightly as well. As a result of these shifts, Toronto's urban forest has slightly less structural value than it did in 2008 and the rates of some annual ecosystem services, such as pollution removal and carbon sequestration, appear to have declined since 2008. However, annual energy savings have increased since 2008, saving homeowners more money on heating and cooling costs and reducing associated carbon emissions.

Canopy cover in the city's ravines remained relatively stable over the ten-year study period. However, the type of vegetation growing in those ravines is not necessarily a sign of a healthy urban forest. Invasive plant species constitute a serious threat to the future quality of Toronto's urban forest, particularly in ravines and other natural areas. The 2018 field survey suggests that nearly a third of the understory shrub layer is composed of invasive species. Invasive tree species also now make up a larger share of the tree canopy in ravines than they did in 2008.[54]

While canopy cover has increased slightly since 2008 (1.4 percentage points), it has not increased uniformly across the city. Neighbourhoods in the north and west of the city have experienced declines in tree cover, while neighbourhoods in the south and east areas have seen increases. Toronto neighbourhoods vary widely in canopy, ranging from 4.3% to 65.3%[55] suggesting that Toronto residents experience an unequal distribution of urban forest benefits from one neighbourhood to the next. This unequal distribution of canopy holds true at the land use level as well. Some land uses, such as Open Space 1, which contains parks and natural areas, experienced an increase in canopy. Others, such as residential and institutional lands, experienced declines in canopy. Overall, the total area of impervious ground cover has increased across the city, which ultimately translates to a reduction in available growing space for trees.

Many public and private agencies have a role in managing Toronto’s urban forest. Future decisions to grow, protect, and enhance Toronto’s urban forest will require partnerships, robust policies and a commitment to protect the growing space for urban forest expansion. Planning for the future of the urban forest will require balancing the needs of a growing human population and the requirements needed to maintain and expand the urban forest so that it continues to provide benefits to Toronto’s residents.

Efforts to expand Toronto’s urban forest constitute a worthwhile investment in the city’s future. As demonstrated by trends in this ten-year comparative analysis, consistent and strategic investments in urban forest programs, particularly street trees, are delivering valuable benefits to the livability of the city. Other less positive findings suggest that significant investments are needed to prevent further decline of the City’s natural areas and ravines.

[54] There has been an increase of 4 percentage points in invasive tree leaf area between 2008 and 2018 in the Open Space 1 (Parks) land use.

[55] Random point sampling of leaf-on aerial imagery, 2018.

Glossary

Canopy – The amount of area covered by trees and shrubs when viewed from above; calculated using point sampling data.

Diameter at breast height (DBH) – The diameter of a tree's stem measured at a height of 1.37 metres from the ground.

Exotic – Refers to a species introduced to an area outside of its native range. *Syn*: non-native.

Invasive – Refers to a non-native species that aggressively out-competes native species and comes to dominate ecosystems that would naturally be populated by native species.

Land Cover – A broad representation of the physical landscape, identifying physical features rather than land usage types.

Leaf Area – The total two dimensional measure of area represented by the surface area of living leaf tissue. Leaf area may be calculated for individual trees or for large populations of trees.

LiDAR – Light Detection and Ranging is a technology for collecting geographic information, allowing for accurate horizontal and vertical measurements.

Native – A species living in a geographical area where it has been historically present and naturally self-sustaining. A native species is distinguished from a non-native species that has been introduced to a new area and become naturalized.

NDVI – Normalized Difference Vegetation Index is a method of analyzing the presence of chlorophyll in objects in a satellite or aerial photograph.

Non-native – Refers to a species introduced to an area outside of its native range. *Syn*: exotic.

Shrub – In i-Tree Eco, a shrub is any woody plant that measures less than 2.5 cm DBH. Immature specimens of tree species may be included, provided they fall below the 2.5 cm DBH threshold.
In the land cover assessment methodology, assisted with LiDAR, a shrub is defined where Maximum LiDAR height $<=1.5$; LiDAR Mean height < 0.75 and NDVI mean > 0.5.

Street tree – A tree that is located on municipal property in the right-of-way and that is managed by municipal personnel.

Structural Value – Structural value is based on the trunk formula method developed by the Council of Tree and Landscape Appraisers (CTLA), an industry best practice for calculating tree value. It is based on the physical asset of the tree and is determined in part by the tree's size, as well as its condition, species, and location. As such, it provides an estimate of the cost that would theoretically be required to replace the tree. Structural value does not encompass the value of any ecosystem service or other benefits provided by trees.

Tree Cover – The amount of area covered by tree canopy when viewed from above; calculated using land cover data with LiDAR data.

Tree – In the i-Tree Eco protocol, a tree is any woody plant that measures at least 2.5 cm DBH.
In the land cover assessment methodology, assisted with LiDAR, a tree is defined where Maximum LiDAR height >=1.5; LiDAR Mean height >= 0.75 and NDVI mean > 0.5.

Appendix A: Street Tree Benefits Analysis

Background & Rationale

Street trees represent an important component of a city's urban forest. Street trees enhance the aesthetics of neighbourhoods, provide valuable ecosystem services, and make up a significant portion of cities' urban forests. In some densely built neighbourhoods, street trees can represent most of the tree cover, and thus make valuable contributions to neighbourhood character and livability. Street trees also play an important role in increasing environmental equity in low income and underserviced communities. Street trees have been linked to a range of physical and mental health benefits (Lovasi et al. 2008, Taylor et al. 2015, Salmond et al. 2016). Street trees also help to reduce runoff from asphalt during rain storms, thereby helping to reduce the burden of storm events on municipal infrastructure (Armson et al. 2013).

However, their location adjacent to roadways also predisposes street trees to a variety of stress factors that trees in woodlands and yards are unlikely to face. Street trees are often subject to road salt during the winter that can alter soil chemistry. Trees and shrubs can be injured by salt spray and drift which can alter soil chemistry and/or the opening of buds and twigs in the spring. Street trees may be planted in confined growing spaces with inadequate soil volume and poor soil quality. When planted along heavily trafficked streets, this soil can become compacted by repeated pedestrian trampling, which contributes to anaerobic soil conditions. Street trees can also be injured by snow removal or construction equipment, vehicles, vandals and other physical impacts such as the installation of street tree lights and the chaining of bicycles to trees. Street trees growing in areas with abundant impervious ground cover and reflective building surfaces can suffer heat stress during the summer months. Injuries and increased stress can predispose trees to insect and disease infestation, further endangering their longevity and sacrificing the benefits that are provided by mature trees.

An analysis of the benefits provided by Toronto's street trees complements the assessment of the city's entire urban forest by highlighting the value provided by the street tree population. The value of a street tree resource is in many ways contingent on the health of the trees and the extent of leaf area they collectively represent. As the City is responsible for planting, maintaining, and removing street trees, an overview of the benefits provided by street trees is pertinent data that can provide insights into the outcomes of the City's investments in the resource and help to inform management decisions.

Methodology

BioForest acquired street tree inventory data in Microsoft Excel files for each of Toronto's 25 electoral wards from the City's Parks, Forestry and Recreation Division in October, 2018. While an analysis of the City's intact street tree inventory was originally proposed, database size limitations in the i-Tree software required the use of smaller databases in order to complete the analyses. The data was pulled from the City's dynamic street tree database on June 5, 2018, and as such represents a snapshot of Toronto's street tree population as of that date. The data provided by the City included a total of 620,228 trees. No attempts were made to ground truth the content of the databases, as the data was collected and provided by the City of Toronto, and no field audits of street tree data were scheduled as part of the Toronto Tree Canopy Study.

i-Tree Eco version 6 software was used to process each ward's tree inventory data and produce the benefits analysis. i-Tree Streets was originally proposed for the benefits analysis, but consultations between BioForest and City of Toronto staff led to the use of the more updated i-Tree Eco version 6 for this portion of the project. Each ward's street tree inventory was edited in accordance with the parameters of the i-Tree Eco software. All data fields that fed directly into the i-Tree Eco analysis were retained: address, DBH, species, condition, and GPS coordinates. All other data fields were removed from each ward's inventory.

The address, species, and condition fields were further edited to make the entries compatible with i-Tree Eco. Address fields, which included building number and street name fields, were concatenated into one column. The entries in the botanical species field were converted to i-Tree species codes. Subspecies, varieties, and cultivars were designated by the appropriate species codes and listed as unique entries. Any subspecies, varieties, or cultivars that were not included in the list of species codes were assigned the closest applicable species code. For example, *Betula pendula* 'Gracilis', a cultivar of European birch, was assigned the species code for European birch because a specific i-Tree species code for this cultivar did not exist. Finally, the tree condition field was converted to condition percentage ranges that reflected the designation assigned to each tree in the City's inventories. For example, a condition rating of Poor was assigned a percentage of 52, which is expressed in the i-Tree Eco software as a canopy condition rating of 50-55%.

Each ward's database was further edited to remove records with erroneous DBH entries. All entries with a DBH of 0 were removed, as were all entries with an unreasonably large number, typically in excess of 250-300 cm.

Once edited, a project was created for each of the 25 wards in i-Tree Eco and the databases were uploaded from Excel to Eco. After the process of editing each ward's inventory, a total of 614,227 trees were submitted for analysis. Each project was submitted to the i-Tree server and results were retrieved and compiled using Microsoft Excel.

Results and Discussion

The structural value of Toronto's street trees (population 614,227) is approximately $1.363 billion. Street trees make up about 5.4% of Toronto's total tree population, but their structural value represents about 19.4% of the structural value of Toronto's trees. Structural value is calculated using the CTLA trunk formula method and represents the value of the physical tree, based on a value per inch of cross-sectional trunk area. Structural value does not include value related to annual ecosystem services.

Street trees store approximately 173,355 tonnes of carbon, with an associated value of $19,882,000. This represents 15.8% of the total carbon stored by Toronto's trees.

Street trees provide annual ecosystem services with an approximate value of $1,277,500. These include annual carbon sequestration, pollution removal, and avoided runoff.

Annual carbon sequestration by street trees totals 2,877.9 tonnes, with an associated value of $330,750. This represents about 8% of the annual carbon sequestration performed by Toronto's trees. Annual pollution removal by street trees totals 125.449 tonnes, with an associated value of $175,450. This represents about 12.9% of the total annual pollution removal performed by all of Toronto's trees. Annual avoided runoff by street trees totals 331,745 m^3, with an associated value of $771,300. This represents about 29% of the total annual avoided runoff performed by all of Toronto's trees.

These results indicate that the benefits provided by Toronto's street trees are outsized compared to the portion of the total tree population they represent. This may be attributed in part to the relatively good condition and health of the street tree population, which the City is responsible for managing, as well as their relative size. The results also speak to the importance of investing in municipal green infrastructure, as the City of Toronto's management of its street trees has clearly resulted in substantial environmental benefits. The City's role in improving neighbourhoods and delivering the benefits to the city's residents that flow from street trees is significant.

The health of Toronto's street trees is relatively good, according to the condition ratings recorded in the city's tree inventory (Figure 33). The overall condition of Toronto's street trees also appears to have improved since the previous urban forest study was completed in 2008. When compared against the results of the previous study, the percentage of the tree population ranked excellent or good has increased, while the percentage ranked fair or poor has decreased. About 74.4% of Toronto's street trees are in excellent or good condition, compared to 49% as reported in *Every Tree Counts* (2013). Dead trees made up about 0.5% of the street tree population in 2018. Dead trees were not reported in the previous study.

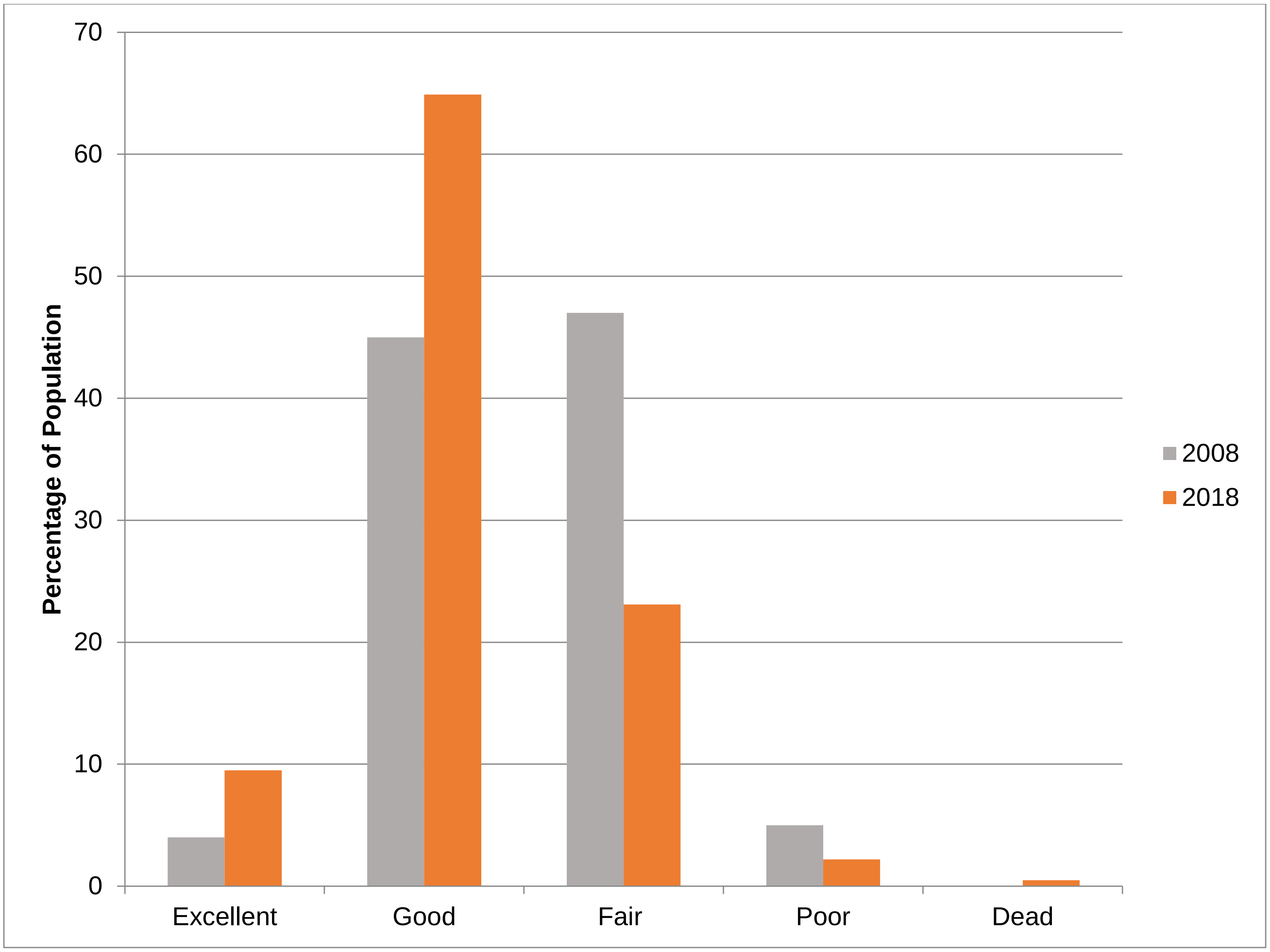


Figure 33. Average street tree condition as percent of population, 2008-2018. (Source: Every Tree Counts and 2018 i-Tree Eco analysis of street tree population)

The results of the street tree analysis in 2008 indicated that 47% of street trees measured 15.2 cm or less in diameter, while only 25% measured more than 30.6 cm in diameter. This was compared to a desired target of 48% of trees measuring more than 30.6 cm in diameter. As of 2018, the average diameter size of street trees has increased so that 43% of street trees now measure 15.2 cm or less in diameter and 33.7% now measure more than 30.6 cm in diameter (Figure 34).

The smallest diameter class is therefore still overrepresented, but to a lesser degree than in 2008. The second smallest diameter class, 15.3-30.5 cm, has reduced from 2008 levels and is approximately in line with the suggested ideal. The next diameter class, 30.6-45.7 cm, has increased in population since 2008 and is now slightly overrepresented. The three largest diameter classes, measuring 45.8 cm and up, are all still underrepresented, though the population of street trees in these diameter classes have all increased since 2008 (Figure 34).

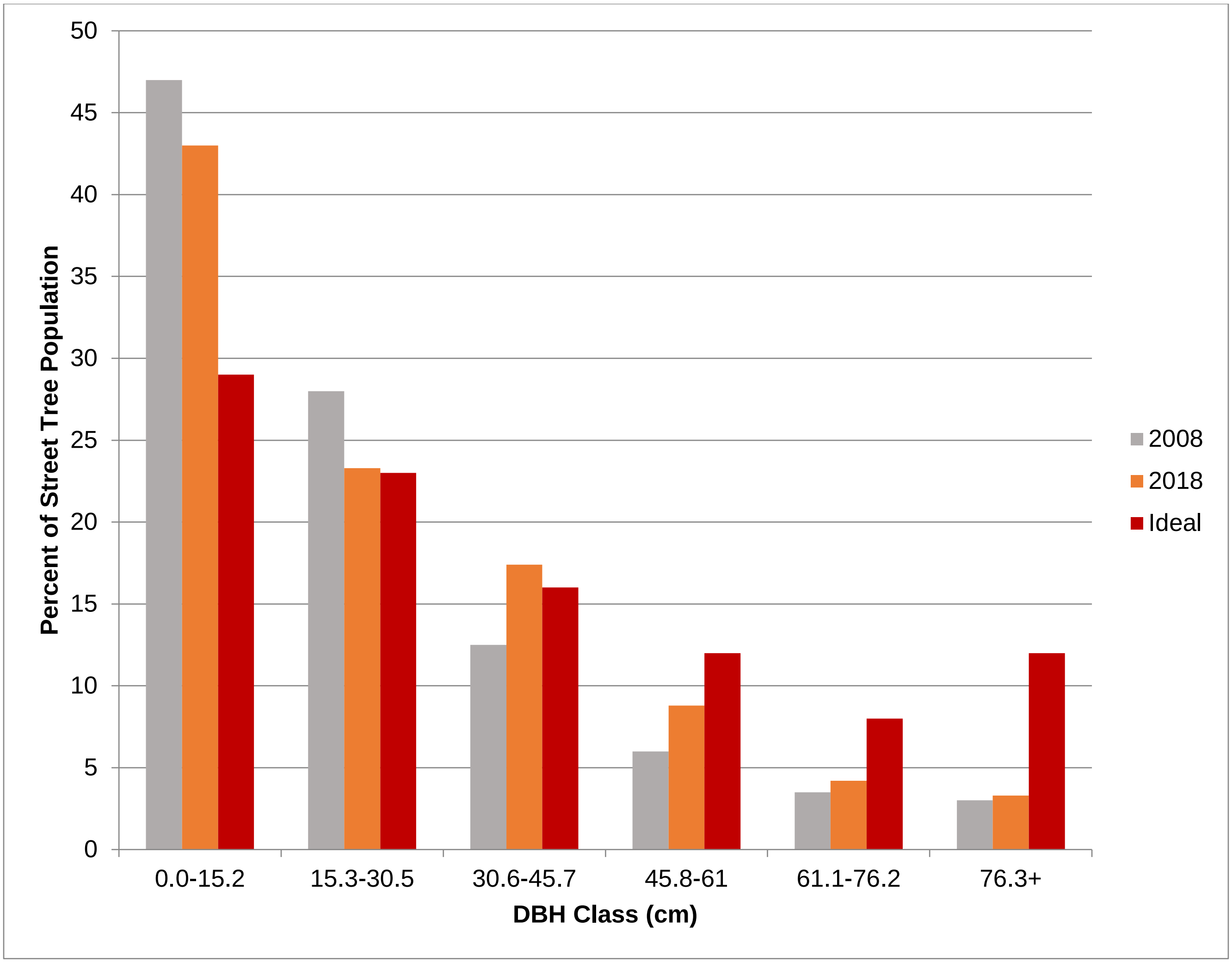


Figure 34: Distribution of Toronto's street tree population by DBH class (cm), 2008-2018, compared to suggested 'ideal' distribution. (Source: Every Tree Counts and 2018 i-Tree Eco analysis of street tree population)

In terms of population, Norway maple (*Acer platanoides*) is the most abundant street tree, comprising about 13.5% of the total street tree population (Figure 35). It is also the most abundant species in all but two of the 25 wards, typically comprising between 9 and 20% of a ward's tree population. In the two wards (wards 10 and 13) where it was not the most abundant, it occupied second place. Norway maple also has by far more leaf area than any other species of street tree, contributing about 28% of the leaf area of all street trees (Figure 35). In 2008, Norway maple was also the most abundant street tree representing 22% of the total street tree population.

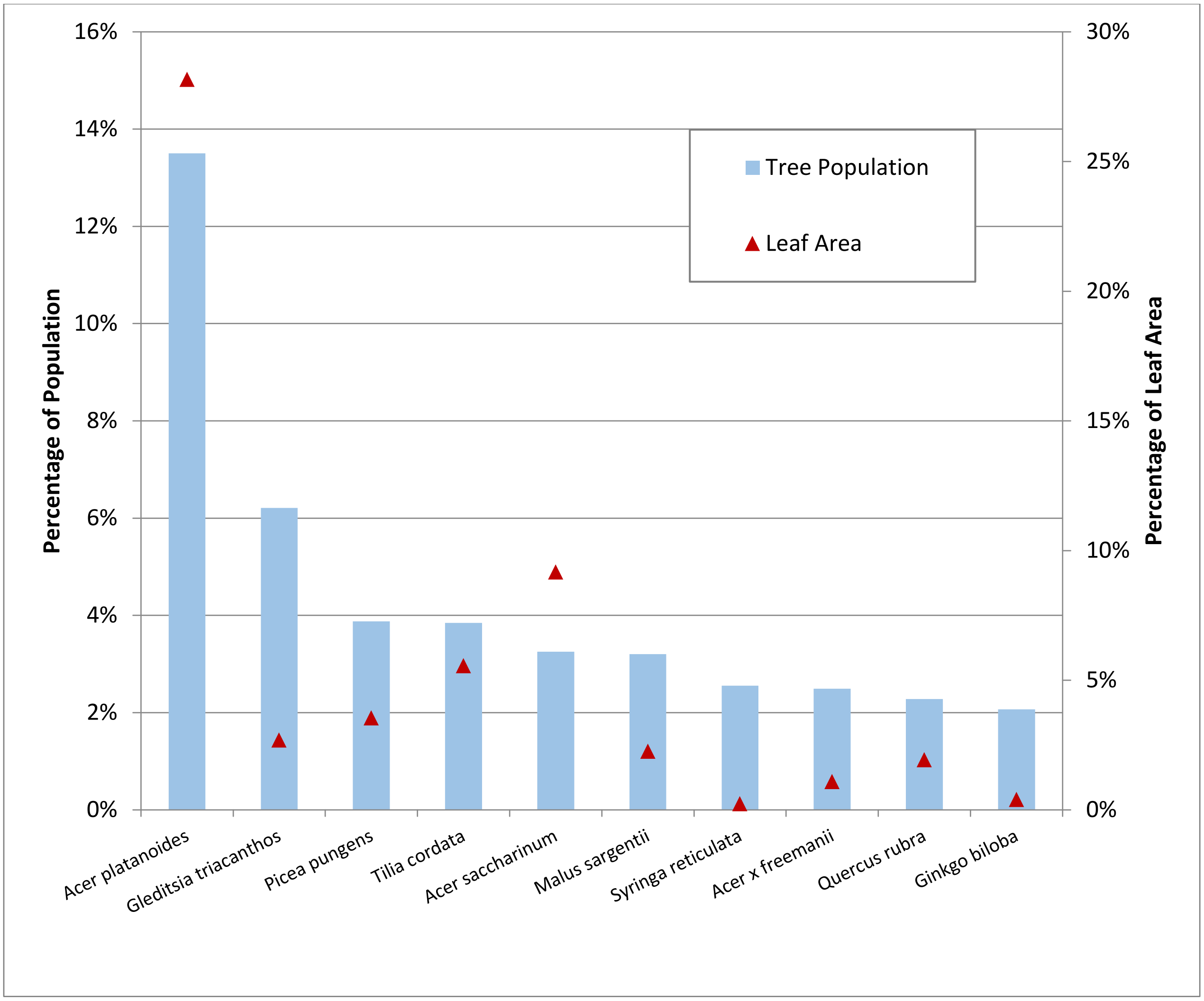


Figure 35: Top ten species of street tree by population, with total leaf area, 2018. (Source: 2018 i-Tree Eco analysis of street tree population)

Norway maple plays a significant role in delivering the benefits provided by street trees. The legacy of this potentially invasive species with respect to ecological health in forest and ravine habitats is problematic, but its contributions to the provision of ecosystem services by the urban forest are undeniable.

However, it should also be noted that Norway maple is one of the preferred host species of Asian long-horned beetle, along with other species of maple, which are abundant in the street tree population. The vulnerability of such a large contingent of the street tree population to a devastating pest is a concern for the long-term resilience of the street tree resource. Planting Norway maple on streets was discontinued years ago due to its overabundance in the population and invasive tendencies, therefore there is an opportunity to gradually reduce the Norway maple population over time. This will likely be a long-term outcome, as mature Norway maples gradually decline and are replaced by a more diverse set of species.

Honey locust (*Gleditsia triacanthos*) is also highly abundant in the street tree population. Honey locust has the second largest population among street trees and was the most abundant species in the two wards in which Norway maple was ranked second in population. Honey locust was also the second most abundant species in 11 of the 25 wards. Unlike Norway maple, honey locust does not currently have a major vulnerability to a serious pest, as Norway maple does with Asian longhorned beetle. However, as seen in Figure 35, honey locust is characterized by relatively low leaf area relative to its population. This may be due to a combination of the species' naturally sparse canopy and a population of relatively young individuals.

As in 2008, silver maple (*Acer saccharinum*) is the fifth most abundant street tree in Toronto, though its share of the population has declined since then and now sits at about 3.25% of the street tree population. The street tree population of silver maple also appears to consist of relatively large-stature trees, as indicated by its total leaf area, which, at 9%, is large relative to its population (Figure 35).

Three species, red/green ash, sugar maple, and white birch (*Betula papyrifera*), were reported in 2008 as being the seventh, eighth, and tenth most abundant street trees, respectively. None of these species are in the top 10 by population in 2018, having been replaced by freeman maple, red oak, and ginkgo, which are now the eighth, ninth, and tenth most abundant street trees (Figure 35). While these three species are capable of growing into large stature trees, their relative contribution to overall leaf area is fairly small, suggesting these populations are currently made up primarily of immature specimens (Figure 35).

Red/green ash is now the fifteenth most abundant street tree and accounts for about 1.37% of Toronto's street tree population. This decline in population is likely due to removals related to decline and mortality caused by emerald ash borer infestation. Nevertheless, the remaining ash population on Toronto's streets makes up about 1.74% of the leaf area, slightly more significant than the population count.

With the exception of Japanese tree lilac (*Syringa reticulata*) and Sargent crabapple (*Malus sargentii*), the top ten species of Toronto's street trees are capable of growing into medium- to large-stature trees. Therefore, they have the potential to deliver more significant benefits, provided the conditions exist to allow them to grow to their full biological potential. As large stature trees, their per-tree leaf area would be much greater than a smaller stature tree such as Japanese tree lilac, and hence each tree would deliver proportionately more benefits.

Both Norway maple and honey locust were noted in the previous urban forest study, *Every Tree Counts*, as being overpopulated according to the "5-10-20" rule that proposes that street tree populations should contain no greater than 5% of the same species, 10% of the same genus, or 20% of the same family. There are various iterations of this rule using different numbers, with each providing a series of ratios by which species diversity should be guided. However, these rules have been criticized for failing to account for the impact a multi-host pest, such as Asian long-horned beetle, might have on a vulnerable tree population. These rules may also be unsuitable for application in certain regions where the range of species available for planting is fairly small. Thus, an approach that is tailored according to local or regional circumstances may be more appropriate than to strictly follow a guideline such as the “5-10-20” rule.

Approximately 40.6% of Toronto’s street trees are native to Europe and/or Asia. About 52.3% are native to North America, though not necessarily native to Ontario (Figure 36).

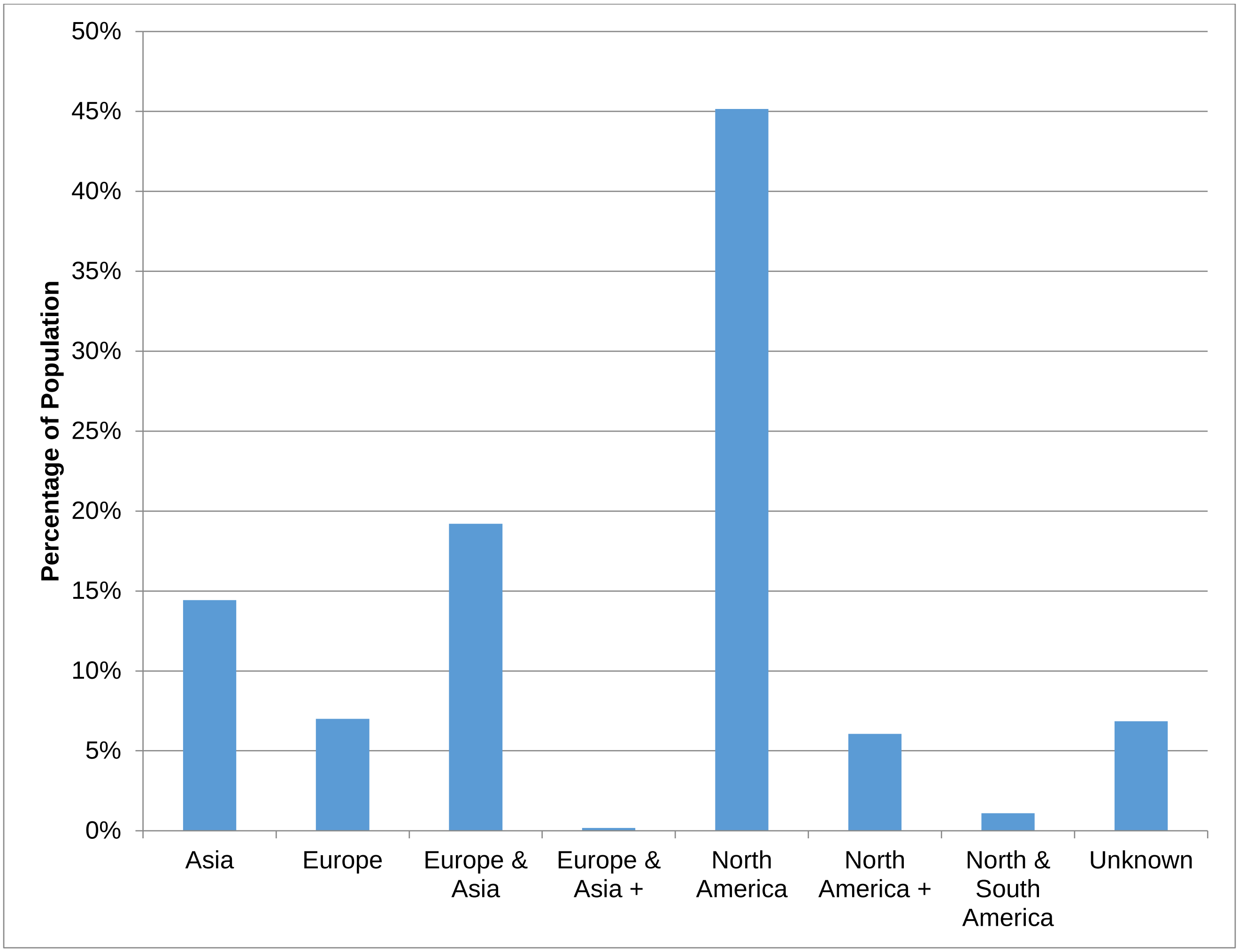


Figure 36: Native place of origin of Toronto's street tree species, 2018. (Source: 2018 i-Tree Eco analysis of street tree population)

Since 2008, the City of Toronto has planted approximately 90,000 street trees. Further investments in Toronto’s street tree resource will be needed to continue the provision of important environmental services it currently provides to Toronto residents. Investments in Toronto’s street trees have helped to improve overall tree condition and allow for the provision of benefits that are disproportionately large compared to the street tree population. In order to maintain the degree of environmental benefits currently provided by street trees, there must be a combination of regular maintenance and sufficient tree planting to sustain a healthy street tree population over the long term.

References

Armson, D., Stringer, P., and A.R. Ennos. 2013. The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. Urban Forestry & Urban Greening 12(3): 282-286.

Lovasi, G.S., Quinn, J.W., Neckerman, K.M., Perzanowski, M.S., and A. Rundle. 2008. Children living in areas with more street trees have lower prevalence of asthma. Journal of Epidemiology & Community Health 62: 647-649.

Salmond, J.A., Tadaki, M., Vardoulakis, S., Arbuthnott, K., Coutts, A., Demuzere, M., Dirks, K.N., Heaviside, C., Lim, S., Macintyre, H., McInnes, R.N. and B.W. Wheeler. 2016. Health and climate related ecosystem services provided by street trees in the urban environment. Environmental Health 15(Suppl 1): S36.

Taylor, M.S., Wheeler, B.W., White, M.P., Economou, T. and N.J. Osborne. 2015. Research note: Urban street tree density and antidepressant prescription rates – A cross-sectional study in London, UK. Landscape and Urban Planning 136-174-179.

Street Tree Benefits and Values by City Ward

Table 16: Street Tree Benefits and Values by City Ward (Source: 2018 i-Tree Eco data of City street tree population)

Ward	Tree Pop. (analyzed)	Total			Annual						
		Structural Value ($M)	C storage (tonnes)	C storage value (CAD)	C sequestration (tonnes)	C sequestration value (CAD)	Pollution Removal (tonnes)	Pollution Removal Value (CAD)	O production (tonnes)	Avoided Runoff (m^3)	Avoided Runoff Value (CAD)
1	31,842	51.4	6,242	$717,000.00	122.8	$14,100.00	5.616	$8,340.00	327.3	15,020	$34,900.00
2	48,503	124	15,230	$1,750,000.00	252.1	$29,000.00	11.47	$17,300.00	672.3	30,900	$71,800.00
3	43,977	124	16,920	$1,940,000.00	234.5	$26,900.00	10.28	$16,700.00	625.4	27,540	$64,000.00
4	26,047	82.9	11,750	$1,350,000.00	154.7	$17,800.00	6.344	$8,590.00	412.6	16,850	$39,200.00
5	25,290	51.1	6,552	$753,000.00	114.5	$13,200.00	4.958	$7,300.00	305.3	13,290	$30,900.00
6	30,050	44.3	5,458	$627,000.00	111.8	$12,800.00	5.125	$6,730.00	298.1	13,620	$31,700.00
7	20,930	24.4	2,881	$331,000.00	64.89	$7,450.00	2.846	$3,830.00	173	7,570	$17,600.00
8	34,815	85.3	10,720	$1,230,000.00	172.2	$19,800.00	7.561	$11,000.00	459.1	20,290	$47,200.00
9	18,687	39.2	5,015	$576,000.00	81.33	$9,340.00	3.464	$4,720.00	216.9	9,223	$21,400.00
10	10,105	14.7	2,001	$230,000.00	35.81	$4,110.00	1.58	$2,230.00	95.5	3,918	$9,110.00
11	23,644	58.4	7,712	$886,000.00	114	$13,100.00	4.881	$6,340.00	304	12,600	$29,300.00
12	25,543	70.4	9,157	$1,050,000.00	136	$15,600.00	5.787	$7,900.00	362.6	15,510	$36,100.00
13	7,197	11.9	1,540	$177,000.00	28.78	$3,310.00	1.256	$1,590.00	76.74	3,048	$7,090.00
14	17,279	49.5	6,574	$755,000.00	91.88	$10,600.00	3.996	$5,380.00	245	10,400	$24,200.00
15	37,943	109	13,570	$1,560,000.00	210.5	$24,200.00	9.529	$12,500.00	561.3	25,480	$59,200.00
16	22,762	44.5	5,594	$643,000.00	104.6	$12,000.00	4.624	$5,540.00	279	12,270	$28,500.00
17	29,907	55.4	6,619	$760,000.00	133.8	$15,400.00	5.991	$8,350.00	356.9	16,060	$37,300.00
18	29,601	74.9	9,457	$1,090,000.00	157.2	$18,100.00	6.821	$10,200.00	419.3	18,180	$42,300.00
19	13,974	41.9	5,659	$650,000.00	79.79	$9,170.00	3.284	$4,470.00	212.8	8,676	$20,200.00
20	17,675	43.4	5,948	$683,000.00	86.25	$9,910.00	3.745	$5,140.00	230	9,961	$23,200.00
21	15,848	34.1	4,023	$432,000.00	70.58	$8,110.00	2.901	$4,100.00	188.2	7,530	$17,500.00
22	19,171	30.9	3,401	$391,000.00	75.41	$8,660.00	3.184	$4,240.00	201.1	8,095	$18,800.00
23	20,797	24.3	2,683	$308,000.00	71.33	$8,190.00	2.976	$3,690.00	190.2	7,114	$16,500.00
24	19,419	37.9	4,469	$513,000.00	82.72	$9,500.00	3.44	$4,440.00	220.6	8,797	$20,500.00
25	23,221	35.2	4,180	$480,000.00	90.4	$10,400.00	3.79	$4,830.00	241.1	9,803	$22,800.00
Total	**614,227**	**1,363**	**173,355**	**$19,882,000.00**	**2,877.9**	**$330,750.00**	**125.449**	**$175,450.00**	**7,674.34**	**331,745**	**$771,300.00**

Appendix B: 2018 i-Tree Eco Complete Study Report

i-Tree Eco Field Survey

Methodology

Plot Selection

In 2008, the City of Toronto established 412 plots, of which 407 were measured, in accordance with i-Tree Eco protocols (then known as the Urban Forest Effects Model, or UFORE model). The same 407 plots were used again in 2018, and an additional 30 plots were created as a reserve of spare plots, in case crews were denied permission to access certain properties. Using the same plots as 2008 allows for a direct comparison of the two years' data sets to establish trends in urban forest conditions. During field surveys, field crews were denied permission to access 13 residential properties and field crews were unable to relocate two plots in the Open Space 1 land use. A total of 15 replacement plots were used in 2018, along with 392 original plots, for a total of 407 plots assessed. For consistency, replacement plots were located in the same land use and in close proximity to the plots they replaced.

Landowner Contact

In order to secure permission from landowners whose properties were included in i-Tree plots, the City of Toronto drafted a letter to property owners explaining the project purpose and requesting permission for field crews to access their property. BioForest staff mailed the letters, along with pre-paid return envelopes, to landowners in spring, 2018. BioForest staff conducted in-person follow-up visits to some properties whose owners did not return a reply to the initial letters. Additional permissions were obtained in this manner, and BioForest field crews continued to conduct landowner outreach during the data collection period, as necessary. Where permission was denied, field crews refrained from entering the property and ceased contact with the landowner.

i-Tree Eco Field Methodology

As in 2008, 407 circular plots measuring 0.04 hectares in area were assessed during the summer of 2018. Field staff revisited 392 of the plots assessed in 2008, along with 15 replacement plots that had not previously been assessed. Field duties were carried out by BioForest staff, under contract to the City of Toronto. There were six field staff members, divided into three crews, supervised by a project manager and a project coordinator. In order to optimize organization and efficiency, the study area was divided into three with a roughly equal distribution of plots and each field crew was assigned one of the zones in which to complete their field work. Field crew training took place from May 28-31 at various plots across the city. Field crews collected data independently from June 1 to September 14, 2018. Field crews recorded data on paper or electronically, using digital tablets. Field crews referred to the original data sheets and field crew notes from 2008, in order to relocate plot centre and identify the trees originally measured in 2008.

Field crews collected the following data at each plot:

Plot Information

- Plot ID number
- Date of data collection
- Crew
- GPS coordinates of plot centre
- Plot address/notes
- Reference object descriptions, and distance and compass directions to plot centre
- Tree measuring point, if used, where plot centre was inaccessible
- Percent tree cover (visual estimate)
- Percent shrub cover (visual estimate)
- Percent plantable space (visual estimate)
- Land use, as observed in the field
- Percent of plot within each land use (visual estimate, based on field map)
- Percent ground cover (visual estimate of each cover type)

Shrub Data

- Species ID
- Shrub mass height
- Shrub mass percent of total shrub area (visual estimate)
- Shrub mass percent missing (visual estimate of the percentage of shrub's volume not occupied by leaves)

Tree Data

- Tree ID number
    - Trees that were recorded in 2008 were reassigned their original ID number. New trees that had generated since 2008 were assigned a number in sequence with the original Tree ID numbers. Trees that had been removed since 2008 were recorded under their original ID number and classified as a removed tree.
- Tree status
    - For new trees: planted, ingrowth, or unknown
    - For trees recorded in 2008: no change, removed for an unknown reason, removed for health/hazard, removed but healthy, or removed due to land use change
- Compass direction and distance from plot centre (or tree measuring plot, if using)
- Land use in which tree is rooted
- Species ID
- Diameter at breast height (1.37 m) for up to six stems, if tree is multi-stemmed
- Tree height
- Live crown height
- Height to crown base
- Crown width (two measurements, in east-west and north-south directions)
- Percent tree canopy missing (visual estimate)
- Percent dieback (visual estimate)
- Percent impervious surface area under the canopy of the tree (visual estimate)
- Percent shrub area under the canopy of the tree (visual estimate)

- Crown light exposure (number of sides of the tree's crown that are exposed to direct sunlight)
- Distance and direction to residential buildings, for trees at least 6 m in height, and within 18 m of a residential building
- Tree site (street tree or not)
- Presence of Pests
    - Insect selections were limited to Asian longhorned beetle, beech bark scale (*Cryptococcus fagisuga*), European elm scale (*Gossyparia spuria*), fall/spring cankerworm (*Alsophila pometaria* and *Paleacrita vernata*), gypsy moth, and hemlock woolly adelgid (*Adelges tsugae*)
    - Disease selections were limited to beech bark disease (*Neonectria faginata*), Dutch elm disease (*Ophiostoma ulmi*), and oak wilt (*Bretziella fagacearum*)
    - When a pest was observed on a host tree, all related signs or symptoms were recorded

Invasive and Noxious Plant Detections

Field crews identified and recorded the distribution of invasive plants in plots located in woodlots and other natural areas. Distribution was quantified using a numbered ranking system in which 1 indicated a single patch of the invasive plant, 2 indicated scattered pockets, 3 indicated a blanket effect, and 4 indicated an extensive blanket effect within the plot and the surrounding area. Field crews used the Esri Collector app on their tablets to record observations of invasive plants.

The following plants were included in this portion of the survey:

- Canada thistle (*Cirsium arvense*)
- Coltsfoot (*Tussilago farfara*)
- Common buckthorn (*Rhamnus cathartica*)
- Common burdock (*Arctium minus*)
- Cow parsnip (*Heracleum maximum*)*
- Creeping bellflower (*Campanula rapunculoides*)
- Dog-strangling vine (*Vincetoxicum rossicum*)
- English ivy (*Hedera helix*)
- Garlic mustard (*Alliaria petiolata*)
- Giant hogweed (*Heracleum mantegazzianum*)
- Goutweed (*Aegopodium podagraria*)
- Greater celandine (*Chelidonium majus*)
- Himalayan balsam (*Impatiens glandulifera*)
- Japanese hedge parsley (*Torilis japonica*)
- Japanese knotweed (*Fallopia japonica*)
- Lily of the Valley (*Convallaria majalis*)
- Oriental bittersweet (*Celastrus orbiculatus*)
- Periwinkle (*Vinca minor*)
- Phragmites (*Phragmites australis* ssp. *australis*)
- Poison hemlock (*Conium maculatum*)
- Poison ivy (*Toxicodendron radicans*)*
- Purple loosestrife (*Lythrum salicaria*)

- Tall sweet white clover (*Melilotus albus*)
- Wild parsnip (*Pastinaca sativa*)
- Winter creeper (*Euonymus* × *fortunei*)

*Native species that is considered noxious.

Field crews also captured photographs of giant hogweed, Himalayan balsam, and Japanese knotweed, due to highly invasive nature of these plants and the need to document infestations for management intervention.

Tracking Progress

Throughout the data collection period, field crews tracked their progress using the Workforce app in their tablets. Once data collection at a plot had been completed, field crews marked the plot as complete in the app. The project coordinator was then able to log into an online dashboard set up for the project and view each crew's completed plots on a map. Thus, the project coordinator was able to ensure that work remained on schedule and could reassign crews to priority areas in the final days of data collection.

Materials

- Clipboard
- Pencils
- Paper data sheets
- Rangefinder
- Clinometer
- 30 m measuring tape
- DBH tape
- Compass
- GPS unit
- Samsung Galaxy Note or Galaxy Tab A tablet, programmed with Workforce and Esri Collector apps
- Flagging tape
- Chalk

Quality Control Audits

The i-Tree Eco protocol outlines methods for ensuring quality and accuracy of the data collected by field crews during the survey. Hot checks are procedures in which an auditor works along with the field crew as they collect data at an i-Tree plot to ensure that the crews have a good understanding of the protocol. Errors are corrected in person, and these checks are typically included in the initial field crew training sessions. Cold checks are procedures in which an auditor makes follow-up visits to plots where the field crew has already collected data. The auditor verifies the crew's data to ensure that it is accurate and complete. Plots selected for cold checks are chosen at random, and ideally include a variety of settings. The i-Tree protocol advises a distribution of about 30% hot checks and 70% cold checks, encompassing about 5% of plots.

City of Toronto staff and BioForest staff completed hot checks in the first week of training and in the week following training when field crews were working independently. City of Toronto Forestry staff completed hot checks at 15 plots and BioForest completed hot checks at 13 plots. BioForest completed cold checks at 15 plots, with 5 plots audited per field crew.

Thus, a total of 43 plots were audited, which represent 10.6% of plots, slightly more than double the amount recommended by the i-Tree Eco protocol.

Cold check procedures varied slightly based on the number of trees present in a plot. For plots with 5 trees or less, each tree was audited. The species ID, DBH, height, crown width, and building interaction (if applicable) were confirmed by the auditor. The land use, as reported by field crews, plot tree cover, and number of trees in the plot were verified. For plots with more than 5 trees, the auditor randomly selected 5 trees and confirmed species ID, DBH, height, crown width, and building interaction (if applicable). The auditor also confirmed the land use, plot tree cover, and total tree count, and verified species ID for all trees in the plot. During the audits, auditors encountered minor errors, such as incorrect species identification, small discrepancies in DBH or crown measurements, or occasionally a measurement that was not recorded properly. In two cases, crews were asked to revisit a plot in order to correct deficiencies in the data. These errors were observed only in plots that were surveyed during the first days of data collection. Plots that were surveyed later were free of errors, as the crews had by then attained greater proficiency with the i-Tree protocol.

Data Submission and Analysis

Throughout the data collection period, field crews used their Samsung tablets to submit their data to the i-Tree server, allowing the project coordinator to download and view the data using i-Tree Eco v. 6 on a desktop computer. Data was either inputted directly through the i-Tree web form in the field, or was entered at a later date, when field crews used paper data sheets to record field data. Following the completion of data collection, the project coordinator reviewed the collected data for errors.

Since the 2018 i-Tree Eco survey was intended as a re-survey of the plots first measured in 2008, it was important to record the trees that had been removed since the original survey. This allows for an analysis of the changes in Toronto's urban forest, including determining the tree mortality rate. However, the most recent version of i-Tree Eco, version 6, does not have the capability built into the software to process these changes, despite the existence of tree status codes for removed trees. Therefore, the database of the 2018 i-Tree plots had to be further edited so that all trees that had been removed since 2008 were removed from the final database submitted for analysis. This was accomplished by sorting all tree records by their status and deleting the records of all trees that had been removed since 2008. Only trees that were retained since 2008 and newly grown trees were included in the final database. A copy of the full database, including removed trees, was kept on file for reference and for analysis of the removed trees.

Once the final edited version of the 2018 database was prepared, it was submitted for analysis using i-Tree Eco v. 6. The results of the analysis were returned by the i-Tree server on the same day. Results were downloaded from i-Tree Eco and organized into Microsoft Excel databases for further analysis and reporting purposes.

Results are presented as an extrapolation of the field data gathered from the 407 i-Tree plots used in the study. These plots constitute a statistically representative sample of Toronto's urban forest. A study using 200 urban plots in a stratified random sample is expected to yield a standard error of about 10% (USDA 2018). Therefore, the 407 plots used in Toronto's i-Tree survey produce results that fall well within the bounds of acceptable standard error. Only a complete inventory would eliminate the possibility of error, but the time requirements, ability to access private properties, and financial cost would make such an undertaking unfeasible.

Change Analysis

An analysis of the changes in Toronto's urban forest was accomplished by comparing the reported results of the 2008 study in *Every Tree Counts* and raw UFORE results data produced in 2008 with the results of the 2018 i-Tree Eco study. Due to changes and updates to the i-Tree Eco protocol since 2008, not all results reported in 2008 are directly comparable to the outputs provided by i-Tree Eco v. 6, and vice-versa. Furthermore, in 2008 USDA staff were more directly involved in the data analysis process, enabling some level of dialogue and consultation between USDA staff and clients. By 2018, the process of analyzing i-Tree Eco data had become automated, requiring virtually no direct input from USDA staff, aside from those working as resource staff for i-Tree user support. These support staff were contacted periodically to provide advice related to some of the features and capabilities of i-Tree Eco v6. Additional custom analyses performed by USDA staff would have required greater financial resources than the project scope allowed.

i-Tree Eco Results

Overview

A high level comparison of the results of the 2008 and 2018 urban forest studies indicate that Toronto's urban forest has undergone some important changes over 10 years, while some aspects of the urban forest have remained relatively constant. Toronto's total tree population has increased by about 12.5%, reaching 11.47 million in 2018, but its structural value has not kept pace with this growth. In 2008, the structural value of Toronto's urban forest was estimated at $7.1 billion.[56] However, the structural value of Toronto's urban forest in 2018 is approximately $7.04 billion, suggesting some of its value has been lost in 10 years.

Toronto's tree population is mostly held in private hands. About 54.4% of Toronto's trees are located on private property, while 45.5% of Toronto's trees are on public property, including parks and city streets. The remaining 0.1% of trees are located on property where ownership is unclear. In 2008, about 60% of Toronto's trees were located on private property, suggesting that tree population growth on public property has outpaced the growth of the tree population on private property (Figure 37).

[56] Structural value is based on the trunk formula method developed by the Council of Tree and Landscape Appraisers (CTLA), an industry best practice for calculating tree value. It is based on the physical asset of the tree and is determined in part by the tree's size, as well as its condition, species, and location. As such, it provides an estimate of the cost that would theoretically be required to replace the tree. Structural value does not encompass the value of any ecosystem service or other benefits provided by trees.

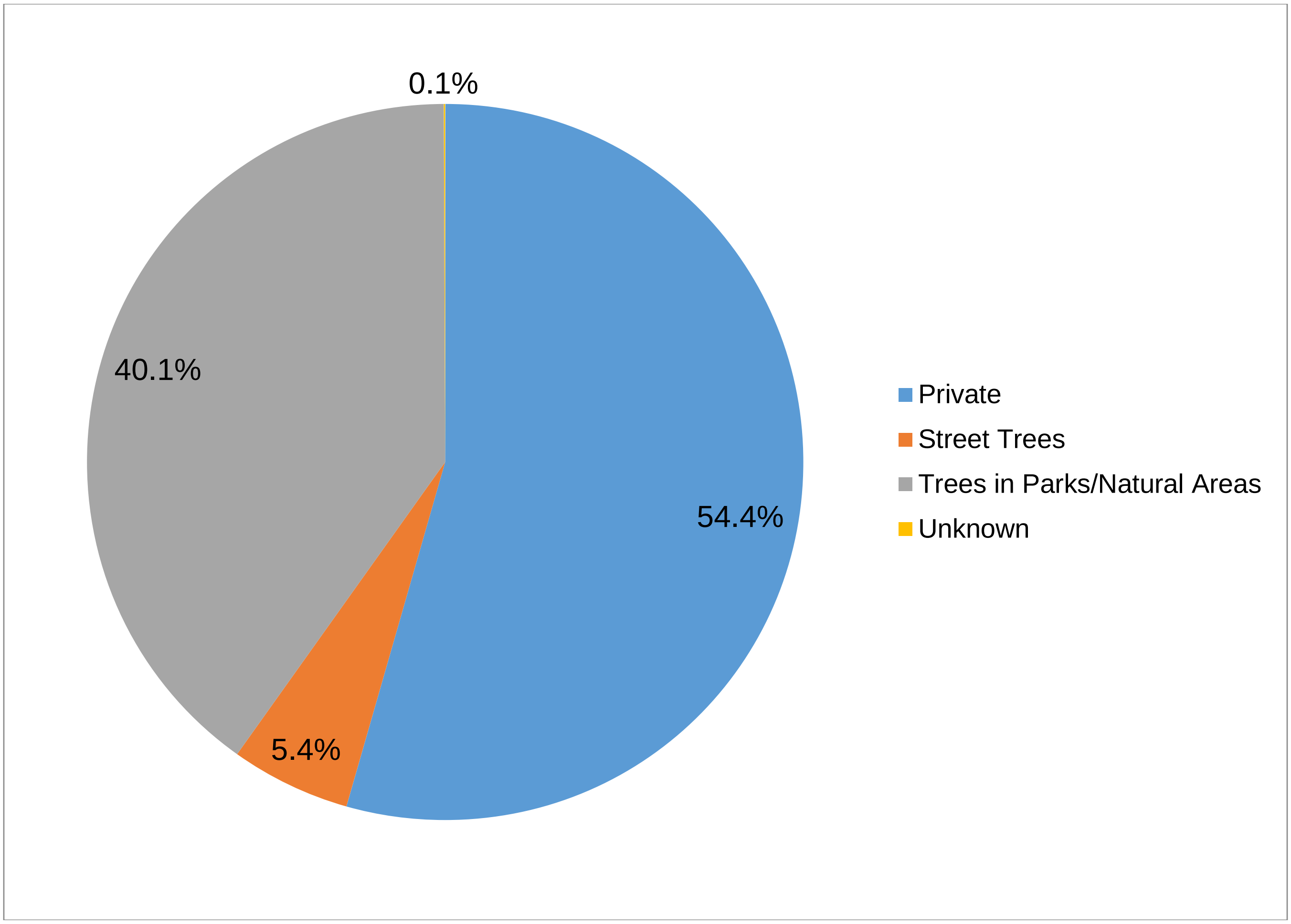


Figure 37: Tree ownership in Toronto, 2018 (Source: 2018 i-Tree Eco data).

The total amount of carbon stored by Toronto's trees has experienced a very slight decline since 2008, dropping from 1,107,645 tonnes to 1,100,393 tonnes. Additionally, annual carbon sequestration rates seem to have declined since 2008, when Toronto's trees sequestered an estimated 46,700 gross tonnes of carbon each year. In 2018, trees are estimated to sequester about 35,170 gross tonnes of carbon each year.

Some insight into these changes may be gained by analyzing the changes to the relative DBH of trees from 2008 to 2018. Since 2008, the smallest size class of trees, 2.5-7.6 cm, has increased from 45% of the population to 49.7%. Meanwhile, the seven next largest size classes, encompassing trees 7.6-61 cm in diameter, have all seen incremental declines. The greatest of these declines was seen in the 22.9-30.5 cm size class, which declined from 8.3% of the total tree population to 5.9%. This indicates that Toronto's urban forest in 2018 is slightly younger relative to the tree population that existed in 2008.

The influence of emerald ash borer and severe storm damage may also be contributing to these declines. Tree mortality and loss of biomass due to these influences could account for declines in DBH size classes that represent more mature trees. For example, when ranked by population, white ash and green ash were the fourth and sixth most abundant tree species in Toronto in 2008. By 2018, they had fallen to sixth and seventh most abundant species, respectively. However, leaf area rankings by species paint an even more stark contrast. In

2008, green and white ash were the fourth and tenth most abundant tree species by leaf area, but by 2018, no ash species was listed in the top 25 species by leaf area. This trend points to a dramatic loss of mature ash due to emerald ash borer and a shift to a relatively younger, smaller-stature ash population.

Meanwhile, there has been a significant increase in the population of common buckthorn, which is now Toronto's fifth most abundant tree and comprises 4.3% of the total tree population. In 2008, common buckthorn was the 14th most abundant tree, comprising 1.6% of the total tree population at the time. This is a concerning development for Toronto's natural areas and ravine properties, as common buckthorn is an opportunistic invader that degrades native ecosystems and contributes relatively little value from an ecological perspective.

Toronto's trees provide annual ecosystem services, including carbon sequestration, pollution removal, avoided runoff, and home energy savings that have an annual value of about $55 million. This averages out to about $4.80 in annual benefits per tree across the city and an average return of about $18.80 in benefits to each person living in Toronto. The most significant factor of the total annual ecosystem services provided by Toronto's urban forest is air pollution removal, which accounts for an annual value of about $37.9 million.

Forest Composition and Structure

Most Common Trees

The most common species in Toronto remain largely the same in 2018 as they were in 2008. In terms of population, the three most abundant tree species by population remain eastern white cedar, sugar maple, and Norway maple. As noted above, the decline in abundance of white and green ash has been accompanied by an increase in common buckthorn, along with other small stature trees, such as staghorn sumac (*Rhus typhina*). It should be noted that the large population of eastern white cedar is not entirely due to natural cedar forests, but to the use of the species as hedges, mainly on residential properties. One promising development is the increase in eastern white pine (*Pinus strobus*), a large stature native tree with ecological importance in Toronto, which increased from the 17th most abundant tree in 2008 to the 8th most abundant in 2018 (Figure 38).

Table 17: Most abundant trees in Toronto by population, 2008 and 2018. (Source: 2008 and 2018 i-Tree Eco data)

Rank by Population	2008	2018
1	Thuja occidentalis	Thuja occidentalis
2	Acer saccharum	Acer saccharum
3	Acer platanoides	Acer platanoides
4	Fraxinus americana	Acer negundo
5	Acer negundo	Rhamnus cathartica
6	Fraxinus pennsylvanica	Fraxinus americana
7	Picea glauca	Fraxinus pennsylvanica
8	Ostrya virginiana	Pinus strobus
9	Ulmus pumila	Rhus typhina
10	Malus sylvatica	Ostrya virginiana

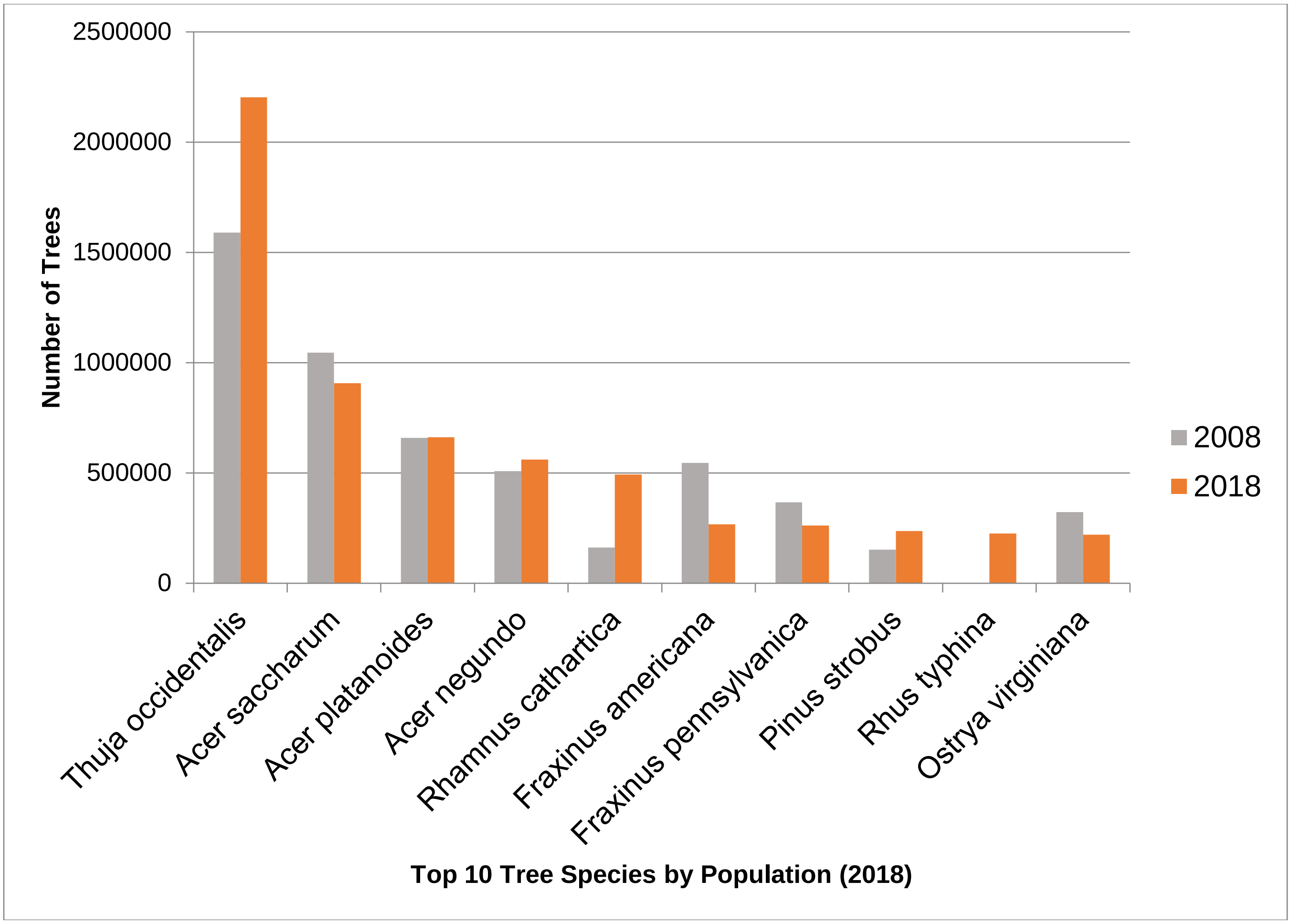


Figure 38: Top 10 tree species by population in 2018, with 2008 population levels. (Source: 2018 i-Tree Eco data)

While tree populations provide insight into the relative abundance of tree species in the city's tree population, measuring the species' abundance by leaf area gives greater insight into which species are making greater contributions to the ecosystem services the urban forest provides. Leaf area is the primary part of a tree's physiology that filters pollution, casts shade, releases oxygen, and provides other valuable benefits. Tree species with a greater potential size at maturity are likely to provide the greatest benefits in the long term, provided conditions exist to support growth to their full biological potential.

When ranked by leaf area, Norway maple remains the most abundant tree in Toronto, while silver maple has taken the position of second most abundant from sugar maple, which is now the third most abundant tree by leaf area. As noted above, the steep decline in leaf area of the two most common ash species, white and green ash, signals a significant loss of leaf area due to the effects of emerald ash borer. American elm (*Ulmus americana*) has also declined in leaf area, likely as a result of the effects of Dutch elm disease. In 2008, American elm was the seventh most abundant species by leaf area, comprising 3.7% of the total leaf area. As of 2018, it is now the 17th most abundant species by leaf area, comprising just 1.5% of the total leaf area.

Table 18: Top 10 tree species in Toronto by leaf area, 2008 and 2018. (Source: 2008 and 2018 i-Tree Eco data)

Rank by Leaf Area	2008	2018
1	Acer platanoides	Acer platanoides
2	Acer saccharum	Acer saccharinum
3	Acer negundo	Acer saccharum
4	Fraxinus pennsylvanica	Acer negundo
5	Picea glauca	Thuja occidentalis
6	Acer saccharinum	Juglans nigra
7	Ulmus americana	Picea abies
8	Thuja occidentalis	Picea pungens
9	Pinus nigra	Betula papyrifera
10	Fraxinus americana	Picea glauca

Tree Size Distribution

When comparing the distribution of DBH (diameter at breast height) classes in 2008 and 2018, it is evident that Toronto's urban forest seems to have shifted to a relatively smaller average DBH. As of 2018, approximately 72.9% of Toronto's trees measure 15.2 cm DBH and under, compared to 68.6% in 2008. Slightly less than half (49.7%) of Toronto's trees currently belong to the smallest diameter class (7.6 cm and under), while 7.5% of trees measure more than 38 cm DBH, and 2.3% of trees measure more than 61 cm DBH. In 2008, about 45% of trees belonged to the 7.6 cm and under DBH class, while 8.7% of trees measured more than 38 cm DBH, and 1.9% of trees measured more than 61 cm DBH (Figure 39). It is interesting to note that there was a slight shift upward in the population of very mature trees that measure greater than 106.7 cm DBH, from 0.1% of the population to 0.4%.

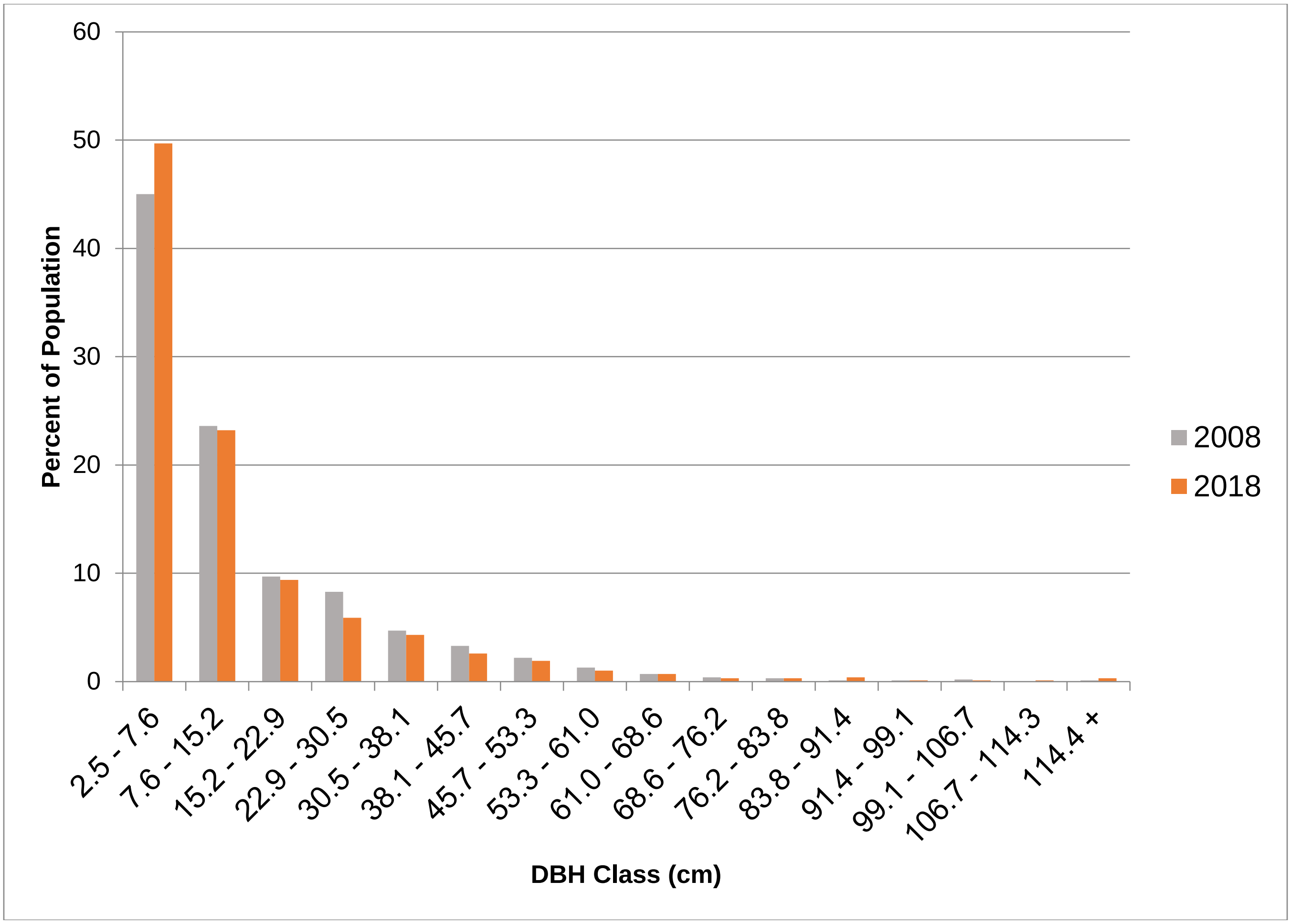


Figure 39: Distribution of Toronto's tree population by DBH class, 2008 and 2018. (Source: 2008 and 2018 i-Tree Eco data)

The precise reasons for this shift are unclear, but there are many possible contributing factors. It could be that an increase in tree planting has led to a larger cohort of young, small trees that will eventually mature into larger trees. However, the losses in the more mature DBH classes are unmistakable. Despite the existence of a municipal private tree protection by-law, mature trees are less abundant in 2018 than they were in 2008. There are likely many factors contributing to this trend, including the loss of mature ash to emerald ash borer.

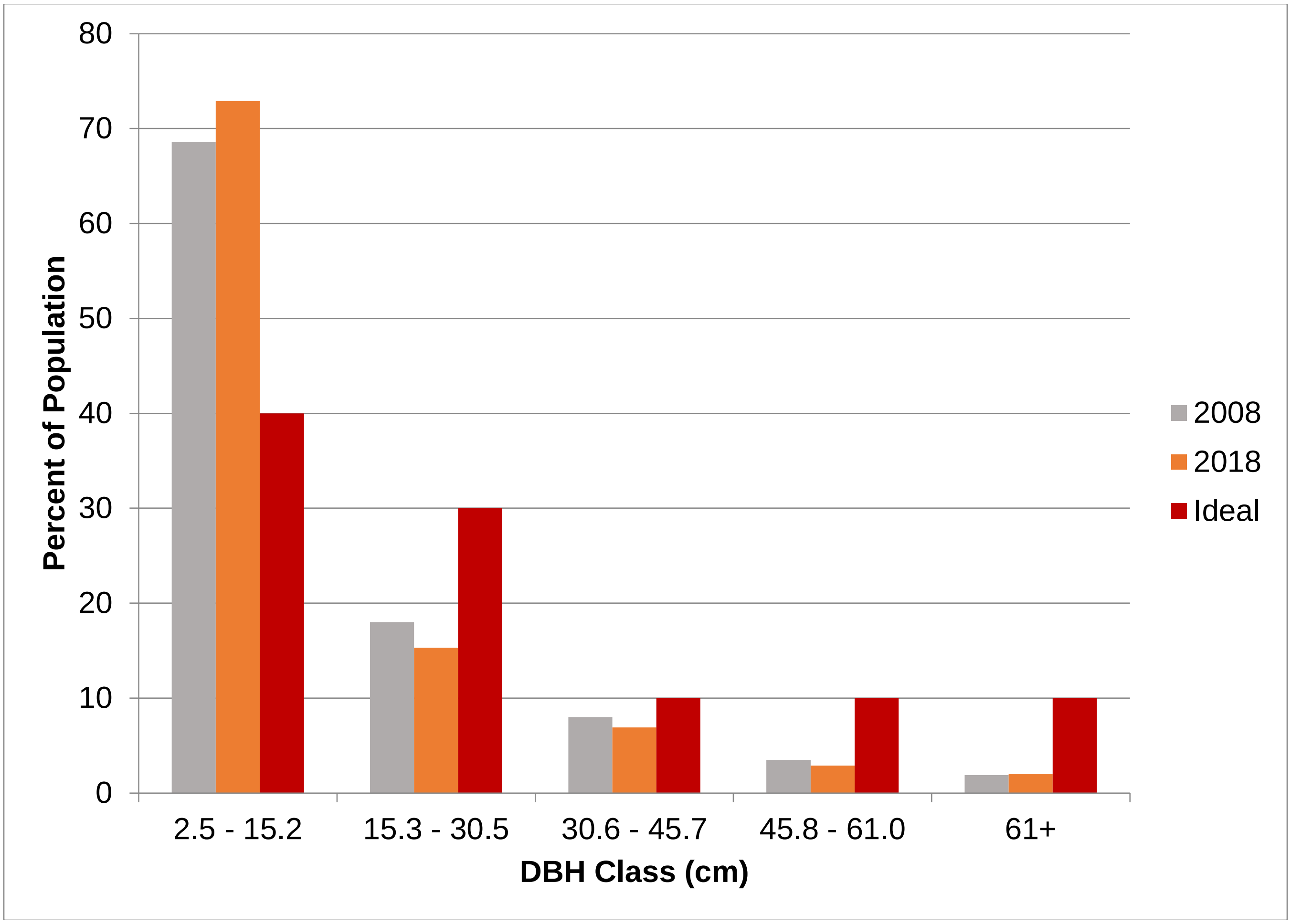


Figure 40: Distribution of tree size by DBH class, 2008-2018, compared to suggested 'ideal'. (Source: 2008 and 2018 i-Tree Eco data, *Every Tree Counts*)

The report on the initial i-Tree study of Toronto's urban forest, *Every Tree Counts*, reported the distribution of tree size by diameter class as compared to a suggested ideal distribution. In 2008, Toronto's trees did not meet the suggested ideal, due to what was considered an overabundance of trees in the smallest diameter class, 2.5-15.2 cm, and a shortfall of trees in each of the larger diameter classes. In 2008, about 68.6% of Toronto's trees fell into this diameter class, compared to the suggested ideal of 40%. As of 2018, Toronto's tree population has shifted even further away from the suggested ideal distribution, with about 73% of trees falling into the smallest diameter class (Figure 40).

Due to the natural distribution of immature trees in natural forests, land uses characterized by natural areas are expected to have a distribution of DBH classes that skews more strongly to the smaller classes. However, the land uses with the highest proportion of small diameter trees (i.e. under 15.3 cm DBH) were Utilities & Transportation (86.2% of trees were under 15.3 cm DBH) and Open Space 2 (78.3% of trees were under 15.3 cm DBH). Multifamily Residential lands had the smallest proportion of small diameter trees, with only 56.9% of trees measuring less than 15.3 cm DBH (Figure 41).

Multifamily Residential lands also had the largest proportion of trees in the largest diameter classes (30.6 cm and up), with 22.5%. The Institutional land use had the second largest proportion of trees in the largest diameter classes, with 19.5% (Figure 41).

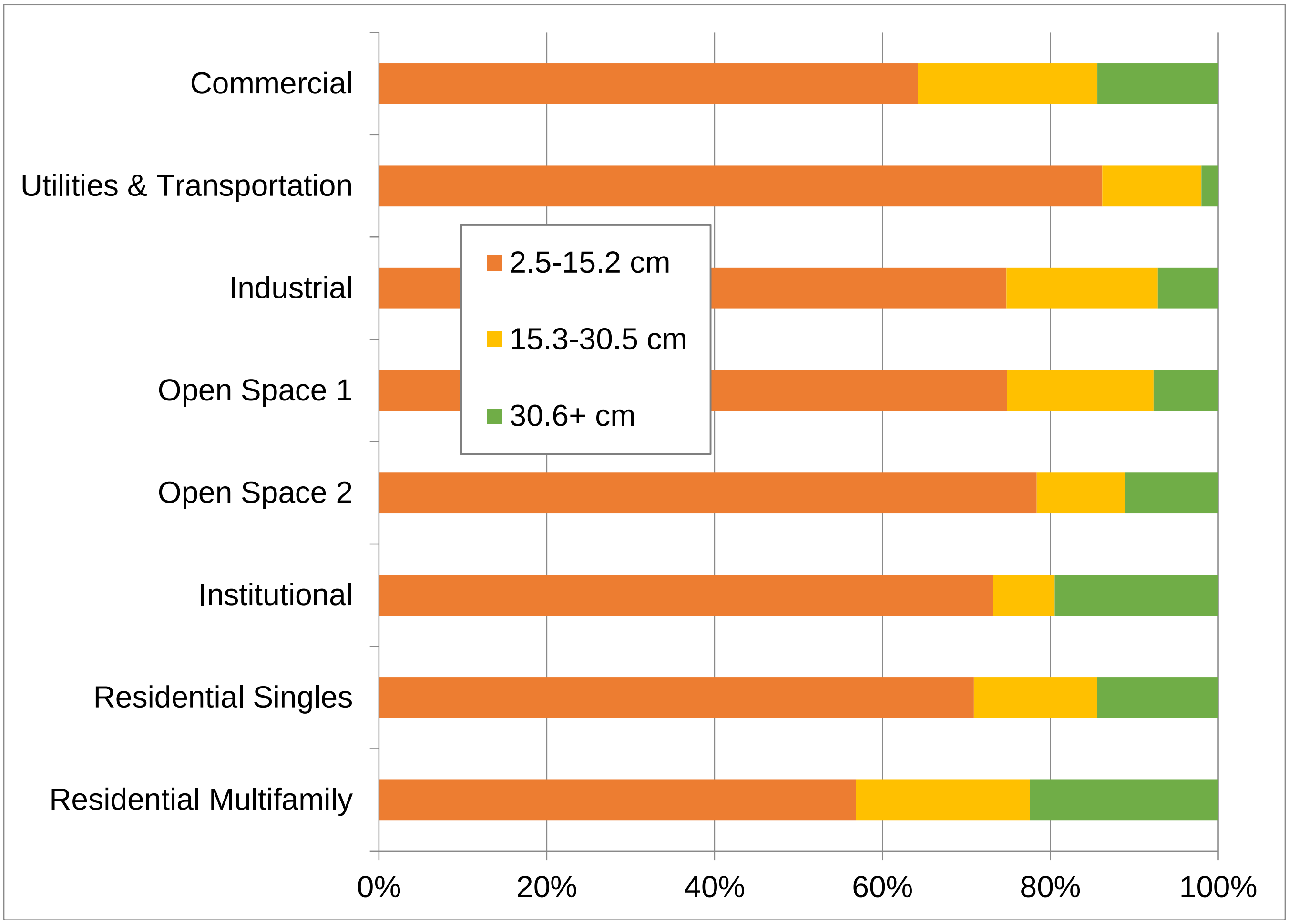


Figure 41: Tree size class distribution by land use (cm diameter at breast height), 2018. (Source: 2018 i-Tree Eco data)

Tree Condition

All trees measured during the i-Tree Eco field survey were assessed for the level of dieback, expressed as the percentage of dead branches located in the live crown. In 2008, approximately 81.6% of trees were estimated to be in excellent or good condition, meaning they had less than 10% dieback in the crown. In 2018, approximately 69.8% of trees were estimated to be in excellent or good condition (Figure 42).

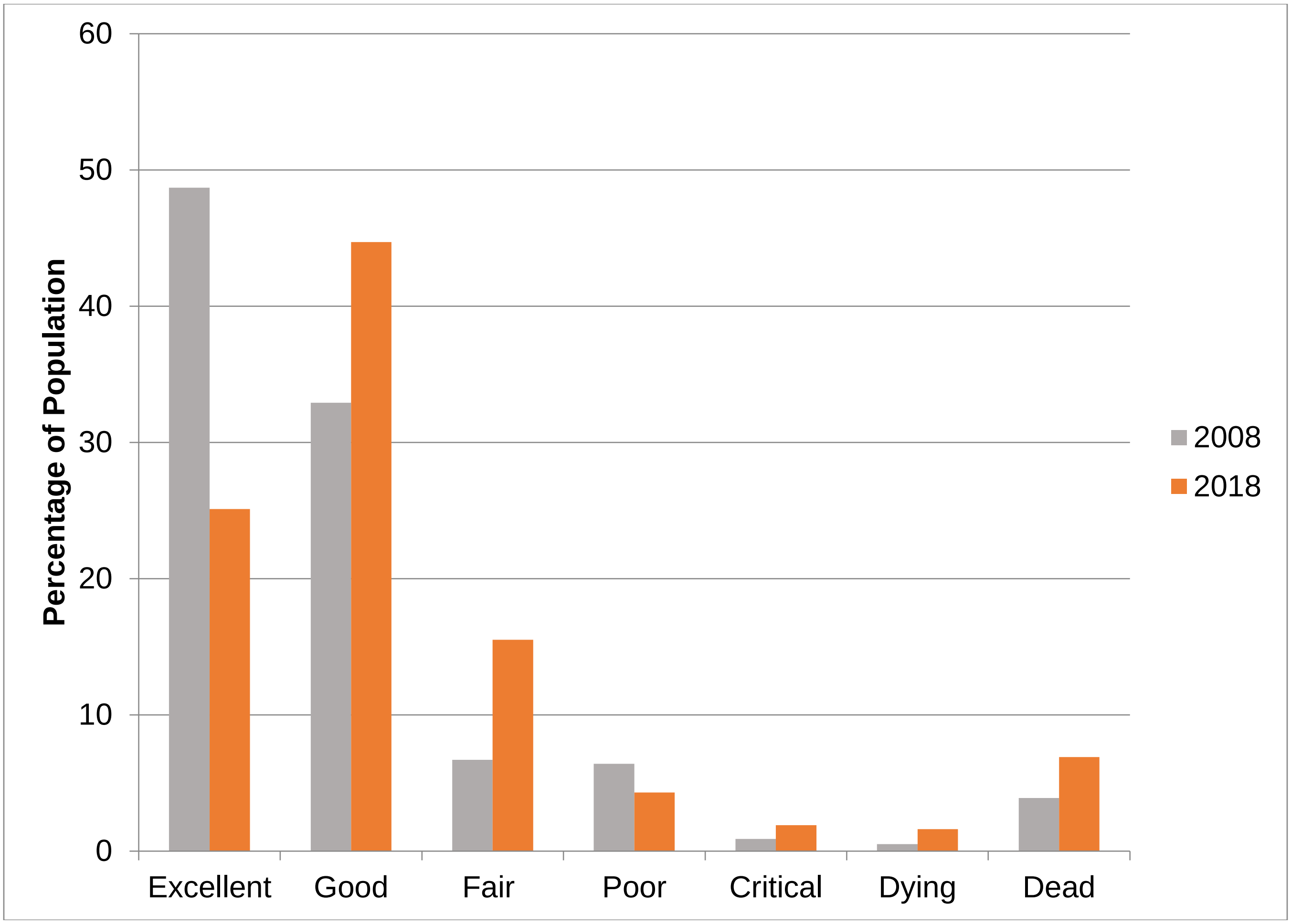


Figure 42: Distribution of tree population by condition rating, 2008-2018. (Source: 2008 and 2018 i-Tree Eco data)

The Residential Singles land use was characterized by the best tree condition ratings, with 79% of trees rated as being in excellent or good condition. Trees in the Commercial and Open Space 2 land use categories were characterized by above average tree condition, with 71.4% and 72.1% of trees rated as being in excellent or good condition, respectively. The high proportion of trees in good condition or better in these categories is likely due to the active management and pruning of trees on residential and municipal park properties. The Institutional land use category was characterized by the worst overall tree condition, with only 43.9% of trees rated as being in excellent or good condition.

The i-Tree Eco software calculates average condition ratings for each tree species based on the average amount of dieback observed throughout the species' population. Average condition is expressed as a percentage, with 100% indicating excellent condition and 0% indicating completely dead trees. Of the top ten most abundant trees by population, white and green ash had the worst overall average condition ratings. White ash had an average condition rating of 44.7% and green ash had an average condition rating of 54.5%, as a result of EAB-related decline and mortality (Figure 43). Of the top ten most abundant trees by population, Norway maple had the best overall average condition rating, at 89.8% (Figure 43).

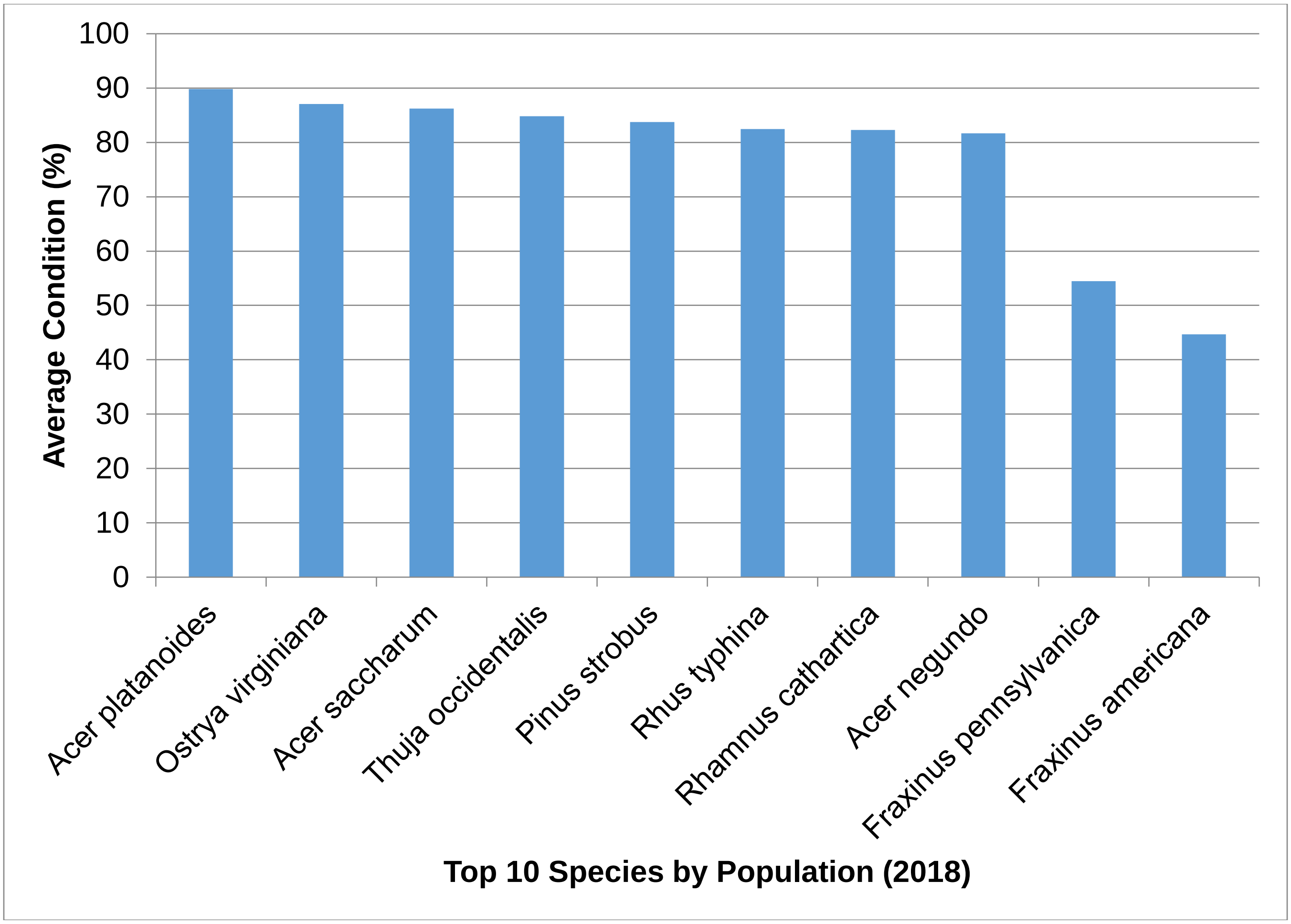


Figure 43: Average condition ratings of top 10 species by population (2018). (Source: 2018 i-Tree Eco data)

When considering the top ten species by leaf area, blue spruce (*Picea pungens*) and black walnut (*Juglans nigra*) were ranked highest in condition, with 95.6% and 89.4% of trees rated as excellent or good, respectively. Silver maple was rated lowest in condition among the top ten species by leaf area, with only 52.7% of trees rated as being in excellent or good condition (Figure 44). This is a steep decline from 2008, when over 90% of silver maples were rated as being in excellent or good condition.

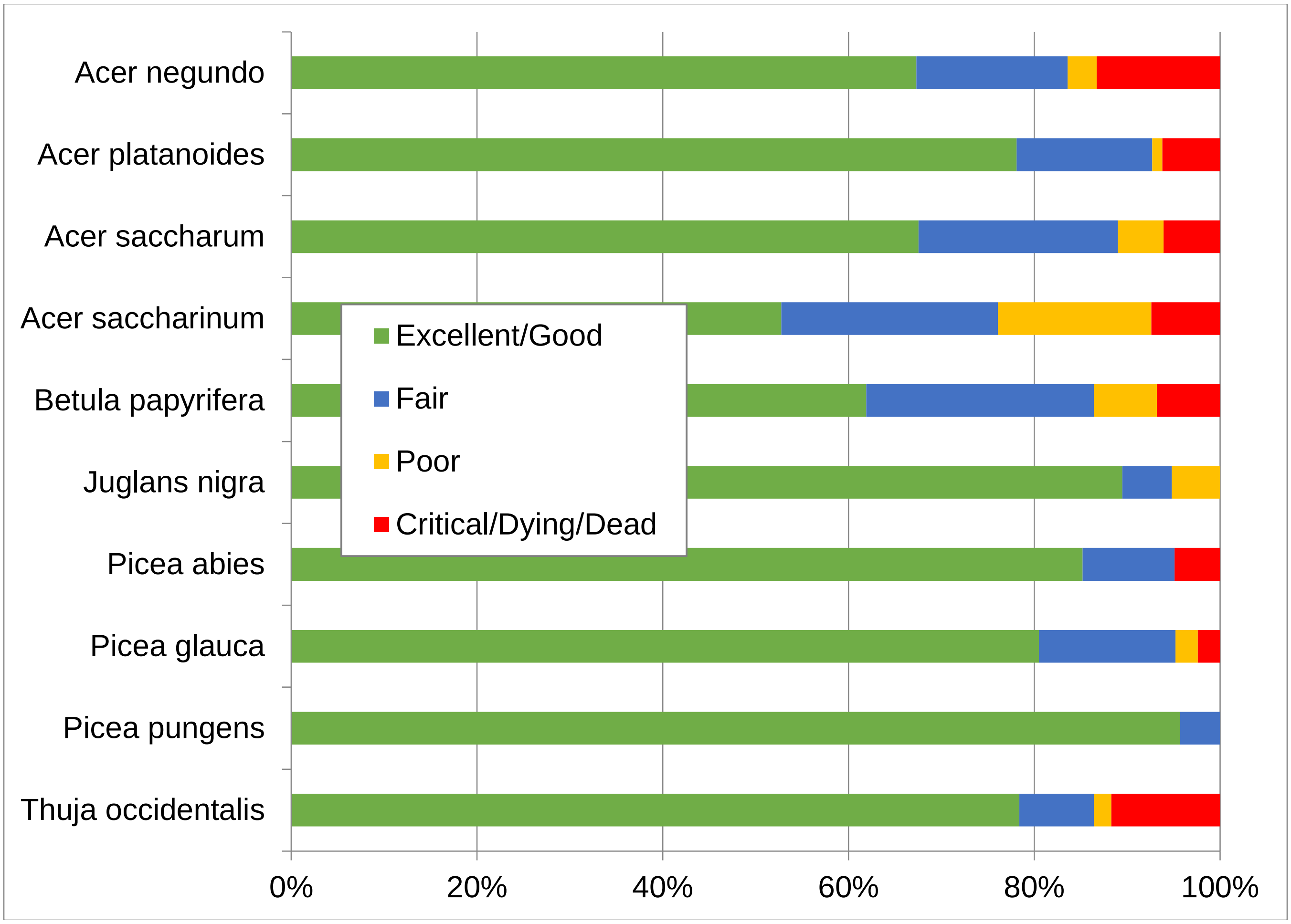


Figure 44: Condition ratings for top 10 species by leaf area, 2018. (Source: 2018 i-Tree Eco data)

Pest Susceptibility

As a major urban centre in southern Ontario, Toronto is host to many native and non-native forest pests that can inflict damaging effects on the city's urban forest. Some of the most serious insect pests that threaten Toronto's urban forest include the invasive Asian longhorned beetle, emerald ash borer, and European gypsy moth. Other insect species that pose a threat to Toronto's urban forest include fall and spring cankerworm, hemlock woolly adelgid, and beech bark scale. Diseases of concern in Toronto's urban forest include Dutch elm disease, beech bark disease, and oak wilt.

Asian Longhorned Beetle

While no longer present within city limits, Asian longhorned beetle (ALHB) was detected along the Toronto-Vaughan border in 2003. The pest was subsequently eradicated through a quarantine program led by the Canadian Food Inspection Agency (CFIA) that resulted in the removal of approximately 13,000 host trees (NRCAN 2018). A new detection in Mississauga in 2013 resulted in the implementation of another quarantine program that is ongoing. ALHB poses a particularly serious threat to Toronto's urban forest because of its wide range of preferred host species, which include maples, birch (*Betula* spp.), willow (*Salix* spp.), poplar

(*Populus* spp.), horsechestnut (*Aesculus* spp.), elm (*Ulmus* spp.), and katsura (*Cercidiphyllum* spp.). A total of about 3.4 million of Toronto's trees are currently threated by this pest, with an associated structural value of about $3.4 billion (Figure 45). These trees also represent 50% of the total leaf area of Toronto's urban forest.

During the 2018 i-Tree Eco field surveys, no signs or symptoms of ALHB were detected by field crews.

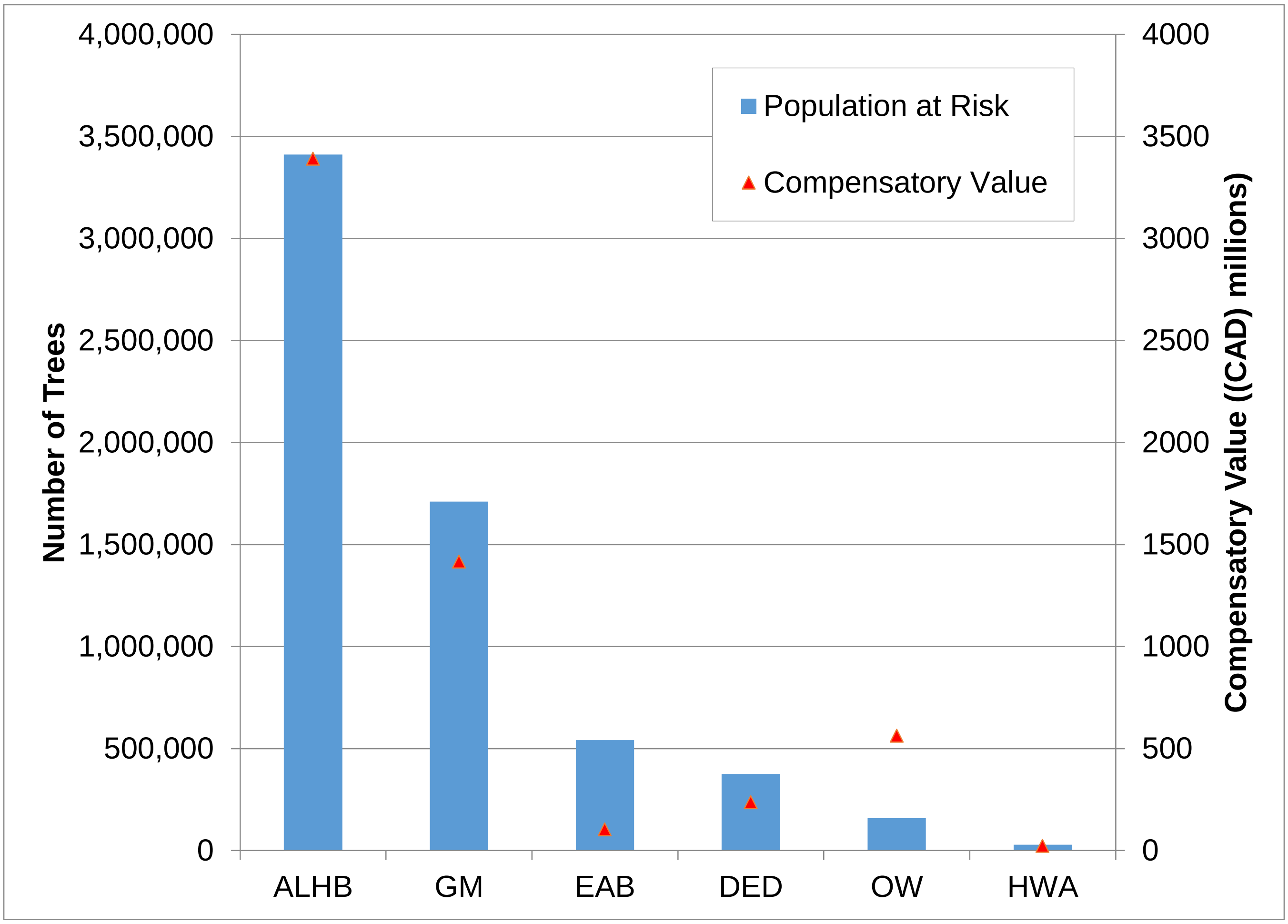


Figure 45: Susceptibility of Toronto's trees to major invasive pests (2018). (Source: 2018 i-Tree Eco data)

Gypsy Moth

European gypsy moth has been present on the landscape in southern Ontario for decades. The larval stage of the insect causes defoliating damage to many species of broadleaf trees, but oaks (*Quercus* spp.) are the preferred hosts of gypsy moth. Defoliation can reduce tree vigour and place stress on trees that can exacerbate other tree health issues. Multiple years of repeated severe defoliation can lead to tree mortality. Gypsy moth populations follow cyclical patterns of expansion and decline, so there are periodic threats to urban forest canopies during years when gypsy moth populations are at high levels. A variety of options are available to homeowners and municipalities to manage gypsy moth, including manual egg mass removal, tree injection of systemic insecticides, and aerial insecticide spraying. Approximately 1.7 million of Toronto's trees are susceptible to damage by gypsy moth, with an associated compensatory value of $1.4 billion (Figure 45). These susceptible trees account for about 18% of Toronto's leaf area.

During the 2018 i-Tree Eco field surveys, evidence of gypsy moth damage was detected on Open Space 1, Open Space 2, Multifamily Residential, and Single Family Residential lands. Approximately 2.35% of trees were observed to exhibit damage from gypsy moth.

Emerald Ash Borer

Since emerald ash borer (EAB) was detected in Toronto in 2007, there has been large-scale mortality of all species of ash, the beetle's host genus. While many trees have been saved through canopy conservation programs using systemic insecticide treatments, the vast majority of untreated trees, including those in natural areas, have succumbed to the effects of the invasive beetle. Approximately 541,000 trees are currently susceptible to EAB infestation, with a compensatory value of about $103.5 million (Figure 45). It should be noted that the compensatory value is somewhat low relative to the portion of the tree population that is at risk of infestation. This is likely due to the lingering effects of ash mortality on the landscape, which has seen the decline and mortality of large, mature ash, which have relatively high compensatory value. As a result of this widespread decline, ash populations are now characterized by relatively smaller, lower value trees.

Dutch Elm Disease

Dutch elm disease (caused by *Ophiostoma ulmi*) has been present on the landscape in Ontario for decades and has resulted in severe declines in the native population of elms. As a result, elms occupy a much less significant place in Toronto's urban forest than they once did. There are currently about 375,000 elm trees in Toronto's urban forest that are susceptible to the effects of Dutch elm disease. These trees have a compensatory value of about $236.8 million (Figure 45).

Oak Wilt

Oak wilt, a devastating disease of oaks caused by the fungus *Bretziella fagacearum*, has not yet been detected in Canada. However, the disease is present in 23 states in the US, including several that border Ontario. An infestation on Belle Isle in Detroit, MI, is less than a kilometer from Windsor, ON, making an introduction of this disease into Canada a likely possibility in the near future. All oaks are susceptible to infection by oak wilt, but oaks in the red oak group, including red oak, pin oak (*Quercus palustris*), and black oak (*Quercus velutina*), are particularly susceptible to rapid mortality. This is particularly concerning in light of the threat posed to the unique ecological feature of High Park's remnant black oak savannah, which is one of the gems of Toronto's park system.

According to the 2018 i-Tree Eco analysis there are approximately 159,000 trees in Toronto's urban forest that are susceptible to infection by oak wilt. The compensatory value of these trees is estimated at about $562.6 million, which is quite high relative to the size of the population at risk (Figure 45). This is likely due to the large stature of many mature oaks in the city's urban forest and the high value those trees represent. No suspected detections of oak wilt were reported during the 2018 Toronto i-Tree Eco field study.

Hemlock Woolly Adelgid

Hemlock woolly adelgid has been detected and eradicated twice in Ontario, in 2011 and 2013. It has also been detected elsewhere in Canada, in British Columbia in the 1920s, and in Nova Scotia in 2017, where it remains active. This pest has had devastating impacts on hemlock forests in the eastern United States, where it has been established since the 1950s. While not a large component of Toronto's urban forests, eastern hemlock (*Tsuga canadensis*) is an important native species that forms unique microclimates and it is susceptible to infestation by hemlock woolly adelgid. About 28,000 trees in Toronto's urban forest are susceptible to infestation by this pest, with a compensatory value of about $22.8 million (Figure 45). No suspected detections of hemlock woolly adelgid were reported during the 2018 Toronto i-Tree Eco field study.

Beech bark disease

Beech bark disease is a fungal disease caused by two species of fungi (*Neonectria faginata* and *N. ditissima*) that are vectored by a non-native insect, the beech scale. The disease causes dieback in American beech (*Fagus grandifolia*), an important tree in eastern North American forests that is a significant food source for wildlife. Some trees exhibit resistance to the disease and it is possible to preserve local populations of beech. Approximately 255,000 trees in Toronto's urban forest are susceptible to beech bark disease, with a compensatory value of about $71.5 million. These trees are mainly found in the Open Space land uses and in the Residential Singles land use. No detections of beech bark disease were reported during the 2018 Toronto i-Tree field study.

Shrub Species Composition

Table 19: Top 10 species of shrubs by leaf area, 2008-2018. (Source: 2008 and 2018 i-Tree Eco data)

2008 Species	Percent of total shrub leaf area	2018 Species	Percent of total shrub leaf area
Thuja occidentalis	20.7	**Thuja occidentalis**	10.8
Syringa vulgaris	6.2	**Rhamnus cathartica**	5
Juniperus chinensis	4.3	**Cornus sericea**	5
Buxus sempervirens	4.3	**Juniper sp.**	4
Cornus alternifolia	4	**Lonicera sp.**	4
Lonicera tatarica	3.8	**Taxus canadensis**	3.5
Euonymus alatus	3.75	**Hibiscus syriaca**	3
Euonymus × fortunei	3.1	**Rubus occidentalis**	2.9
Hibiscus syriaca	2.7	**Prunus sp.**	2.7
Rhus typhina	2	**Euonymus × fortunei**	2.5

**Note that the 2008 shrub list differs from the list published in Every Tree Counts. A re-examination of the 2008 raw field data revealed different results than were reported in Every Tree Counts. The list shown here represents a revised list based on the original 2008 raw data and reflects the percentage of leaf area represented by each species as a component of the total shrub leaf area in Toronto.*

Shrubs are an important component of Toronto's urban forest, and they make a valuable contribution to the total ecosystem services the urban forest provides. Overall, Toronto's shrubs constitute about 14,472 hectares of leaf area, which is equivalent to about 16% of the leaf area represented by trees. Following i-Tree Eco protocols, shrubs include all woody vegetation less than 2.5 cm DBH, including immature individuals of tree species.

When measured by leaf area, the dominant shrub species in Toronto's urban forest is eastern white cedar, which comprises 10.8% of the total shrub leaf area. The species is popular in landscaping and in residential areas, particularly as hedges, which certainly help to contribute to its dominance of other shrubs. The second most abundant shrubs are red osier dogwood (*Cornus sericea*), a native species, and the invasive common buckthorn, each comprising about 5% of the total shrub leaf area (Table 19).

The increase in common buckthorn since 2008, when it composed about 1.8% of the total shrub layer, is a concerning development. This increase suggests that common buckthorn is assuming a more prominent place in the understory of Toronto's urban forest. Increases in natural areas are particularly concerning, because the species can inhibit regeneration of native species and affect forest succession. Indeed, common buckthorn was over-represented in the Open Space 1 and Open Space 2 land uses, comprising 17.6% and 9% of the shrub layer in those land uses, respectively. The Utilities & Transportation land use also contained a significant amount of buckthorn, with about 12.6% of the shrub layer in that land use consisting of buckthorn.

Figure 46 illustrates the proportion of invasive shrubs present in each land use. Values are expressed as the percentage of invasive leaf area out of the total shrub leaf area in each land use. For consistency with the methodology in 2008, the list of invasive shrub species was drawn from the Canadian Botanical Conservation Network.[57] The commercial land use contained the greatest proportion of invasive shrubs, with about 47% of the shrub leaf area consisting of invasive species, which was primarily due to an abundance of Russian olive (*Elaeagnus angustifolia*). About 32.5% of the shrub layer leaf area in the Open Space 1 land use was made up of invasive species. Given that this land use consists of natural areas and woodland parks, this is a concerning increase from 2008, when approximately 15% of the shrub layer leaf area was defined as invasive. In fact, the Open Space 1 land use had the third lowest percentage of invasive shrubs in 2008; as of 2018, invasive shrub cover in this land use had doubled and it is now the land use with the second highest percentage of invasive shrubs (Figure 46).

[57] http://www.rbg.ca/archive/cbcn/en/projects/invasives/i_list.html

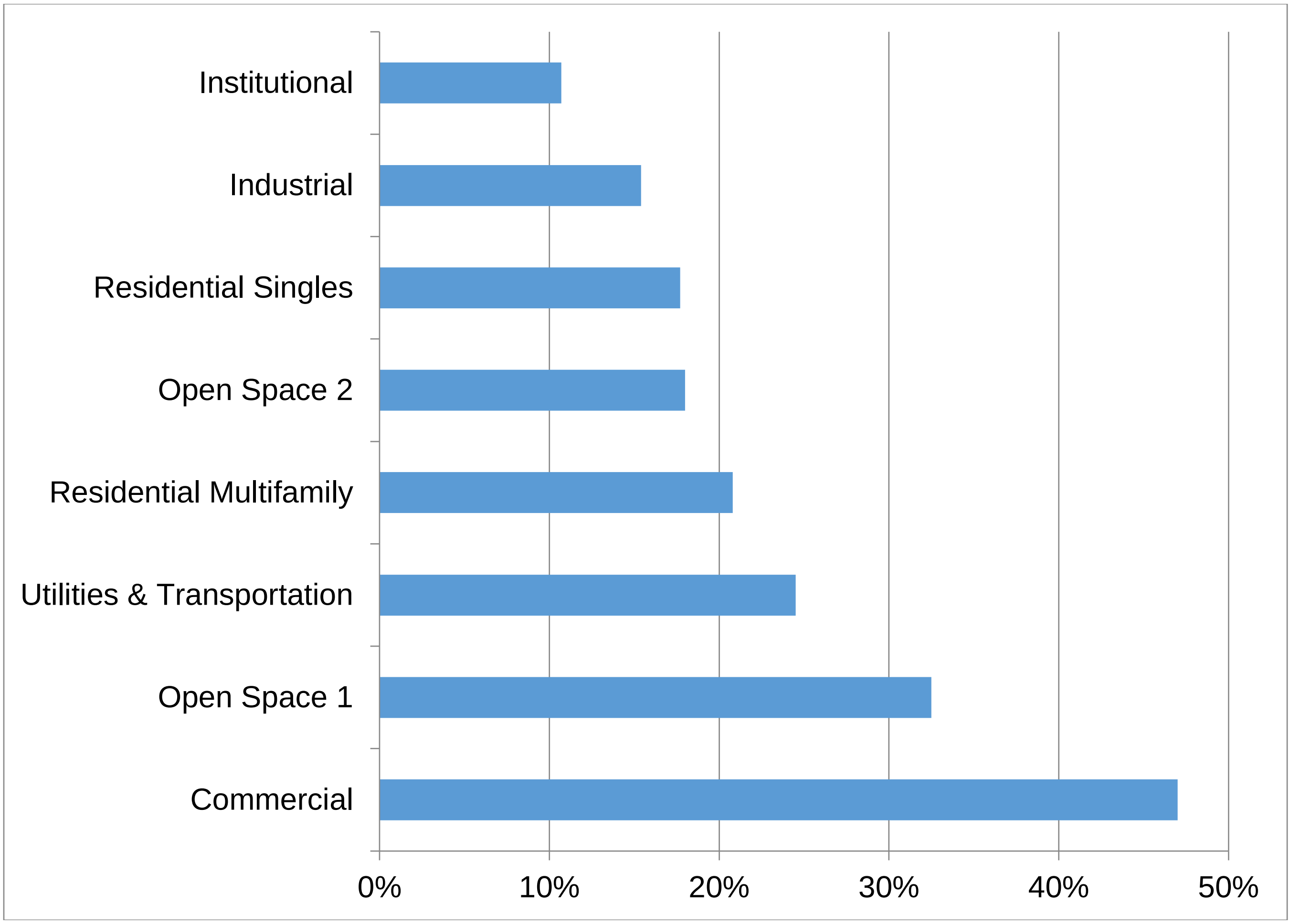


Figure 46: Proportion of invasive shrubs by land use (as percent of leaf area), 2018. (Source: 2018 i-Tree Eco data)

Species Diversity

Biodiversity is often upheld as a measure of healthy ecosystems, but it is important to consider the context of individual scenarios. Urban forests may be characterized by an inconsistent distribution of species diversity, as residential and other highly cultivated landscapes may contain a relatively diverse mix of native and non-native species, while natural areas may be relatively less diverse. In this case, less diverse areas may not necessarily be "unhealthy" ecosystems. It is also important to consider the role of invasive plant and tree species, which are a risk associated with a highly diverse urban forest, as well as pest susceptibility, which may be mitigated by greater species diversity.

A total of 179 species were recorded during the 2018 Toronto i-Tree Eco field surveys. The Residential Singles land use had the highest number of species, with 138 species recorded. However, the Open Space 1 land use had the highest amount of species per unit area. The lowest number of species was found in the Institutional land use, with only 12 species recorded. Interestingly, the Simpson Diversity Index ranks the Residential Singles land use second lowest, using the 2018 findings, due to the relative distribution of species across the full extent of land that makes up that land use.

Table 20: Simpson Diversity Index ratings by land use, 2008-2018. (Source: 2008 and 2018 i-Tree Eco data)

Land Use	Simpson Index – 2008	Simpson Index – 2018
Commercial	4.45	9.50
Industrial	8.34	10.80
Institutional	17.73	9.20
Open Space 1	10.36	16.80
Open Space 2	11.19	12.90
Other	9.25	n/a
Multifamily Residential	8.34	15.10
Single Family Residential	23.78	8.60
Utilities & Transportation	5.52	6.20

Species Origins

Figure 47 illustrates the percentage of total leaf area composed of native, invasive, and non-invasive exotic species by land use in Toronto. Overall, about 50% of Toronto's urban forest canopy is made up of species native to southern Ontario. About 26% of the leaf area in Toronto's urban forest is composed of invasive species, including Norway maple.[58]

The land use with the highest proportion of native species is Open Space 1, with about 70% of the tree canopy composed of native species, which is similar to the level reported in *Every Tree Counts*. Next to the Open Space 2 land use, Open Space 1 also has the lowest percentage of leaf area composed of invasive species, at 14% (Figure 47). However, the extent of invasive cover in Open Space 1 has increased since 2008, when it was just under 10%.

The land use with the highest proportion of tree canopy composed of invasive species is Commercial, at 54%. The Commercial land use also has the lowest proportion of native species, with only 21% of the tree canopy composed of species native to southern Ontario (Figure 47).

[58] http://www.rbg.ca/archive/cbcn/en/projects/invasives/i_list.html

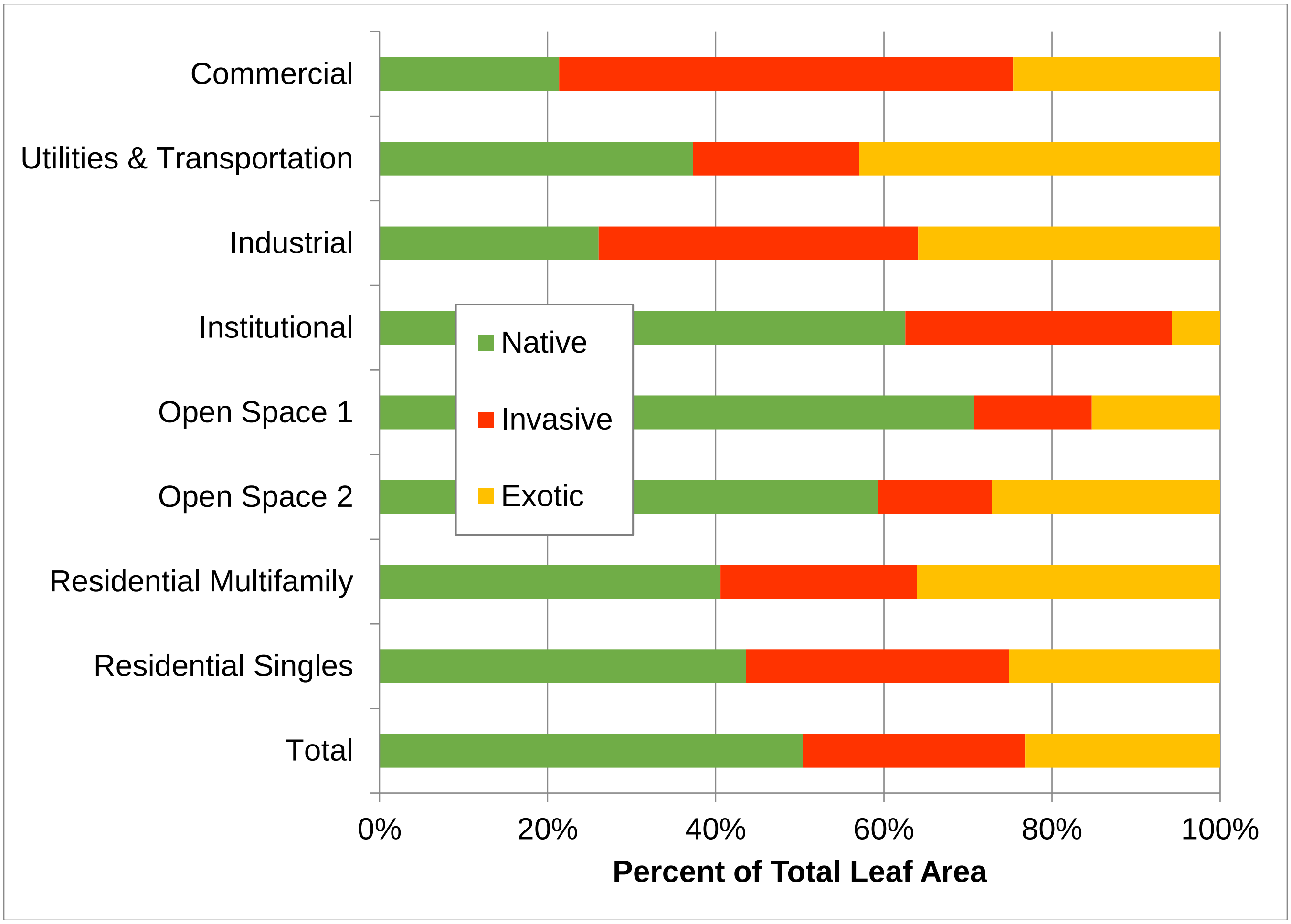


Figure 47: Percentage of canopy composed of native, invasive, and non-invasive exotic species by land use, 2018. (Source: 2018 i-Tree data)

Ecosystem Services

In 2008, Toronto's urban forest was estimated to provide ecosystem services with an annual value of about $28.2 million (Table 21). As of 2018, Toronto's trees are estimated to provide annual ecosystem services worth more than $55 million. These include home energy savings, carbon sequestration, pollution removal, and avoided runoff. Each tree provides an average of $4.80 in benefits each year. These benefits have an annual value of about $18.80 for each resident of Toronto (Table 22). Because these services are typically associated with leaf area and tree health, an analysis of ecosystem services provides additional insight into the functioning of the urban forest and its state of health over time. Furthermore, large stature trees with relatively large leaf area will make disproportionately large per-tree contributions to the ecosystem services provided by the urban forest when compared to smaller stature trees.[59]

[59] The financial values of ecosystem services performed in 2008 are presented as they were reported in *Every Tree Counts* (2013) and have not been adjusted for inflation. The value of

Table 21: Annual ecosystem services performed by Toronto's trees, 2008. (Source: *Every Tree Counts*)

Benefits	Total Units	Total (CAD)	Can$/tree	Can$/capita
Energy savings	749,000 MBTUS; 41,200 MWH	10,200,000	1.00	3.82
Gross Carbon Sequestration	46,740 tonnes	1,100,000	0.11	0.41
Pollution Removal	1,905 tonnes	16,900,000	1.66	6.34
Avoided Runoff	N/A	Not reported	-	-
Total Annual Benefits	**-**	**28,200,000**	**2.77**	**10.57**

Table 22: Annual ecosystem services performed by Toronto's trees, 2018. (Source: 2018 i-Tree Eco data)

Benefits	Total Units	Total (CAD)	Can$/tree	Can$/capita
Energy savings	893,796 MBTUs; 47,871 MWHs	8,279,540	0.72	2.83
Gross Carbon Sequestration	35,165 tonnes	4,039,488	0.35	1.38
Pollution Removal	972 tonnes	37,909,683	3.31	12.94
Avoided Runoff	2,119,544 m^3	4,845,926	0.42	1.65
Total Annual Benefits	**-**	**55,074,637**	**4.80**	**18.80**

Carbon Storage

As trees grow, they accumulate wood in their stems and branches, which results in the long-term storage of carbon through the tree’s life. As such, tree species that attain a large stature at maturity are capable of storing more carbon per tree than tree species that attain only small

these services on the market may have changed since 2008 and the comparative values should be interpreted as a direct expression of proportionate ecosystem function.

or medium stature at maturity. When trees lose biomass through injury or decay, or the tree dies, the stored carbon is released into the atmosphere over time, if the tree is able to decay naturally. Reusing or recycling the wood as wood products can maintain the storage of the carbon the tree accumulated during its lifetime.

In 2008, Toronto's trees stored about 1,107,645 tonnes of carbon. By 2018, the total amount of carbon stored by trees had declined slightly to 1,100,393 tonnes. Rather than increasing over the ten year time frame, this slight decline suggests that tree mortality has resulted in reduced carbon stores in Toronto's urban forest. The total value of carbon storage by Toronto's urban forest in 2018 is about $126 million.

Norway maple remains the species that stores the most carbon, and its total carbon storage has increased since 2008. Norway maple alone stores 14.1% of the carbon stored by all the trees in Toronto's urban forest. Silver maple has seen a large increase in carbon stored since 2008, while sugar maple has seen a decrease (Figure 48). Silver maple alone stores 12.1% of the carbon stored by all the trees in Toronto's urban forest.

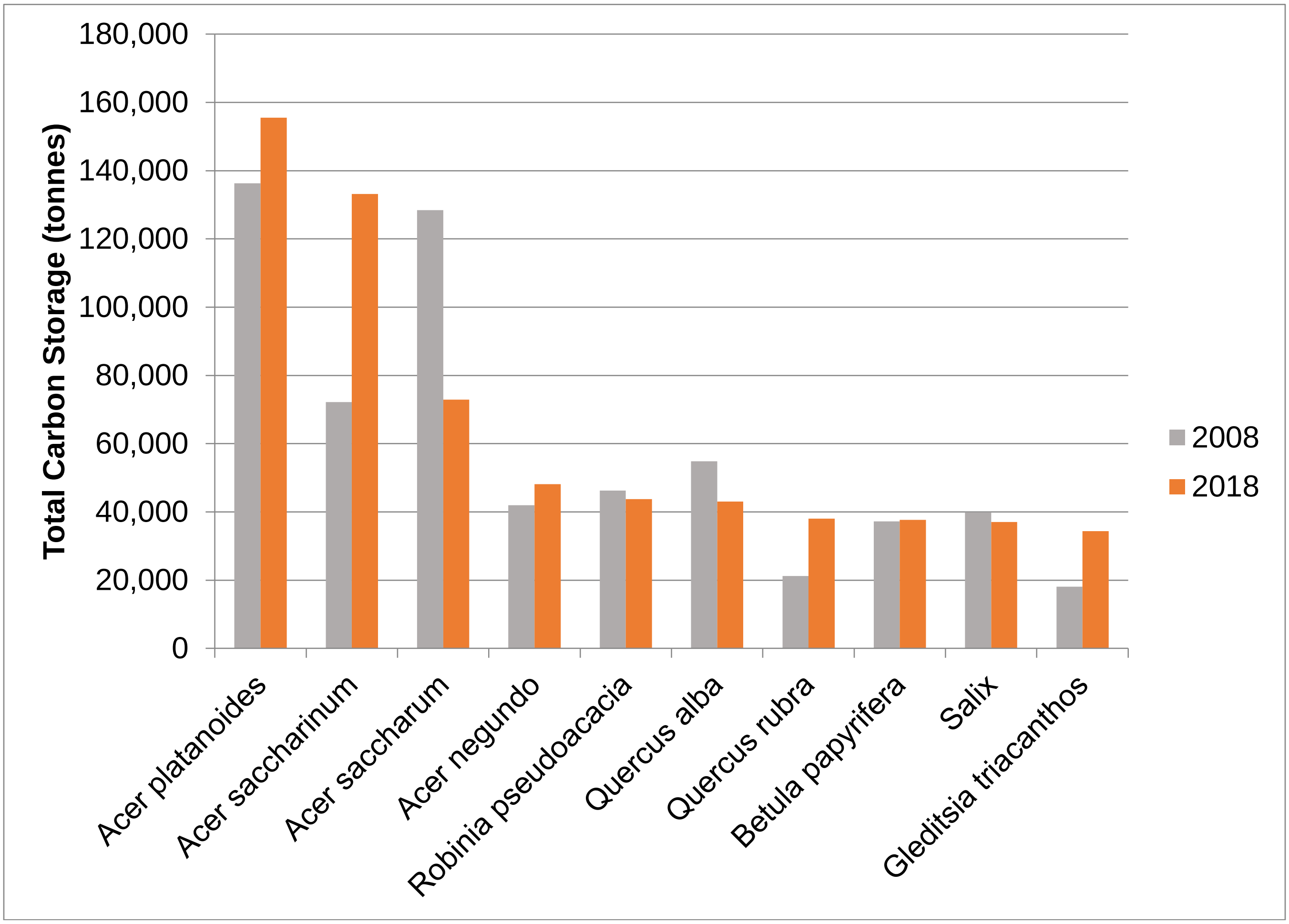


Figure 48: Total carbon stored by top 10 tree species by carbon storage (2018), 2008-2018. (Source: 2008 and 2018 i-Tree Eco data)

The effect of tree mortality on carbon stores is clearly illustrated by the changes in carbon storage among ash species. In 2008, Toronto's white ash trees stored about 40,928 tonnes of carbon, green ash trees stored about 35,183 tonnes of carbon, and European ash stored about 692 tonnes of carbon. By 2018, the combined carbon stored by all species of ash totaled only 21,465 tonnes (Table 23). The steep decline is likely the result of mortality, particularly of mature specimens, due to emerald ash borer infestation.

Table 23: Total carbon storage by ash trees (*Fraxinus* spp.), 2008-2018. (Source: 2008 and 2018 i-Tree Eco data)

Species	Carbon Storage (tonnes)	
	2008	**2018**
Fraxinus sp.	n/a	232
Fraxinus americana	40,928	14,456
Fraxinus excelsior	692	300
Fraxinus nigra	n/a	11
Fraxinus pennsylvanica	35,183	6,466
Total	**76,803**	**21,465**

Carbon Sequestration

During the growing season, when trees are at their most active, they sequester atmospheric carbon through the process of photosynthesis. Carbon is captured through the leaves and deposited into the tree's leaves and wood, and in soils, where it is stored over the longer term. Carbon sequestration is measured in annual amounts, with net carbon sequestration calculated based on the gross amount of carbon sequestered and the amount of carbon loss through the decay of biomass.

In 2008, Toronto's trees sequestered about 46,740 gross tonnes of carbon per year. In 2018, Toronto's trees are estimated to sequester about 35,165 gross tonnes of carbon annually. After accounting for loss of carbon through mortality and decay, Toronto's trees sequester about 17,737 net tonnes of carbon annually. This is equivalent to the annual carbon emissions from 27,400 automobiles. The associated annual value of this service is estimated at about $4.04 million.

Norway maple and sugar maple are still the top two species, respectively, that sequester the most net annual carbon, although the estimates of annual sequestration for both species are lower than in 2008 (Figure 54). Norway maple sequesters about 3,196 tonnes of carbon annually, which is equivalent to the absorption of about 11,723 tonnes of carbon dioxide. Norway maple alone currently sequesters about 18% of the carbon sequestered by all the trees in Toronto's urban forest each year, while sugar maple is responsible for about 13% of the total annual carbon sequestration. In 2008, Manitoba maple was estimated to sequester the third highest level of net annual carbon, but as of 2018, it has dropped to tenth place (Figure 49).

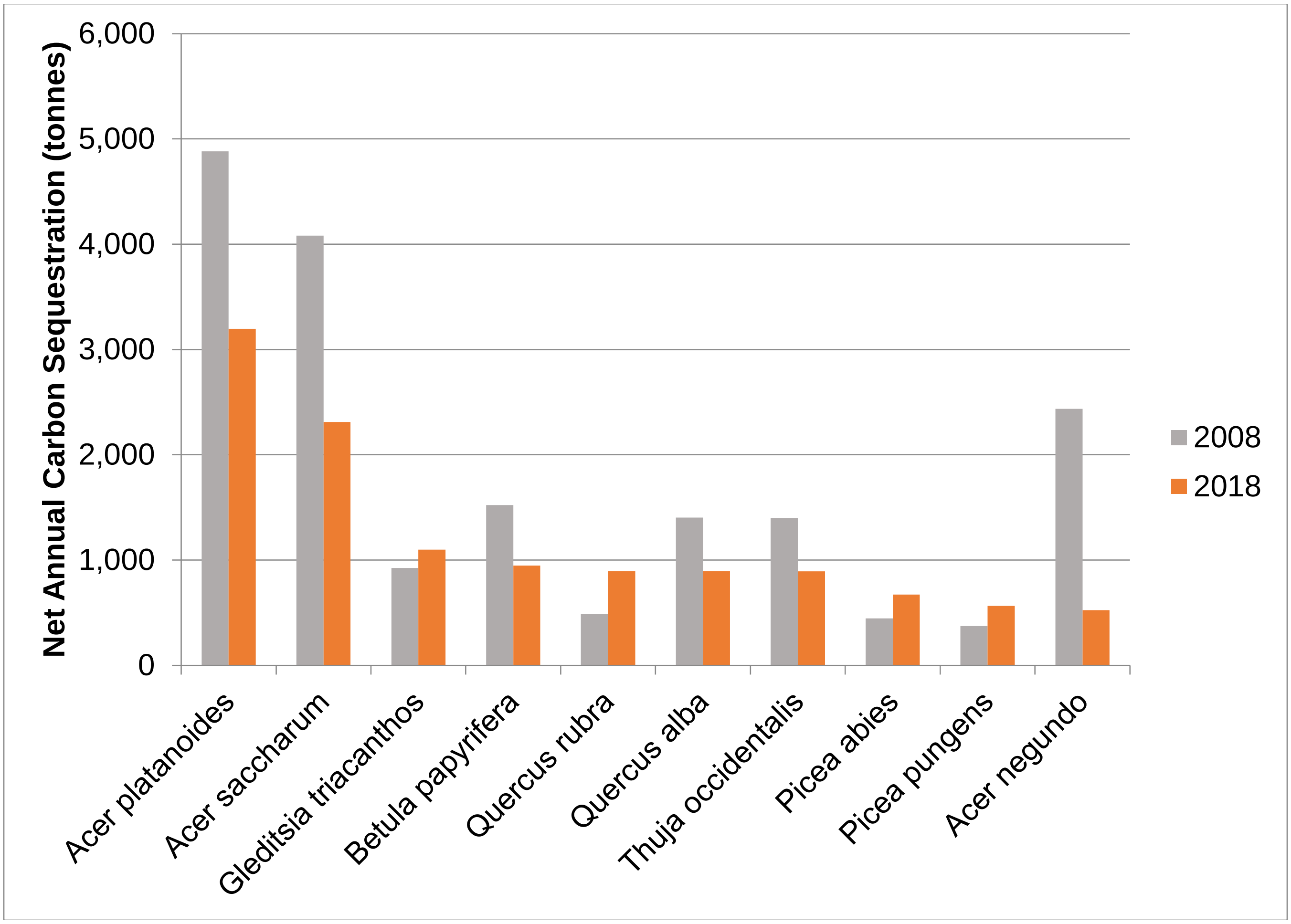


Figure 49: Net annual carbon sequestration of top 10 species by carbon sequestration (2018), 2008-2018. (Source: 2008 and 2018 i-Tree Eco data)

The greatest annual loss of carbon is attributed to white ash, which has a net annual carbon sequestration rate of -2,902 tonnes. This is equivalent to the annual emission of 10,643 tonnes of carbon dioxide.

The trees on Single Family Residential lands are responsible for about 65% of the net annual carbon sequestration performed by Toronto's urban forest. This is disproportionately higher than the population of trees in that land use, which represents about 46.3% of the city's trees.

Pollution Removal

As with atmospheric carbon, trees remove pollution from the air by direct absorption through the leaf stomata as well as by capturing particulate matter on and in plant tissue. In doing so, trees can mitigate air pollution to some extent. The removal of air pollution and particulate matter can have beneficial effects on human health, including reducing instances of respiratory conditions (Nowak et al. 2018). Because this benefit is linked to leaf area and function and because sources of pollution may be scattered across a city, the distribution of the effect may be uneven across the landscape. Areas with less trees and trees of smaller stature may experience relatively less pollution mitigation benefits than areas with larger trees and more urban forest cover.

In 2008, Toronto's trees were estimated to remove about 1,906 tonnes of pollution per year. As of 2018, Toronto's trees are estimated to remove about 972 tonnes of pollution per year. The total annual value of pollution removal performed by Toronto's trees is estimated at about $37,909,683 (Table 22).

Toronto's urban forest removed ozone (O_3) at higher levels than any other pollutant – approximately 607 tonnes, which has an associated annual value of about $12.9 million (Table 22).

The annual rate of removal of nitrogen dioxide (NO_2) is similar to, though slightly lower than, the level reported in 2008, at 240.5 tonnes per year. This has an associated value of about $762,700 and is equivalent to the annual nitrogen dioxide emissions of 37,900 automobiles.

Sulphur dioxide removal appears to have increased since 2008, with 87.4 tonnes removed each year. This has an associated value of about $101,000 and is equivalent to the annual sulphur dioxide emissions from 1.04 million automobiles.

Table 24: Annual removal of criteria pollutants by Toronto's trees, 2008-2018. (Source: 2008 and 2018 i-Tree Eco data)

Pollutant	Annual Pollution Removal (tonnes)	
	2008	**2018**
CO	10	3.6
NO_2	297	240.5
O_3	1,180	607.8
$PM_{2.5}$	n/a	32.7
PM_{10}	357	n/a
SO_2	62	87.4
Total	**1,906**	**972**

It should be noted that the criteria pollutants measured in 2008 are slightly different from those measured in 2018. In 2008, the earlier version of the i-Tree Eco software, UFORE, measured large particulate matter (PM_{10}). In later iterations of the software, PM_{10} was phased out in favour of small particulate matter ($PM_{2.5}$), which has more serious effects on human health. Furthermore, annual meteorological variations and changes in pollution emissions can affect pollution removal rates by trees. Changes in the health and structure of the urban forest canopy can also affect air pollution removal. Therefore, a direct comparison of pollution removal between two data sets is not entirely straightforward and must include the contextual influences mentioned here.

Residential Energy Savings

When properly placed, the presence of trees on residential properties helps to lower home energy costs. In summer, trees that shade the residence contribute to lower cooling costs, and in winter, evergreen trees can help to block cold winds, thus lowering the cost of home heating. By lowering home energy demands, trees help to reduce carbon emissions that result from energy use as well. These benefits are enhanced as the size and leaf area of the trees increase.

In Toronto, trees currently reduce annual home energy consumption by approximately 893,796 million British thermal units (MBTUS) and 47,871 mega-watt hours (MWHs), which translates to a total annual savings of $8,279,541 (Table 23).[60]

As a result of these energy savings, Toronto's trees reduce carbon emissions related to home energy use by 20,349 tonnes each year, a service that has an associated annual value of about $2.6 million. This represents an annual increase of nearly 8,000 tonnes of avoided carbon emissions over 2008 levels (Table 23). It should be noted that, while home energy savings are higher in 2018 than in 2008, the associated values of these services are quite different in 2018, due to changes in energy and carbon prices.[61]

Table 25: Annual building energy savings for residential properties, resulting from trees, 2008-2018. (Source: 2008 and 2018 i-Tree Eco data)

Unit	Heating		Cooling		Total	Savings	Total	Savings
Year	**2008**	**2018**	**2008**	**2018**	**2008**	**2018**	**2008**	**2018**
MBTUs	749,000	893,796	n/a	n/a	749,000 MBTUs	893,796 MBTUs	$6,502,000	$2,056,222
MWHs	6,400	7,623	34,800	40,248	41,200 MWHs	47,871 MWHs	$3,208,000	$6,223,319
Carbon avoided	12,500 tonnes	20,349 tonnes	4,500 tonnes	2,732 tonnes	17,000 tonnes	23,081 tonnes	$483,600	$2,651,376

Note: Financial figures from 2008 are presented in the value they were reported at the time and are not adjusted for inflation. The financial figures cited reflect the energy prices current as of each respective year.

Toronto's Future Urban Forest

One of the central goals of the 2018 Toronto Tree Canopy Study was to harness comparative data to make forecasts for the future of Toronto's urban forest. By comparing the data sets gathered during the 2008 and 2018 urban forest studies, it is possible to use tree mortality and

[60] Home energy savings are calculated based on home energy costs in 2018. Electricity/hydro cost was set at $0.13/kwh (Toronto Hydro on-peak rate). Natural gas rate for heating was set at 9.2346 cents per m³ ($0.23/therm), as cited by Enbridge Gas Distribution.

[61] Energy prices used in 2018 results: $0.13/kWh (electricity), $0.23/therm (heating), $114.87/tonne of carbon.

recruitment rates and calculate estimates of the future condition of Toronto's urban forest using the Forecast tool in i-Tree Eco. Mortality and establishment rates can help to inform tree planting strategies on public and private property by providing insight into the level of tree planting required to outpace mortality and insure that benefits continue to grow in the future.

A forecast scenario of 30 years was run using the i-Tree Eco Forecast tool for Toronto's urban forest to determine its projected future conditions. Actual annual mortality rates calculated from the change in Toronto's tree population since 2008 were used for each land use. Actual numbers of new recruits recorded in 2018 (by natural ingrowth, planting, or unknown means) were calculated based on the trees measured in the i-Tree Eco sample plots. Total numbers of new trees were then averaged over the ten year time span to calculate the approximate number of trees that have been added to each land use every year since 2008.

The calculations produced for this 30-year forecast assume that existing average annual mortality rates and rates of establishment will continue unchanged. The calculations also do not take into account any unanticipated storm or invasive pest events that may influence future population dynamics. However, it should be noted that the average annual mortality rates used in the calculations reflect mortality rates during a period of significant ash mortality due to EAB infestation. These rates may prevail in the future, or may fluctuate based on potential introductions of new invasive pests.

Furthermore, the calculations assume that Toronto will experience about 137 frost-free growing days over the next 30 years. However, the effects of climate change present some uncertainty in this regard. Higher average temperatures may result in more frost-free growing days in Toronto, which would alter the growth dynamics of the urban forest that have been the standard up to present day. Future climate scenarios could either promote tree growth through longer growing seasons or could cause drought stress and exacerbate attendant stresses such as insect infestations, thus increasing tree mortality (Bergh et al. 2003, Williams et al. 2013).

Table 26: Parameters used in i-Tree Forecast tool for 30-year scenario of Toronto's urban forest. (Source: calculated based on 2008 and 2018 i-Tree Eco data)

Land Use	Average Annual Mortality Rate (%)	Average Annual New Trees
Commercial	3.05	8,575
Industrial	5.33	20,694
Institutional	0.74	45,717
Open Space 1	2.94	153,095
Open Space 2	2.73	47,994
Multifamily Residential	5.81	35,563
Single Family Residential	3.42	283,857
Utilities & Transportation	3.44	36,119
City Total	3.33	631,614

Note: Average annual mortality rate and average annual amount of new trees reflect current conditions, as derived from i-Tree Eco data, 2008-2018.

According to the results provided by the forecast tool in i-Tree Eco Toronto’s tree population is forecast to decline to approximately 7.5 million by 2049, assuming existing mortality and establishment rates are held constant. Increasing annual tree planting in each land use by 10% above current establishment rates would only raise the tree population at the end of 30 years to about 7.8 million. Increasing annual tree planting in each land use by 25% above current establishment rates would result in a total tree population of about 8.3 million after 30 years.

Total leaf area is forecast to increase from about 90,500 hectares to a peak of about 92,600 by year 13, but will decline to about 88,800 hectares by year 30 (Figure 50). Increasing annual tree planting in each land use by 10% above current establishment rates would result in a total leaf area approximately equal to the present level, at the end of 30 years. Increasing annual tree planting in each land use by 25% above current establishment rates would result in a total leaf area of about 92,600 hectares by year 30, with a peak of about 93,700 hectares in year 16.

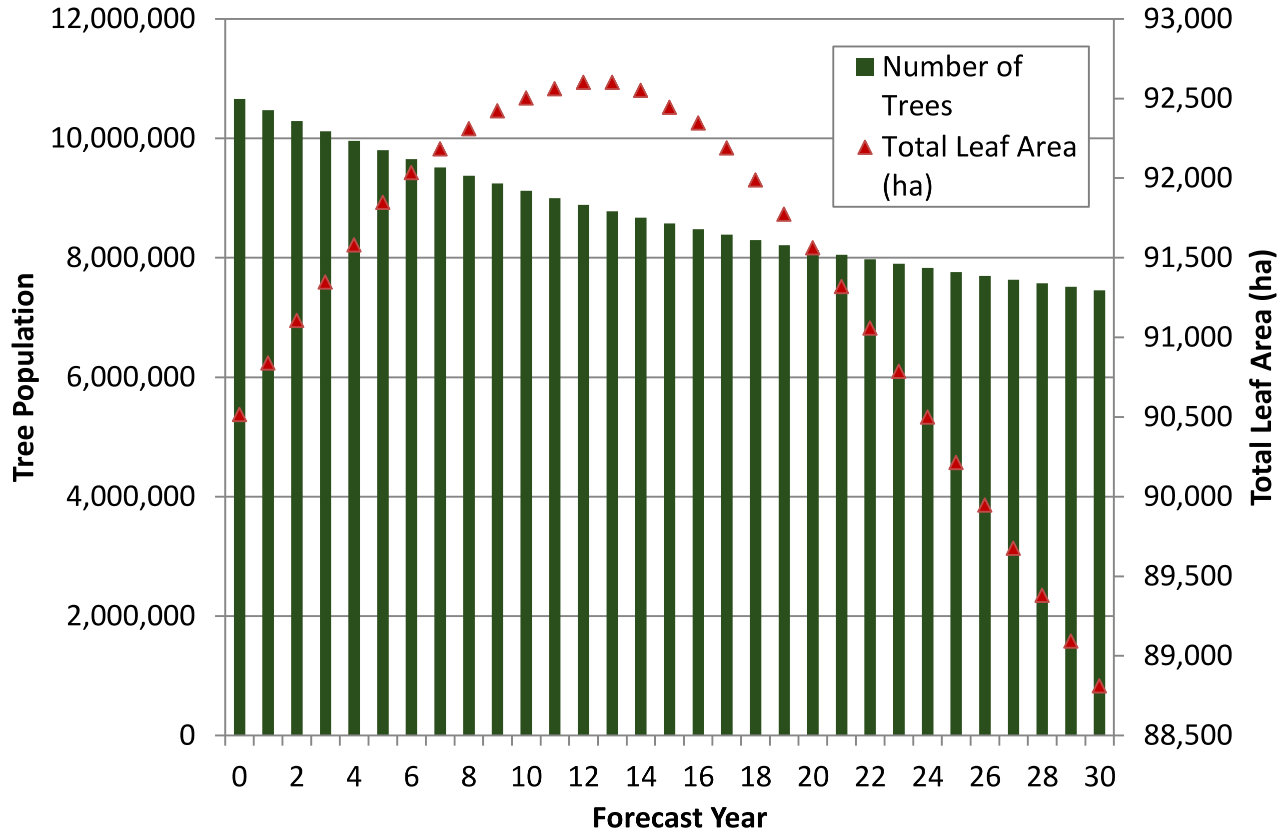


Figure 50: Forecasted trend in tree population and total leaf area (ha) over the next thirty years, under current mortality and establishment rates. (Source: i-Tree Eco Forecast)

Under current mortality and establishment rates, total carbon storage is expected to increase over the next thirty years, reaching about 1.2 million tonnes by year 30. Gross carbon sequestration is forecast to peak at about year 17, at 39,798.4 gross annual tonnes of carbon sequestered. By year 30, gross carbon sequestration is expected to dip slightly to about 38,800 tonnes per year, which is above the current rate of about 35,000 tonnes per year (Figure 51). Increasing tree planting in each land use by 10% or 25% above current establishment rates would result in slight increases in carbon storage and sequestration above the amounts projected for year 30 under existing mortality and establishment rates.

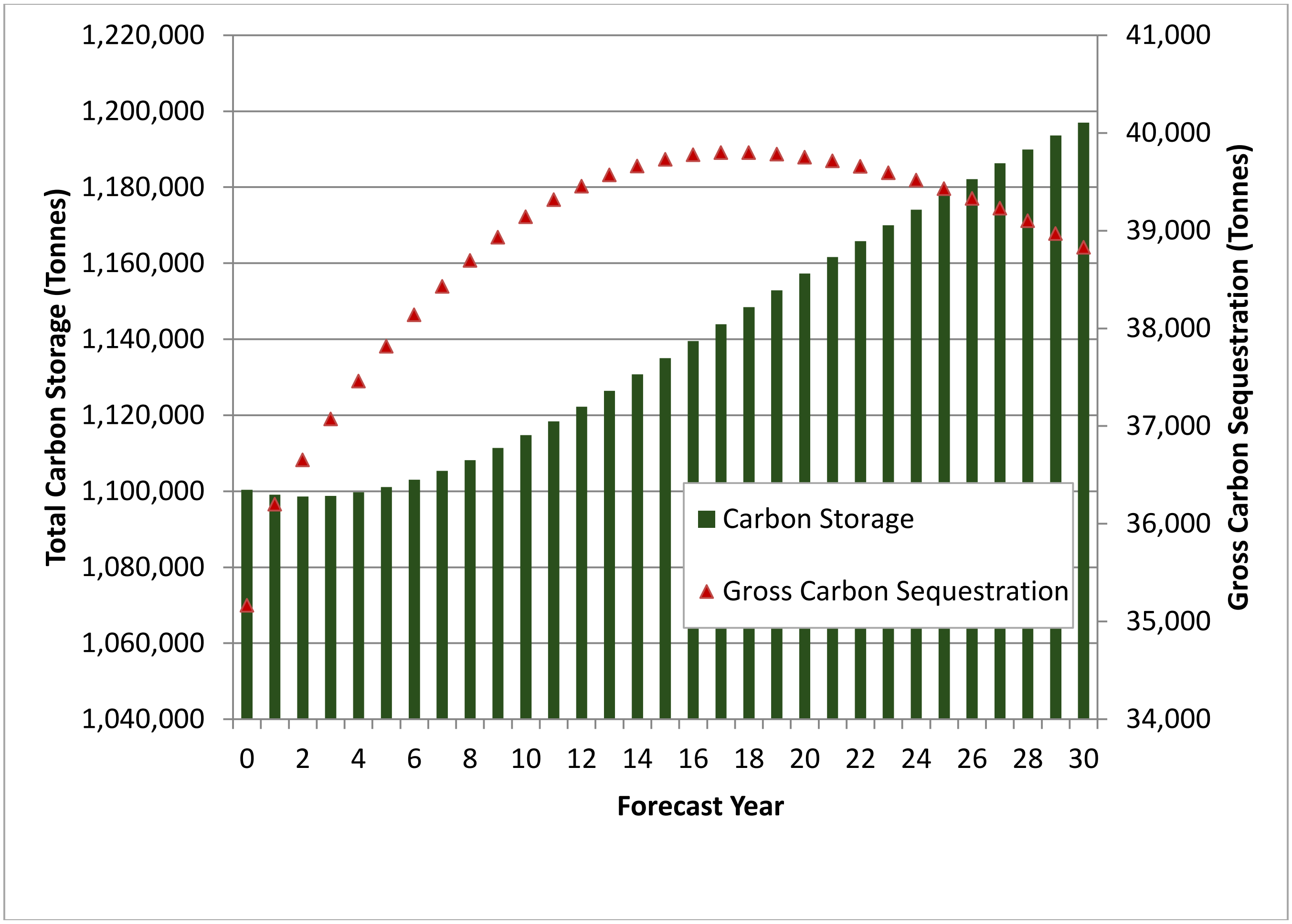


Figure 51: Forecasted trend in carbon storage and gross carbon sequestration (tonnes) over thirty years, under current mortality and establishment rates. (Source: i-Tree Eco Forecast)

From 2008 to 2018, the City of Toronto planted a total of 1,160,100 trees on City property, including all street and park trees. The rate of trees planted annually has risen each year since 2013, when it reached its lowest point over the ten year period. As reported in *Every Tree Counts*, the number of trees planted by the City increased significantly around 2006. Since 2016, the City has been planting at least double the amount of trees planted in 2004 and 2005. Figure 52 illustrates the numbers of trees planted each year.

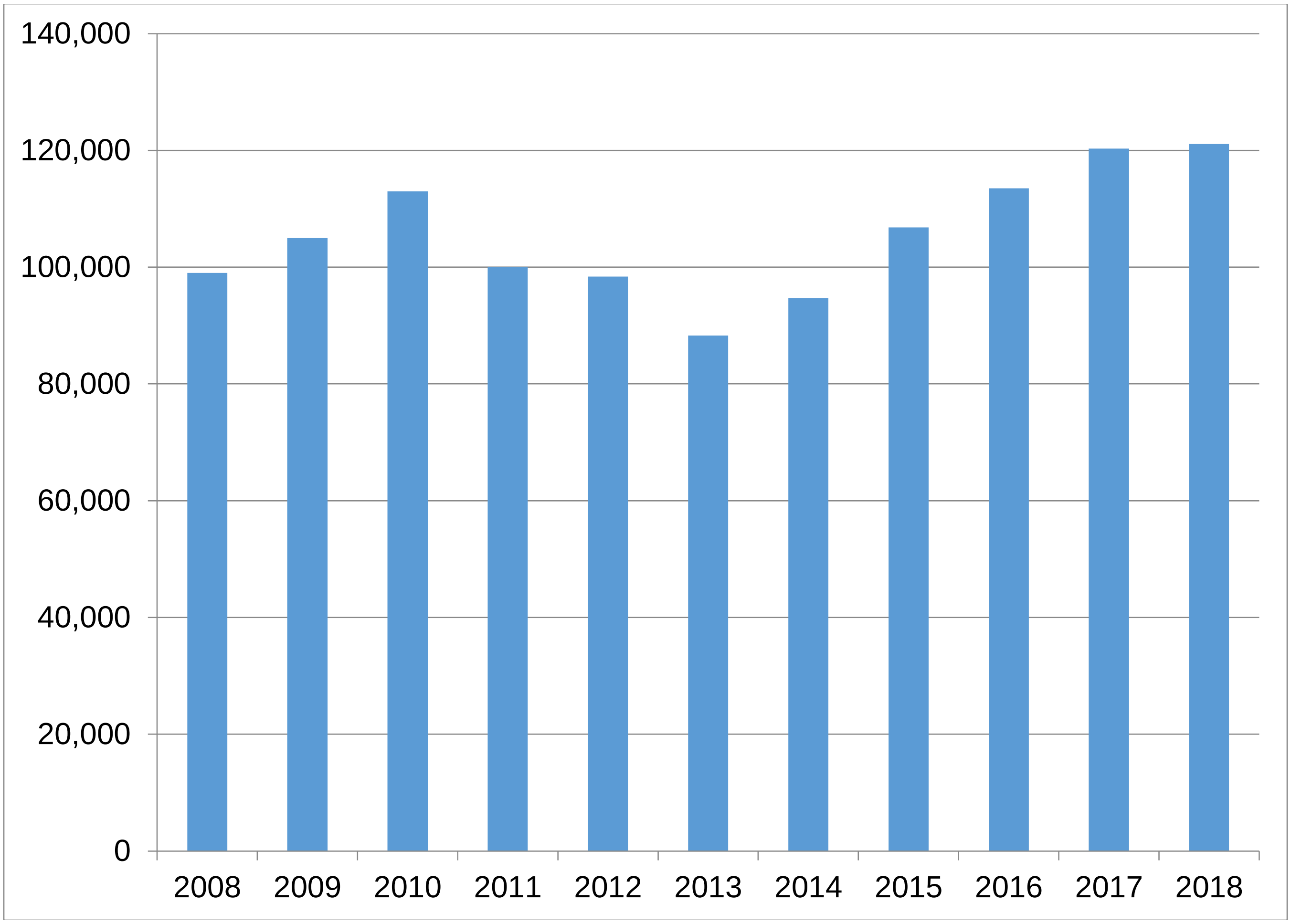


Figure 52: Total number of trees planted by the City of Toronto on City property, 2008-2018. (Source: City of Toronto)

Invasive Plant Monitoring

Toronto's natural areas, many of which are contained in extensive ravine systems, are some of the city's most significant and unique assets. However, like many other urban areas, Toronto hosts many non-native and invasive species that have varying degrees of influence on native ecosystem dynamics. For example, the presence of invasive plants in natural forests has been found to reduce floristic diversity and inhibit the growth of ectomycorrhizal fungi, which play key roles in forest ecosystem dynamics (Wolfe et al. 2008, Hejda et al. 2009).

During the 2018 i-Tree Eco survey, field crews recorded the presence and extent of invasive and noxious plants in all plots located in ravines and natural areas. This set of data helps to provide additional insight into the nature of invasive plant distributions in Toronto's ravines and natural areas and assist with any potential operational activities aimed at managing local invasive plant populations. The list of plants included in this portion of the survey was limited to 23 non-native invasive species and two native noxious species (See Methodology section above for the full list of species).

Out of the list of 25 species, field crews detected 14 species of invasive and noxious plants. Based on the findings of these assessments, the three most common invasive plants in

Toronto's natural areas and ravines are dog-strangling vine (35 detections), common buckthorn (28 detections), and garlic mustard (20 detections). Dog-strangling vine was also detected most frequently (in 4 plots) as a species that blanketed the understory of the plot and the surrounding area (Table 27). A total of 47 plots were found to contain at least one invasive plant species.

Table 27: Summary of invasive and noxious plant detections in Toronto's natural areas, 2018. (Source: 2018 field data) organized by number of plots per level of infestation

Species	Level of Infestation			
	1	2	3	4
Aegopodium podagragria	2	0	0	0
Alliaria petiolata	5	10	3	2
Arctium minus	3	5	0	0
Cirsium arvense	3	7	3	0
Convallaria majalis	2	3	0	0
Fallopia japonica	0	1	0	1
Pastinaca sativa	1	0	0	0
Phragmites australis ssp. australis	2	1	1	1
Rhamnus cathartica	8	16	4	0
Torilis japonica	1	1	1	0
Toxicodendron radicans*	5	5	2	0
Tussilago farfara	1	0	0	0
Vinca minor	1	1	0	0
Vincetoxicum rossicum	10	14	7	4

*Native species but considered noxious.

References

Bergh, J., Freeman, M., Sigurdsson, B., Kellomäki, S., Laitinen, K., Niinistö, S., Peltola, H., and S. Linder. 2003. Modelling the short-term effects of climate change on the productivity of selected tree species in Nordic countries. Forest Ecology and Management 183: 327-340.

Davies, E., Dong, A., Berka, C., Scrivener, P., Talyor, D., and S. Smith. 2018. The Toronto Ravines Study: 1977-2017, Long Term Changes in the Biodiversity and Ecological Integrity of Toronto's Ravines. Available online at: https://torontoravinesdotorg.files.wordpress.com/2018/09/toronto-ravines-study-1977-to-2017-short.pdf [Accessed January 21, 2019]

Hejda, M., Pyšek, P., and V. Jarošík. 2009. Impact of invasive plants on the species richness, diversity, and composition of invaded communities. Journal of Ecology 97: 393-403.

Natural Resources Canada (NRCAN). Asian longhorned beetle. Available online at: https://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13369 [Accessed December 7, 2018]

Nowak, D. J., Hirabayashi, S., Doyle, M., McGovern, M. and J. Pasher. 2018. Air pollution removal by urban forests in Canada and its effect on air quality and human health. Urban Forestry & Urban Greening 29: 40-48.

USDA. 2018. i-Tree Eco v 6 Manual.

Williams, A.P., Allen, C.D., Macalady, A.K., Griffin, D., Woodhouse, C.A., Meko, D.M., Swetnam, T.W., Rauscher, S.A., Seager, R., Grissino-Mayer, H.D., Dean, J.S., Cook, E.R., Gangodagamage, C., Cai, M., and N.G. McDowell. 2013. Temperature as a potent driver of regional forest drought stress and tree mortality. Nature Climate Change 3: 292-297.

Wolfe, B.E., Rodgers, V.L., Stinson, K.A., and A. Pringle. 2008. The invasive plant *Alliaria petiolata* (garlic mustard) inhibits ectomycorrhizal fungi in its introduced range. Journal of Ecology 96: 777-783.

Supplement A: Complete List of Tree Species

Table 28: Complete list of tree species. (Source: 2018 field data)

Species	Percent Population	Percent Leaf Area	Importance Value[62]
Abies	0.00	0.20	0.20
Abies balsamea	0.20	0.20	0.40
Abies concolor	0.00	0.00	0.10
Acer campestre	0.10	0.30	0.30
Acer ginnala	0.00	0.00	0.00
Acer negundo	4.90	4.60	9.50
Acer nigrum	0.40	0.70	1.10
Acer palmatum	0.50	0.30	0.90
Acer palmatum 'Dissectum'	0.10	0.00	0.10
Acer platanoides	5.80	16.70	22.40
Acer platanoides 'Crimson King'	0.20	0.70	0.90
Acer rubrum	0.10	0.50	0.70
Acer saccharinum	1.70	7.70	9.40
Acer saccharum	7.90	7.50	15.40
Acer x freemanii	0.20	0.40	0.60
Aesculus glabra	0.00	0.00	0.10
Aesculus hippocastanum	0.20	0.70	0.90
Ailanthus altissima	0.20	0.20	0.40

[62] Importance value represents the sum of the percent population and percent leaf area of each species. High importance values indicate that a species is relatively dominant in the urban forest.

Species	Percent Population	Percent Leaf Area	Importance Value[62]
Alnus glutinosa	0.60	0.20	0.80
Alnus incana ssp. rugosa	0.10	0.10	0.20
Amelanchier	0.40	0.10	0.50
Amelanchier alnifolia	0.10	0.10	0.10
Amelanchier arborea	0.00	0.00	0.00
Amelanchier laevis	0.10	0.00	0.20
Berberis thunbergii	0.10	0.00	0.10
Betula	0.00	0.00	0.00
Betula alleghaniensis	0.20	0.40	0.60
Betula nigra	0.20	0.10	0.20
Betula papyrifera	0.90	2.40	3.30
Buddleja	0.00	0.00	0.00
Carpinus caroliniana	0.10	0.00	0.10
Carya cordiformis	0.40	0.20	0.60
Catalpa	0.10	0.10	0.20
Catalpa speciosa	0.30	0.40	0.70
Celtis	0.00	0.00	0.00
Celtis occidentalis	0.10	0.10	0.20
Cercis	0.00	0.00	0.00
Cercis canadensis	0.10	0.10	0.20
Chamaecyparis nootkatensis	0.00	0.10	0.10
Cornus	0.20	0.00	0.20
Cornus alternifolia	0.20	0.10	0.20

Species	Percent Population	Percent Leaf Area	Importance Value[62]
Cornus sericea	0.40	0.00	0.50
Corylopsis spicata	0.10	0.00	0.10
Corylus colurna	0.00	0.00	0.00
Cotoneaster buxifolius	0.00	0.00	0.00
Crataegus	0.30	0.20	0.60
Crataegus chrysocarpa	0.10	0.10	0.20
Crataegus crus-galli	0.50	0.20	0.70
Crataegus flabellata	0.10	0.00	0.10
Crataegus pedicellata	0.80	0.20	1.00
Crataegus punctata	0.00	0.00	0.00
Crataegus spathulata	0.10	0.10	0.20
Cupressus	0.00	0.00	0.00
Cydonia oblonga	0.00	0.00	0.00
Elaeagnus	0.10	0.00	0.10
Elaeagnus angustifolia	0.80	0.40	1.20
Euonymus	0.00	0.00	0.00
Euonymus alatus	0.20	0.10	0.30
Euonymus atropurpurea	0.60	0.20	0.80
Euonymus europaea	0.10	0.00	0.20
Euonymus fortunei	0.00	0.00	0.00
Fagus	0.00	0.00	0.00
Fagus grandifolia	0.80	0.90	1.70
Fagus sylvatica	1.40	0.40	1.90
Fagus sylvatica 'Purpurea'	0.50	0.10	0.60

Species	Percent Population	Percent Leaf Area	Importance Value[62]
Forsythia	0.00	0.00	0.00
Forsythia x intermedia	0.10	0.00	0.10
Frangula alnus	0.00	0.10	0.10
Fraxinus	0.10	0.10	0.10
Fraxinus americana	2.30	0.40	2.70
Fraxinus excelsior	0.00	0.10	0.10
Fraxinus nigra	0.00	0.00	0.00
Fraxinus pennsylvanica	2.30	0.80	3.10
Ginkgo biloba	0.20	0.10	0.20
Gleditsia triacanthos	1.80	1.90	3.80
Hamamelis virginiana	0.50	0.20	0.70
Hibiscus syriacus	0.20	0.00	0.20
Hydrangea paniculata	0.00	0.00	0.00
Juglans cinerea	0.00	0.50	0.50
Juglans nigra	0.60	2.90	3.50
Juniperus	0.20	0.10	0.20
Juniperus scopulorum	0.00	0.00	0.00
Juniperus virginiana	0.70	0.50	1.20
Kolkwitzia amabilis	0.00	0.00	0.10
Ligustrum obtusifolium	1.10	0.10	1.20
Ligustrum vulgare	0.10	0.00	0.10
Liriodendron tulipifera	0.10	0.10	0.20
Lonicera	0.40	0.10	0.50
Lonicera tatarica	0.10	0.00	0.20

Species	Percent Population	Percent Leaf Area	Importance Value[62]
Lonicera x bella	0.00	0.00	0.00
Magnolia	0.20	0.30	0.60
Magnolia acuminata	0.00	0.00	0.10
Magnolia stellata	0.00	0.00	0.10
Malus	0.70	0.90	1.60
Malus baccata	0.00	0.00	0.00
Malus coronaria	0.20	0.10	0.20
Malus sylvestris	1.30	0.80	2.10
Malus tschonoskii	0.10	0.20	0.30
Morus	0.20	0.40	0.60
Morus alba	0.50	0.20	0.70
Morus nigra	0.00	0.20	0.20
Morus rubra	0.00	0.30	0.30
Ostrya virginiana	1.90	1.80	3.70
Philadelphus coronarius	0.00	0.00	0.00
Picea	0.00	0.00	0.00
Picea abies	1.20	2.70	3.90
Picea glauca	1.30	2.30	3.50
Picea omorika	0.10	0.10	0.20
Picea pungens	0.90	2.60	3.40
Pinus nigra	0.80	2.20	3.00
Pinus resinosa	0.30	0.00	0.30
Pinus strobus	2.10	2.20	4.20
Pinus sylvestris	0.50	0.80	1.30

Species	Percent Population	Percent Leaf Area	Importance Value[62]
Populus	0.20	0.10	0.30
Populus alba	0.00	0.10	0.20
Populus grandidentata	0.60	1.00	1.60
Populus tremuloides	0.20	0.40	0.60
Prunus	1.00	0.70	1.70
Prunus americana	0.00	0.10	0.10
Prunus armeniaca	0.10	0.00	0.10
Prunus avium	0.40	0.90	1.20
Prunus domestica	0.10	0.00	0.10
Prunus pensylvanica	0.00	0.00	0.00
Prunus serotina	1.00	1.30	2.30
Prunus serrula	0.10	0.00	0.10
Prunus virginiana	1.50	0.30	1.70
Prunus x cistena	0.10	0.10	0.20
Pseudotsuga menziesii	0.00	0.10	0.10
Pyrus	0.20	0.10	0.20
Pyrus calleryana 'Chanticleer'	0.10	0.00	0.10
Pyrus communis	0.20	0.10	0.40
Quercus alba	0.50	1.00	1.50
Quercus bicolor	0.00	0.00	0.00
Quercus macrocarpa	0.10	0.30	0.40
Quercus robur	0.00	0.10	0.10
Quercus rubra	0.70	2.20	2.90

Species	Percent Population	Percent Leaf Area	Importance Value[62]
Rhamnus cathartica	4.30	1.40	5.70
Rhus hirta	2.00	0.50	2.50
Robinia pseudoacacia	0.80	0.80	1.60
Rosa	0.20	0.10	0.20
Salix	0.30	1.40	1.70
Salix alba	0.10	0.00	0.10
Salix amygdaloides	0.00	0.00	0.10
Salix caprea	0.00	0.10	0.10
Salix cinerea	0.00	0.00	0.00
Salix sericea	0.00	0.30	0.30
Sambucus	0.10	0.00	0.10
Sassafras albidum	0.00	0.30	0.30
Shepherdia canadensis	0.10	0.00	0.10
Sorbus americana	0.00	0.00	0.10
Sorbus aucuparia	0.10	0.00	0.10
Sorbus decora	0.00	0.00	0.00
Stewartia pseudocamellia	0.00	0.00	0.00
Syringa	0.50	0.10	0.60
Syringa reticulata	0.20	0.10	0.20
Syringa vulgaris	0.40	0.10	0.50
Taxus	0.20	0.10	0.20
Taxus baccata	0.20	0.10	0.30
Taxus canadensis	0.30	0.10	0.50
Thuja	0.00	0.00	0.00

Species	Percent Population	Percent Leaf Area	Importance Value[62]
Thuja occidentalis	19.20	4.10	23.30
Tilia	0.10	0.00	0.10
Tilia americana	1.10	1.40	2.50
Tilia cordata	0.50	1.40	2.00
Tsuga canadensis	0.20	0.30	0.60
Ulmus	0.10	0.00	0.10
Ulmus americana	1.20	1.50	2.70
Ulmus glabra	0.10	0.20	0.30
Ulmus pumila	1.90	1.70	3.50
Ulmus rubra	0.00	0.00	0.00
Viburnum	0.00	0.00	0.00
Viburnum lantana	0.00	0.00	0.00
Viburnum lentago	0.10	0.00	0.10
Viburnum opulus	0.10	0.00	0.10
Weigela florida	0.10	0.00	0.10
Zelkova serrata	0.00	0.00	0.10

Supplement B: Leaf Area and Biomass Estimates

Table 29: Leaf area and biomass estimates for all shrub species, by land use, 2018. (Source: 2018 field data)

Stratum	Species	Leaf Area (m^2/ha)	Leaf Biomass (kg/ha)
Commercial	Acer negundo	30.00	2.70
	Acer platanoides	0.90	0.10
	Acer spicatum	<0.1	<0.1

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Ailanthus altissima	10.10	0.80
	Celtis	32.90	1.90
	Corylus cornuta	2.90	0.20
	Corylopsis spicata	6.70	0.50
	Elaeagnus angustifolia	332.60	24.90
	Euonymus fortunei	4.40	0.30
	Fraxinus americana	5.40	0.30
	Lonicera	7.30	0.40
	Malus	2.90	0.30
	Malus tschonoskii	0.30	<0.1
	Morus alba	1.30	0.10
	Morus rubra	29.40	2.90
	Prunus	6.30	0.50
	Prunus virginiana	5.60	0.40
	Rhamnus cathartica	12.40	0.50
	Ribes	13.10	1.00
	Robinia pseudoacacia	0.10	<0.1
	Rosa virginiana	2.10	0.20
	Sorbus americana	0.40	<0.1
	Spiraea japonica	2.50	0.20
	Taxus baccata	63.40	9.90
	Tabebuia	39.10	2.90
	Thuja occidentalis	168.00	32.30
	Ulmus americana	0.10	<0.1

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Ulmus pumila	11.80	0.80
	Ulmus rubra	9.80	0.40
	Ulmus	0.20	<0.1
	Total	**802.30**	**84.70**
Utilities and Transportation	Acer x freemanii	2.60	0.10
	Acer negundo	8.00	0.70
	Acer saccharinum	0.70	<0.1
	Acer saccharum	<0.1	<0.1
	Ailanthus altissima	3.00	0.20
	Amelanchier	2.00	0.20
	Amelanchier laevis	84.30	6.40
	Betula	6.60	0.40
	Berberis vulgaris	6.40	0.50
	Carya	8.50	0.50
	Cornus	73.10	4.30
	Cornus florida	1.70	0.10
	Cornus sericea	170.40	9.80
	Euonymus alatus	52.90	4.00
	Eugenia monticola	91.50	6.90
	Fraxinus americana	12.60	0.70
	Hydrangea	1.60	0.10
	Juniperus	62.90	17.50
	Juglans nigra	0.20	<0.1

Stratum	Species	Leaf Area (m^2/ha)	Leaf Biomass (kg/ha)
	Juniperus virginiana	28.90	8.00
	Larix laricina	28.70	1.30
	Lonicera	99.60	4.90
	Lonicera tatarica	21.20	1.00
	Morus alba	34.40	2.50
	Morus rubra	3.90	0.40
	Physocarpus	2.30	0.20
	Physocarpus opulifolius	25.00	1.90
	Picea glauca	5.20	0.80
	Pinus sylvestris	1.40	0.10
	Populus	10.00	0.70
	Populus grandidentata	18.60	1.00
	Prunus	3.80	0.30
	Prunus virginiana	4.70	0.40
	Quercus rubra	1.70	0.10
	Rhus aromatica	44.70	4.30
	Rhamnus cathartica	169.20	7.50
	Rhus hirta	56.50	5.40
	Robinia pseudoacacia	0.50	0.10
	Rosa	2.40	0.20
	Rosa blanda	61.60	4.60
	Rubus idaeus	7.20	0.30
	Rubus occidentalis	24.30	0.90
	Salix	0.80	<0.1

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Spiraea japonica	1.50	0.10
	Spiraea trilobata	41.80	3.10
	Spiraea x vanhouttei	<0.1	<0.1
	Syringa vulgaris	0.90	0.10
	Thuja	1.70	0.30
	Thuja occidentalis	38.10	7.30
	Tilia americana	0.10	<0.1
	Ulmus pumila	0.30	<0.1
	Ulmus rubra	4.30	0.20
	Ulmus	0.70	<0.1
	Viburnum acerifolium	1.10	0.10
	Viburnum	10.20	0.80
	Total	**1346.30**	**111.30**
Industrial	Acer negundo	1.90	0.20
	Acer platanoides	<0.1	<0.1
	Ailanthus altissima	0.40	<0.1
	Amelanchier	6.50	0.50
	Cotinus coggygria	0.50	<0.1
	Cornus sericea	109.00	6.20
	Euonymus alatus	0.40	<0.1
	Fraxinus	0.10	<0.1
	Fraxinus pennsylvanica	13.30	0.90
	Juniperus	348.70	96.90
	Lonicera	21.40	1.10

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Lonicera tatarica	43.50	2.10
	Pinus resinosa	14.30	2.10
	Populus tremuloides	7.90	0.60
	Prunus avium	9.50	0.70
	Prunus virginiana	4.90	0.40
	Quercus x macnabiana	2.50	0.20
	Rhamnus cathartica	43.40	1.90
	Rhus hirta	20.40	2.00
	Ribes nigrum	2.30	0.20
	Ribes rubrum	1.00	0.10
	Ribes	21.40	1.60
	Rosa	2.50	0.20
	Rubus idaeus	8.50	0.30
	Sorbus	0.30	<0.1
	Spiraea japonica	16.70	1.20
	Taxus	2.50	0.40
	Taxus canadensis	46.10	7.20
	Ulmus pumila	7.90	0.50
	Ulmus rubra	<0.1	<0.1
	Total	**758.40**	**127.70**
Institutional	Acer negundo	1.80	0.20
	Acer platanoides	2.30	0.10
	Betula papyrifera	<0.1	<0.1
	Cornus sericea	358.30	20.50

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Euonymus alatus	115.50	8.70
	Ligustrum vulgare	57.50	5.20
	Lonicera	11.40	0.60
	Morus alba	8.40	0.60
	Prunus virginiana	31.70	2.50
	Rhamnus cathartica	164.80	7.30
	Ribes nigrum	14.40	1.10
	Ribes rubrum	0.50	<0.1
	Rosa	50.60	3.80
	Rubus idaeus	657.60	24.50
	Rubus occidentalis	748.20	27.90
	Sambucus nigra	29.50	2.20
	Sorbus americana	1.10	0.10
	Syringa vulgaris	5.30	0.50
	Thuja occidentalis	67.60	13.00
	Ulmus americana	1.10	0.10
	Ulmus glabra	0.70	<0.1
	Total	**2328.60**	**118.90**
Open Space 1	Acer ginnala	<0.1	<0.1
	Acer negundo	16.80	1.50
	Acer nigrum	<0.1	<0.1
	Acer pensylvanicum	0.10	<0.1
	Acer platanoides	2.50	0.10
	Acer rubrum	0.70	<0.1

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Acer saccharum	34.70	2.10
	Acer spicatum	0.20	<0.1
	Alnus glutinosa	20.00	1.50
	Alnus incana ssp. rugosa	74.80	6.40
	Betula	<0.1	<0.1
	Betula papyrifera	0.20	<0.1
	Berberis	12.60	0.90
	Carya cordiformis	15.70	1.00
	Carya glabra	7.40	0.10
	Carya x ludoviciana	0.10	<0.1
	Cornus	7.10	0.40
	Cornus alternifolia	12.40	0.80
	Cornus florida	33.00	1.90
	Corylopsis spicata	1.10	0.10
	Cornus sericea	514.90	29.50
	Crataegus	14.50	0.50
	Crataegus pedicellata	16.20	1.20
	Crataegus flabellata	1.70	0.10
	Elaeagnus	141.80	10.60
	Elaeagnus angustifolia	6.00	0.40
	Euonymus alatus	1.40	0.10
	Euonymus	25.10	1.90
	Fagus grandifolia	29.60	1.30
	Forsythia	1.00	0.10

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Fraxinus	1.20	0.10
	Fraxinus americana	43.30	2.50
	Fraxinus pennsylvanica	44.10	2.90
	Hamamelis virginiana	2.40	0.10
	Juglans nigra	10.70	0.90
	Juniperus virginiana	147.40	41.00
	Larix laricina	1.10	0.10
	Lonicera	96.90	4.80
	Lonicera tatarica	58.60	2.90
	Magnolia	0.90	0.10
	Malus	7.30	0.60
	Nerium oleander	3.90	0.60
	Ostrya virginiana	20.70	1.40
	Pinus	15.40	1.50
	Picramnia glazioviana	8.00	0.60
	Picea glauca	2.60	0.40
	Pinus strobus	1.80	0.10
	Pinus sylvestris	44.20	4.30
	Populus alba	0.10	<0.1
	Populus grandidentata	39.90	2.00
	Populus tremuloides	6.60	0.50
	Prunus	0.10	<0.1
	Prunus serotina	17.80	1.40
	Prunus virginiana	185.80	14.40

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Malus coronaria	1.50	0.10
	Quercus macrocarpa	2.80	0.30
	Quercus palustris	0.60	0.10
	Quercus rubra	3.00	0.20
	Rhamnus cathartica	435.70	19.40
	Rhus	0.90	0.10
	Rhus hirta	3.10	0.30
	Ribes rubrum	13.00	1.00
	Ribes	1.90	0.10
	Rosa	2.60	0.20
	Rosa multiflora	0.30	<0.1
	Robinia pseudoacacia	1.40	0.10
	Rubus idaeus	21.00	0.80
	Rubus macrophyllus	0.10	<0.1
	Salix	20.80	1.30
	Salix alba	19.70	1.20
	Salix x sepulcralis Simonkai	1.50	0.10
	Salix cinerea	26.40	1.70
	Sorbus aucuparia	1.00	0.10
	Syringa	2.80	0.30
	Taxus	75.10	11.80
	Thuja occidentalis	29.20	5.60
	Tilia americana	37.10	1.10

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Toxicodendron radicans	0.10	<0.1
	Ulmus americana	5.50	0.40
	Ulmus rubra	<0.1	<0.1
	Ulmus	<0.1	<0.1
	Viburnum acerifolium	5.00	0.40
	Viburnum lentago	8.20	0.60
	Viburnum opulus	5.20	0.40
	Total	**2477.90**	**193.20**
Open Space 2	Acer x freemanii	5.20	0.30
	Acer negundo	16.20	1.50
	Acer platanoides	1.10	0.10
	Acer saccharinum	13.30	0.70
	Acer saccharum	5.50	0.30
	Betula	0.90	0.10
	Buxus sempervirens	16.80	1.30
	Cornus	1.70	0.10
	Cornus alternifolia	7.80	0.50
	Cornus sericea	306.10	17.50
	Elaeagnus	31.00	2.30
	Euonymus alatus	123.50	9.20
	Euonymus alata	0.70	0.10
	Euonymus	5.50	0.40
	Forsythia	5.30	0.40
	Frangula	0.10	<0.1

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Fraxinus americana	0.10	<0.1
	Fraxinus pennsylvanica	5.80	0.40
	Hamamelis virginiana	2.00	0.10
	Hibiscus syriacus	123.40	6.00
	Juniperus	156.30	43.40
	Juglans nigra	1.00	0.10
	Juniperus virginiana	22.40	6.20
	Ligustrum	15.10	1.40
	Lonicera	33.60	1.70
	Lonicera tatarica	26.70	1.30
	Malus sylvestris	4.30	0.40
	Morus	114.90	9.70
	Picea glauca	195.20	31.40
	Pinus strobus	208.50	13.40
	Prunus	28.10	2.20
	Prunus serotina	8.40	0.70
	Prunus virginiana	27.80	2.20
	Quercus macrocarpa	9.80	1.00
	Rhamnus cathartica	181.70	8.10
	Rhus hirta	101.70	9.70
	Ribes rubrum	0.30	<0.1
	Ribes	<0.1	<0.1
	Rosa	0.10	<0.1
	Rubus idaeus	21.50	0.80

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Rubus occidentalis	20.80	0.80
	Rubus odoratus	57.10	2.10
	Salix	2.30	0.10
	Sambucus nigra	8.50	0.60
	Sorbus aucuparia	0.20	<0.1
	Sorbaria sorbifolia	2.70	0.20
	Spiraea japonica	1.90	0.10
	Spiraea x vanhouttei	11.50	0.90
	Syringa	27.00	2.60
	Syringa vulgaris	1.50	0.10
	Thuja occidentalis	23.40	4.50
	Tilia americana	38.80	1.10
	Ulmus americana	0.40	<0.1
	Ulmus pumila	0.50	<0.1
	Viburnum lentago	1.10	0.10
	Total	**2027.50**	**188.10**
Multi-family Residential	Acer x freemanii	0.40	<0.1
	Acer negundo	31.30	2.90
	Acer platanoides	37.40	2.00
	Acer rubrum	0.10	<0.1
	Acer tataricum	<0.1	<0.1
	Ailanthus altissima	0.50	<0.1
	Berberis	0.30	<0.1

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Berberis thunbergii	6.10	0.50
	Cornus	2.40	0.10
	Cotoneaster buxifolius	31.90	2.40
	Cornus florida	5.40	0.30
	Cotoneaster horizontalis	0.30	<0.1
	Crataegus	21.20	0.80
	Dasiphora	0.90	0.10
	Elaeagnus angustifolia	4.60	0.30
	Euonymus alatus	3.90	0.30
	Euonymus fortunei	94.30	7.10
	Euonymus	6.70	0.50
	Forsythia x intermedia	23.30	1.70
	Hibiscus syriacus	175.10	8.50
	Hydrangea	34.20	2.60
	Ilex	16.10	2.10
	Juniperus	170.20	47.30
	Ligustrum	12.40	1.10
	Lonicera	163.60	8.10
	Philadelphus	123.40	9.20
	Pinus	0.90	0.10
	Picramnia glazioviana	8.90	0.70
	Picea pungens	167.30	28.40
	Populus deltoides	6.00	0.40
	Prunus	300.20	23.20

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Prunus x cistena	1.00	0.10
	Rhamnus cathartica	128.00	5.70
	Rosa	158.60	11.90
	Rosa canina	2.00	0.10
	Rosa multiflora	17.30	1.30
	Rubus occidentalis	10.20	0.40
	Sambucus	9.30	0.70
	Salix matsudana	4.90	0.30
	Sambucus nigra	51.90	3.90
	Schaefferia frutescens	6.10	0.50
	Sorbus aucuparia	3.30	0.30
	Spiraea japonica	24.10	1.80
	Spiraea	0.20	<0.1
	Spiraea x vanhouttei	8.00	0.60
	Syringa	74.60	7.20
	Syringa vulgaris	32.50	3.10
	Taxus	48.60	7.60
	Taxus canadensis	159.50	25.00
	Thuja occidentalis	125.70	24.20
	Tilia cordata	0.30	<0.1
	Ulmus americana	0.10	<0.1
	Ulmus pumila	1.60	0.10
	Ulmus	0.40	<0.1
	Weigela florida	1.50	0.10

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Total	**2319.10**	**245.60**
Single Family Residential	Acer	<0.1	<0.1
	Acer campestre	0.10	<0.1
	Acer x freemanii	11.50	0.60
	Acer negundo	15.10	1.40
	Acer palmatum	39.60	2.20
	Acer palmatum 'Dissectum'	2.20	0.10
	Acer platanoides	23.60	1.30
	Acer platanoides 'Crimson King'	0.10	<0.1
	Acer rubrum	1.00	0.10
	Acer saccharinum	1.20	0.10
	Acer saccharum	6.40	0.40
	Aesculus glabra	2.90	0.20
	Aesculus hippocastanum	0.40	<0.1
	Ailanthus altissima	5.10	0.40
	Amelanchier	1.80	0.10
	Amelanchier canadensis	0.20	<0.1
	Berberis	47.60	3.60
	Berberis thunbergii	9.70	0.70
	Bursaria incana	1.20	0.10
	Buddleja	9.40	0.70
	Buxus sempervirens	26.40	2.00
	Buxus	64.40	4.80

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Catalpa	0.10	<0.1
	Carya cordiformis	2.30	0.10
	Catalpa speciosa	2.70	0.20
	Cercis	0.40	<0.1
	Cedrus	21.80	3.40
	Cercis canadensis	0.20	<0.1
	Celtis occidentalis	0.10	<0.1
	Chamaecyparis	5.50	1.40
	Chaenomeles	20.00	1.50
	Chaenomeles japonica	4.80	0.40
	Clethra alnifolia	0.10	<0.1
	Cornus	28.80	1.70
	Corylus	0.70	0.10
	Cotoneaster	<0.1	<0.1
	Cornus alternifolia	1.50	0.10
	Cornus alba	22.00	1.30
	Cornus florida	24.30	1.40
	Cotoneaster horizontalis	0.80	0.10
	Cornus sanguinea	6.20	0.40
	Cornus sericea	13.50	0.80
	Crataegus	2.40	0.10
	Crataegus crus-galli	0.50	<0.1
	Cupressus	11.60	1.80
	Deutzia	3.50	0.30

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Duranta erecta	17.30	1.30
	Elaeagnus commutata	0.60	<0.1
	Euonymus alatus	39.70	3.00
	Euonymus alata	8.80	0.70
	Euonymus europaea	7.70	0.60
	Euonymus fortunei	117.80	8.80
	Euonymus	58.80	4.40
	Fagus grandifolia	34.30	1.50
	Fagus sylvatica 'Purpurea'	13.90	0.70
	Forsythia x intermedia	65.00	4.90
	Forsythia	4.70	0.40
	Fraxinus	0.90	0.10
	Fraxinus americana	5.80	0.30
	Fraxinus excelsior	0.10	<0.1
	Fraxinus pennsylvanica	11.10	0.70
	Gleditsia triacanthos	0.50	0.10
	Hamamelis virginiana	39.40	2.30
	Hibiscus rosa-sinensis	0.40	<0.1
	Hibiscus	0.20	<0.1
	Hibiscus syriacus	122.00	5.90
	Hypericum	2.00	0.10
	Hydrangea arborescens	3.00	0.20
	Hypericum densiflorum	0.10	<0.1
	Hydrangea paniculata	5.60	0.40

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Hydrangea	45.40	3.40
	Ilex altaclarensis	1.60	0.20
	Ilex aquifolium	0.90	0.10
	Ilex	3.40	0.50
	Juniperus	88.30	24.50
	Juniperus chinensis	46.80	13.00
	Juniperus communis	12.60	3.50
	Juglans nigra	7.30	0.60
	Juniperus virginiana	13.30	3.70
	Kerria japonica	4.60	0.30
	Lavandula	0.40	<0.1
	Ligustrum	98.90	9.00
	Ligustrum vulgare	19.80	1.80
	Lonicera japonica	7.20	0.40
	Lonicera	162.10	8.00
	Lonicera tatarica	26.40	1.30
	Lycium chinense	0.60	<0.1
	Magnolia	4.10	0.30
	Malus	5.20	0.40
	Malus domestica	0.70	0.10
	Mahonia haematocarpa	0.40	<0.1
	Malus sylvestris	0.40	<0.1
	Malus tschonoskii	8.20	0.70
	Morus	44.60	3.80

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Morus alba	8.10	0.60
	Morus nigra	0.40	<0.1
	Morus rubra	0.60	0.10
	Ostrya virginiana	<0.1	<0.1
	Physocarpus	25.20	1.90
	Philadelphus coronarius	19.80	1.50
	Physocarpus opulifolius	10.30	0.80
	Philadelphus oreganus	3.90	0.30
	Philadelphus	12.00	0.90
	Photinia	0.30	<0.1
	Picea	24.70	4.20
	Pinus	6.00	0.60
	Picramnia glazioviana	8.40	0.60
	Picea glauca	64.70	10.40
	Pinus mugo	3.60	0.30
	Picea pungens	18.70	3.20
	Pinus resinosa	0.20	<0.1
	Pinus sylvestris	3.70	0.40
	Dasiphora floribunda	0.80	0.10
	Potentilla fruiticosa	2.20	0.20
	Prunus	98.50	7.60
	Prunus armeniaca	0.30	<0.1
	Prunus avium	0.70	0.10
	Prunus x cistena	10.00	0.80

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Prunus x orthosepala	0.10	<0.1
	Prunus padus	0.10	<0.1
	Prunus serotina	30.10	2.30
	Prunus virginiana	26.90	2.10
	Pyrus	1.40	0.10
	Quercus	0.10	<0.1
	Quercus alba	<0.1	<0.1
	Quercus x macnabiana	<0.1	<0.1
	Quercus rubra	0.30	<0.1
	Rhus aromatica	1.20	0.10
	Rhamnus cathartica	79.40	3.50
	Rhododendron	5.80	1.20
	Rhamnus	0.30	<0.1
	Rhus hirta	3.30	0.30
	Ribes rubrum	16.90	1.30
	Ribes	30.60	2.30
	Ribes uva-crispa	1.90	0.10
	Rosa	92.00	6.90
	Rosa canina	0.10	<0.1
	Rosa gallica	2.70	0.20
	Rosa multiflora	0.90	0.10
	Robinia pseudoacacia	0.20	<0.1
	Rubus	9.50	0.40
	Rubus idaeus	9.50	0.40

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Rubus occidentalis	23.90	0.90
	Rubus odoratus	0.10	<0.1
	Salix	2.80	0.20
	Sambucus nigra	0.40	<0.1
	Sorbus	4.90	0.40
	Sorbus americana	0.60	<0.1
	Sorbus aucuparia	0.80	0.10
	Sorbaria sorbifolia	2.00	0.20
	Spiraea douglasii	<0.1	<0.1
	Spiraea japonica	25.60	1.90
	Spiraea	12.50	0.90
	Spiraea x subcanescens	1.60	0.10
	Spiraea x vanhouttei	48.40	3.60
	Symphoricarpos albus	1.70	0.10
	Syringa	31.60	3.10
	Syringa vulgaris	16.90	1.60
	Taxus	140.00	21.90
	Taxus baccata	5.30	0.80
	Taxus canadensis	152.40	23.90
	Tabebuia	27.50	2.10
	Thuja	18.50	3.60
	Thuja occidentalis	510.30	98.10
	Tilia	3.50	0.20
	Tilia americana	38.80	1.10

Stratum	Species	Leaf Area (m²/ha)	Leaf Biomass (kg/ha)
	Tilia cordata	2.20	0.20
	Ulmus americana	1.10	0.10
	Ulmus glabra	<0.1	<0.1
	Ulmus pumila	2.70	0.20
	Ulmus rubra	1.00	<0.1
	Ulmus	0.30	<0.1
	Vaccinium	0.90	0.10
	Viburnum acerifolium	0.10	<0.1
	Viburnum lantana	<0.1	<0.1
	Viburnum lentago	2.40	0.20
	Viburnum opulus	8.30	0.60
	Viburnum	10.60	0.80
	Weigela	43.60	3.30
	Weigela florida	0.30	<0.1
	Total	**3386.60**	**371.80**
Study Area	**TOTAL**	**2467.50**	**253.30**

Supplement C: Annual Tree Mortality Rates

A re-assessment of 392 urban forest research plots after a 10-year period provides the City of Toronto with a unique opportunity to understand how their urban forest has changed.[63] Moreover, research of this nature is rare and affords new insight into urban ecological change in Canadian cities in general.

Toronto's annual tree mortality rate during the 2008-2018 period was 3.3%, which is comparable to other medium-to-large American cities (Nowak et al., 2004; Roman & Scatena, 2011). A similar pattern can be seen at the land-use level, with lower mortality rates in parks and open space and higher mortality rates in higher-density residential and industrial land uses. The mortality rate in the single-family residential land use was comparable to the city average, given that it is the most extensive land use, while mortality rates in commercial, utility, and transportation land uses were lower than might be expected. Institutional land uses had the lowest mortality rate in the city, though the sample size is small and the low rate was explained by the death of just one tree. Mortality rates increased with declining tree condition, while both smaller and larger trees (i.e., younger and older) had higher mortality rates than medium sized/aged trees. Nevertheless, tree establishment rates in the smallest DBH classes were so high that the population of small trees grew since 2008. Tree species with the highest mortality rates included invasive, in-grown trees that frequent unmanaged spaces (e.g., tree of heaven (*Ailanthus altissima*), Siberian elm (*Ulmus pumila*)) and early-successional species common in parks and open spaces (e.g., choke cherry (*Prunus virginiana*), aspen (*Populus* spp.)). Ash species had notably high mortality at 8.3% due to the emerald ash borer.

Tree establishment rates are measured by the number of new stems (i.e., trees) per hectare, and are comprised of both planted trees and in-grown trees that have germinated from seed. Urban forest establishment rates are under-reported in the literature, though the rates tend to range from 1 to 12 stems/ha (Steenberg et al., 2017). Toronto's overall establishment rate was somewhat higher at 10 stems/ha, ranging from 29 stems/ha in parks and TRCA lands (Open Space 1 land use) to 8 stems/ha in multi-family residential land use. With regards to species-specific establishment, some of the dominant species in 2008 were also common establishment species in 2018, including white cedar, sugar maple, Norway maple, and Manitoba maple (*Acer negundo*). Some species showed a noted increase in 2018, such as common buckhorn, while others showed a decline, such as ash species and ironwood (*Ostrya virginiana*).

[63] A total of 392 plots were assessed for mortality and growth rates. Fifteen of the original 407 i-Tree plots were inaccessible and 2018, and were replaced by new plots. Since the new plots had not been included in the 2008 study, it was not possible to calculate mortality and growth rates for those plots.

Tree diameter growth rates were variable by species and land use, with an overall city average growth rate of 0.46 cm/yr. However, it should be noted that assessing diameter growth rates over multiple time periods is subject to high rates of variability and measurement error. Slight changes in the angle and height of measuring tapes can outweigh actual growth rates. Consequently, the growth results should be observed with caution. Lastly, street trees represent a small but very important urban tree sub-population because they span the entire city, are directly managed by the municipal government, and deliver a high level of benefits for Torontonians compared to trees in other locations. However, street trees also face higher levels of stress than other trees and saw a much higher annual mortality rate at 10.1%.

Annual Tree Mortality Rates

Table 30: Annual mortality rates for trees by land use (Source: 2008 and 2018 i-Tree Eco data).

Land Use	Living 2018	Living 2008	Mortality
Commercial	22	30	3.053945
Industrial	48	83	5.329142
Institutional	13	14	0.73834
Open Space1	570	768	2.937524
Open Space2	116	153	2.730506
Multifamily Residential	50	91	5.812589
Single Family Residential	793	1123	3.419524
Utilities & Transportation	50	71	3.445801
City	1662	2333	3.334472

Table 31: Annual mortality rates for trees 30-60 cm DBH, by land use (Source: 2008 and 2018 i-Tree Eco plot data).

Land Use	Living 2018	Living 2008	Mortality
Commercial	4	9	7.789209
Industrial	2	4	6.696701
Institutional	4	5	2.206723
Open Space1	29	50	5.301566
Open Space2	22	29	2.724725
Multifamily Residential	13	19	3.723792
Single Family Residential	78	138	5.54574
Utilities & Transportation	0	2	100
City	152	256	5.079425

Table 32: Annual mortality rates for trees 60 cm +, by land use (Source: 2008 and 2018 i-Tree Eco plot data).

Land Use	Living 2018	Living 2008	Mortality
Commercial	0	0	0
Industrial	1	1	0
Institutional	1	2	6.696701
Open Space1	3	6	6.696701
Open Space2	1	3	10.40415
Multifamily Residential	3	4	2.835834
Single Family Residential	18	29	4.657299
Utilities & Transportation	0	0	0
City	27	45	4.979978

Table 33: Annual mortality rates for ash trees (*Fraxinus* spp.) by land use (Source: 2008 and 2018 i-Tree Eco plot data).

Land Use	Living 2018	Living 2008	Mortality
Commercial	0	1	100
Industrial	15	31	7.00214
Institutional	0	0	0
Open Space1	44	105	8.330189
Open Space2	0	9	100

Land Use	Living 2018	Living 2008	Mortality
Multifamily Residential	6	12	6.696701
Single Family Residential	6	30	14.86601
Utilities & Transportation	16	18	1.170921
City	87	206	8.258634

Table 34: Annual mortality rates for trees, by DBH class (cm) (Source: 2008 and 2018 i-Tree Eco data).

DBH Class (cm)	Living 2018	Living 2008	Mortality
0.0 to 7.6	50	77	4.225933
7.7 to 15.2	545	772	3.422064
15.3 to 22.9	323	476	3.803437
23.0 to 30.5	136	198	3.686454
30.6 to 38.1	68	84	2.090922
38.2 to 45.7	80	107	2.866146
45.8 to 53.3	70	97	3.209523
53.4 to 61.0	92	112	1.947882
61.1 to 68.6	51	62	1.934138
68.7 to 76.2	39	51	2.646977
76.3 to 83.8	32	49	4.171346
83.9 to 91.4	25	38	4.100655
Greater than 91.5	151	210	3.244477
All	1662	2333	3.334472

References

Nowak, D. J., Kuroda, M., & Crane, D. E. (2004). Tree mortality rates and tree population projections in Baltimore, Maryland, USA. *Urban Forestry & Urban Greening, 2*, 139-147.

Roman, L. A., & Scatena, F. N. (2011). Street tree survival rates: Meta-analysis of previous studies and application to a field survey in Philadelphia, PA, USA. *Urban Forestry & Urban Greening, 10*, 269-274.

Steenberg, J. W. N., Millward, A. A., Nowak, D. J., Robinson, P. J., & Ellis, A. (2017). Forecasting urban forest ecosystem structure, function, and vulnerability. *Environmental Management, 59*, 373-392.

Appendix C: Summary of Tree Cover Change and Possible Planting Area (PPA) by Neighbourhood

Table 35: Summary of tree cover change (2008-2018) and possible planting area as percent and area in hectares (2018). (Source: 2008 and 2018 Land Cover data, City of Toronto)

Neighbourhood	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	*Pervious PPA (%)	*Pervious PPA (ha)	**Impervious PPA (%)	**Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
Agincourt North (129)	17	17	0.1	726.28	25	180.28	30	215.95	55	396.2
Agincourt South-Malvern West (128)	18	18	0.3	787.42	25	196.15	27	212.01	52	408.2
Alderwood (20)	22	21	-0.8	497.98	20	99.61	27	133.35	47	233.0
Annex (95)	28	28	-0.5	279.09	7	19.43	22	62.52	29	82.0
Banbury-Don Mills (42)	42	35	-7.6	1004.32	20	201.38	20	202.47	40	403.8
Bathurst Manor (34)	38	33	-4.8	476.14	25	119.17	16	76.89	41	196.1
Bay Street Corridor (76)	8	9	1.6	180.97	6	10.33	28	49.82	33	60.1
Bayview Village (52)	46	41	-5.6	516.00	17	88.27	17	86.09	34	174.4
Bayview Woods-Steeles (49)	46	41	-4.3	408.97	20	80.18	14	57.01	34	137.2
Bedford Park-Nortown (39)	42	34	-8.6	551.93	16	87.43	19	104.74	35	192.2
Beechborough-Greenbrook (112)	26	21	-4.5	183.40	19	34.25	33	61.22	52	95.5

Neighbourhood	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	*Pervious PPA (%)	*Pervious PPA (ha)	**Impervious PPA (%)	**Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
Bendale (127)	24	25	1.2	745.74	23	171.83	20	152.51	43	324.3
Birchcliffe-Cliffside (122)	34	36	2.0	600.97	22	132.79	18	108.41	40	241.2
Black Creek (24)	21	15	-6.8	345.47	30	103.18	24	83.07	54	186.3
Blake-Jones (69)	26	26	-0.2	94.13	12	11.50	28	26.78	41	38.3
Briar Hill-Belgravia (108)	9	10	1.0	183.07	16	29.73	33	60.42	49	90.2
Bridle Path-Sunnybrook-York Mills (41)	62	54	-7.5	883.98	19	164.98	12	103.10	30	268.1
Broadview North (57)	38	39	1.1	174.63	18	32.21	15	26.27	33	58.5
Brookhaven-Amesbury (30)	24	20	-4.1	350.82	23	79.16	28	97.57	50	176.7
Cabbagetown-South St.James Town (71)	44	45	1.0	141.82	11	16.19	14	20.41	26	36.6
Caledonia-Fairbank (109)	21	22	1.2	154.48	19	29.79	24	36.67	43	66.5
Casa Loma (96)	46	42	-4.5	192.29	9	17.87	19	36.86	28	54.7
Centennial Scarborough (133)	33	36	3.1	546.89	26	142.08	14	74.56	40	216.6
Church-Yonge Corridor (75)	9	11	2.4	136.48	5	6.22	29	39.59	34	45.8
Clairlea-Birchmount (120)	17	17	-0.8	739.83	23	167.99	30	224.49	53	392.5

Neighbourhood	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	*Pervious PPA (%)	*Pervious PPA (ha)	**Impervious PPA (%)	**Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
Clanton Park (33)	25	19	-6.0	414.33	26	107.64	24	98.74	50	206.4
Cliffcrest (123)	34	37	2.6	719.22	29	206.52	16	115.28	45	321.8
Corso Italia-Davenport (92)	18	20	2.0	188.51	16	30.14	23	43.69	39	73.8
Danforth (66)	25	24	-1.1	111.98	11	12.08	25	27.59	35	39.7
Danforth East York (59)	19	20	0.8	218.89	15	32.28	27	58.52	41	90.8
Don Valley Village (47)	33	26	-6.7	421.31	24	99.89	21	88.94	45	188.8
Dorset Park (126)	11	11	0.7	601.29	22	132.95	31	185.55	53	318.5
Dovercourt-Wallace Emerson-Junction (93)	11	14	3.0	372.66	14	51.11	26	97.96	40	149.1
Downsview-Roding-CFB (26)	16	12	-4.1	1499.57	39	584.96	25	369.78	64	954.7
Dufferin Grove (83)	18	19	0.9	138.83	15	20.75	25	34.73	40	55.5
East End-Danforth (62)	30	28	-1.2	263.94	12	31.88	25	65.31	37	97.2
Edenbridge-Humber Valley (9)	51	45	-5.9	551.30	22	123.28	13	71.88	35	195.2
Eglinton East (138)	20	22	2.1	322.35	26	84.16	24	78.94	51	163.1
Elms-Old Rexdale (5)	34	30	-3.7	293.19	33	96.42	15	43.34	48	139.8

Neighbourhood	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	*Pervious PPA (%)	*Pervious PPA (ha)	**Impervious PPA (%)	**Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
Englemount-Lawrence (32)	27	22	-4.4	347.89	25	87.47	20	71.01	46	158.5
Eringate-Centennial-West Deane (11)	27	24	-3.7	864.79	34	293.38	14	120.86	48	414.2
Etobicoke West Mall (13)	25	21	-3.8	179.71	26	47.55	19	34.65	46	82.2
Flemingdon Park (44)	41	37	-3.8	247.37	21	52.53	17	43.16	39	95.7
Forest Hill North (102)	37	36	-1.1	156.94	14	21.45	18	28.71	32	50.2
Forest Hill South (101)	45	41	-4.4	248.05	13	33.06	18	43.94	31	77.0
Glenfield-Jane Heights (25)	23	17	-6.1	515.10	28	144.52	24	124.19	52	268.7
Greenwood-Coxwell (65)	32	29	-2.2	167.54	10	17.58	24	40.81	35	58.4
Guildwood (140)	44	43	-0.9	380.47	23	88.55	14	53.89	37	142.4
Henry Farm (53)	26	20	-6.0	259.37	21	54.62	28	73.32	49	127.9
High Park North (88)	38	32	-6.0	535.93	11	61.54	13	68.70	24	130.2
High Park-Swansea (87)	51	49	-2.6	188.27	11	20.98	23	43.33	34	64.3
Highland Creek (134)	28	29	1.9	524.85	29	152.80	15	78.16	44	231.0
Hillcrest Village (48)	29	25	-4.2	539.66	23	125.66	20	106.23	43	231.9

Neighbourhood	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	*Pervious PPA (%)	*Pervious PPA (ha)	**Impervious PPA (%)	**Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
Humber Heights-Westmount (8)	44	38	-6.6	280.34	22	62.94	17	46.46	39	109.4
Humber Summit (21)	13	11	-1.7	796.90	19	148.42	35	275.10	53	423.5
Humbermede (22)	23	19	-3.3	442.28	24	106.86	25	110.13	49	217.0
Humewood-Cedarvale (106)	37	35	-1.8	187.16	15	27.13	19	34.86	33	62.0
Ionview (125)	21	22	1.0	195.31	23	44.85	22	43.00	45	87.8
Islington-City Centre West (14)	18	17	-1.4	1624.39	18	295.03	33	543.52	52	838.5
Junction Area (90)	18	16	-2.3	263.24	13	33.64	32	84.81	45	118.5
Keelesdale-Eglinton West (110)	21	14	-6.3	175.12	19	32.94	31	55.06	50	88.0
Kennedy Park (124)	23	23	-0.1	358.12	31	109.80	20	73.32	51	183.1
Kensington-Chinatown (78)	12	15	3.1	153.50	7	10.63	26	40.22	33	50.8
Kingsview Village-The Westway (6)	32	26	-6.6	506.47	32	164.39	17	86.27	49	250.7
Kingsway South (15)	53	47	-5.7	263.89	12	32.38	17	44.57	29	76.9
Lambton Baby Point (114)	45	49	4.0	715.60	27	191.88	20	141.45	47	333.3
L'Amoreaux (117)	32	22	-9.6	178.24	13	23.63	14	24.27	27	47.9
Lansing-Westgate (38)	53	46	-7.2	534.73	22	118.49	12	65.46	34	183.9

Neighbourhood	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	*Pervious PPA (%)	*Pervious PPA (ha)	**Impervious PPA (%)	**Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
Lawrence Park North (105)	49	34	-14.9	229.02	12	27.81	20	45.31	32	73.1
Lawrence Park South (103)	56	44	-11.8	324.29	11	36.84	17	54.32	28	91.2
Leaside-Bennington (56)	46	43	-3.1	478.56	16	78.32	16	75.48	32	153.8
Little Portugal (84)	10	14	4.3	121.66	12	15.07	27	33.36	40	48.4
Long Branch (19)	33	31	-1.9	226.25	19	42.12	24	54.50	43	96.6
Malvern (132)	14	20	5.8	886.72	28	249.28	22	193.42	50	442.7
Maple Leaf (29)	32	23	-9.3	252.70	28	69.94	20	51.04	48	121.0
Markland Wood (12)	36	32	-3.4	295.46	26	77.09	16	47.46	42	124.6
Milliken (130)	11	9	-1.6	947.91	26	249.41	32	304.03	58	553.4
Mimico (includes Humber Bay Shores) (17)	15	16	0.5	706.09	21	151.28	31	216.71	52	368.0
Morningside (135)	40	43	2.9	574.07	22	127.16	11	65.06	33	192.2
Moss Park (73)	15	19	3.9	141.33	8	11.56	25	35.52	33	47.1
Mount Dennis (115)	33	30	-2.9	212.99	20	43.11	20	42.51	40	85.6

Neighbourhood	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	*Pervious PPA (%)	*Pervious PPA (ha)	**Impervious PPA (%)	**Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
Mount Olive-Silverstone-Jamestown (2)	29	24	-4.1	463.89	32	148.32	20	93.29	52	241.6
Mount Pleasant East (99)	45	44	-1.6	308.95	14	42.85	16	49.44	30	92.3
Mount Pleasant West (104)	24	22	-2.3	134.36	11	14.81	29	38.35	40	53.2
New Toronto (18)	15	15	-0.2	348.21	26	91.96	31	108.10	57	200.1
Newtonbrook East (50)	38	32	-6.4	408.56	21	83.89	17	71.47	38	155.4
Newtonbrook West (36)	31	25	-6.3	469.67	24	112.76	20	92.79	44	205.6
Niagara (82)	9	12	3.6	324.19	16	50.31	36	115.84	51	166.1
North Riverdale (68)	33	33	-0.3	178.63	15	27.52	18	31.47	33	59.0
North St.James Town (74)	15	16	1.4	42.43	12	4.89	33	14.13	45	19.0
Oakridge (121)	28	31	2.8	487.75	16	78.80	19	92.83	35	171.6
Oakwood Village (107)	15	16	1.5	187.88	20	37.30	22	42.04	42	79.3
O'Connor-Parkview (54)	40	40	-0.6	221.99	15	33.75	27	61.04	43	94.8
Old East York (58)	32	33	0.9	235.03	20	46.15	18	42.78	38	88.9
Palmerston-Little Italy (80)	20	23	2.2	143.55	10	14.68	21	29.59	31	44.3

Neighbourhood	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	*Pervious PPA (%)	*Pervious PPA (ha)	**Impervious PPA (%)	**Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
Parkwoods-Donalda (45)	41	34	-7.1	746.55	25	184.12	16	119.96	41	304.1
Pelmo Park-Humberlea (23)	25	21	-4.1	427.71	31	132.51	19	80.80	50	213.3
Playter Estates-Danforth (67)	35	32	-3.3	88.77	10	8.91	22	19.35	32	28.3
Pleasant View (46)	28	20	-8.0	296.80	27	80.40	20	58.37	47	138.8
Princess-Rosethorn (10)	39	38	-0.8	517.26	23	117.88	13	67.73	36	185.6
Regent Park (72)	19	14	-4.9	65.04	15	9.63	33	21.30	48	30.9
Rexdale-Kipling (4)	30	27	-3.1	250.63	24	59.21	19	48.63	43	107.8
Rockcliffe-Smythe (111)	30	26	-4.4	507.20	28	142.35	21	105.61	49	248.0
Roncesvalles (86)	21	25	3.8	150.48	10	15.30	24	36.64	35	51.9
Rosedale-Moore Park (98)	55	52	-2.6	466.99	9	44.10	13	62.92	23	107.0
Rouge (131)	34	35	1.1	3753.80	37	1406.34	10	369.23	47	1775.6
Runnymede-Bloor West Village (89)	33	31	-2.2	159.43	10	16.53	24	37.61	34	54.1
Rustic (28)	26	18	-7.8	209.69	34	71.20	18	38.62	52	109.8
Scarborough Village (139)	36	38	2.5	315.13	24	75.67	17	52.00	41	127.7
South Parkdale (85)	16	19	3.6	228.75	21	47.34	25	57.97	46	105.3

Neighbourhood	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	*Pervious PPA (%)	*Pervious PPA (ha)	**Impervious PPA (%)	**Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
South Riverdale (70)	14	16	1.6	1096.63	25	276.77	29	312.76	54	589.5
St.Andrew-Windfields (40)	43	37	-6.1	730.09	18	130.37	18	133.75	36	264.1
Steeles (116)	22	16	-6.5	456.21	27	121.98	21	97.73	48	219.7
Stonegate-Queensway (16)	32	34	2.3	794.81	20	154.97	19	149.47	38	304.4
Tam O'Shanter-Sullivan (118)	32	24	-7.6	542.31	29	155.50	20	106.09	48	261.6
Taylor-Massey (61)	34	35	1.1	106.31	15	16.21	23	24.66	38	40.9
The Beaches (63)	39	38	-1.4	359.63	12	41.96	21	76.65	33	118.6
Thistletown-Beaumond Heights (3)	44	40	-4.4	334.04	22	73.55	15	49.25	37	122.8
Thorncliffe Park (55)	24	26	1.9	312.71	16	49.79	31	98.40	47	148.2
Trinity-Bellwoods (81)	14	20	5.8	173.01	12	19.90	21	36.16	32	56.1
University (79)	17	21	3.9	140.55	12	17.01	22	30.97	34	48.0
Victoria Village (43)	32	28	-4.9	475.59	20	95.28	23	111.38	43	206.7
Waterfront Communities-The Island (77)	11	13	2.1	1341.87	13	168.20	19	249.14	31	417.3
West Hill (136)	35	37	2.0	962.63	27	257.27	16	158.01	43	415.3

Neighbourhood	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	*Pervious PPA (%)	*Pervious PPA (ha)	**Impervious PPA (%)	**Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
West Humber-Clairville (1)	10	9	-0.8	3015.40	30	893.94	31	938.84	61	1832.8
Westminster-Branson (35)	38	32	-5.5	366.86	22	81.54	18	67.45	41	149.0
Weston (113)	31	25	-6.9	146.09	16	22.77	31	46.00	47	68.8
Weston-Pellam Park (91)	11	11	0.6	256.62	18	45.84	28	70.70	45	116.5
Wexford/Maryvale (119)	20	15	-4.4	1026.53	23	235.87	27	272.60	50	508.5
Willowdale East (51)	37	29	-8.4	506.20	17	85.07	21	106.45	38	191.5
Willowdale West (37)	39	29	-9.7	288.41	23	65.23	19	54.15	41	119.4
Willowridge-Martingrove-Richview (7)	31	25	-6.0	551.89	29	158.92	17	91.52	45	250.4
Woburn (137)	22	26	3.3	1233.55	27	328.07	19	240.53	46	568.6
Woodbine Corridor (64)	42	38	-3.9	119.64	16	19.67	22	26.24	38	45.9
Woodbine-Lumsden (60)	28	28	-0.3	159.59	12	18.63	20	31.99	32	50.6
Wychwood (94)	27	27	-0.4	168.25	9	15.24	22	37.23	31	52.5
Yonge-Eglinton (100)	36	30	-5.4	165.08	10	16.30	22	36.73	32	53.0
Yonge-St.Clair (97)	37	33	-3.9	116.15	10	11.71	22	25.88	32	37.6

Neighbourhood	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	*Pervious PPA (%)	*Pervious PPA (ha)	**Impervious PPA (%)	**Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
York University Heights (27)	16	13	-2.6	1324.98	24	317.78	31	406.44	55	724.2
Yorkdale-Glen Park (31)	11	9	-2.1	603.97	21	127.85	31	189.98	53	317.8

Appendix D: Tree Cover and Possible Planting Area by Land Use

Table 36: Summary of tree cover and possible planting area by land use (Source: Land Use 2018 (Zoning) and 2018 Automated Land Cover

Land Use	% Tree Cover 2008	% Tree Cover 2018	% Change	Total Land Area (ha)	Pervious PPA (%)	Pervious PPA (ha)	Impervious PPA (%)	Impervious PPA (ha)	Total PPA (%)	Total PPA (ha)
Commercial	6.05	6.71	0.7	3447.69	10	341.14	38	1297.84711	48	1638.98
Industrial	5.72	4.72	-1.0	8948.15	19	1732.86	42	3764.77362	61	5497.63
Institutional	18.40	13.76	-4.6	1352.78	37	502.95	26	347.286135	63	850.24
***No Data**	17.62	10.32	-7.3	3482.75	27	934.13	27	926.574648	53	1860.70
Open Space 1 (Parks / TRCA lands)	56.58	59.82	3.2	7139.62	27	1902.21	5	325.062515	31	2227.28
Open Space 2 (Commercial / Recreation / Agriculture)	33.61	34.05	0.4	4329.18	45	1935.61	8	340.294189	53	2275.90
Other (mainly vacant and marinas)	23.52	32.45	8.9	42.31	30	12.71	28	11.801597	58	24.51
Multifamily Residential	23.87	20.18	-3.7	5575.08	22	1250.54	26	1434.89533	48	2685.44
Single Family Residential	34.89	30.62	-4.3	26574.17	20	5292.45	19	4946.35192	39	10238.80
Utilities & Transportation	16.04	12.69	-3.3	3275.50	28	917.41	14	450.625721	42	1368.04

**2018 Land use (Zoning) Sports fields and Hydro Corridor Parcels were removed from the Total PPA calculations*

Appendix E: Tree Cover and Possible Planting Areas Assessment

Tree Canopy Assessment

The assessment of Toronto's tree cover was carried out in collaboration with the City of Toronto. The analysis included data from 2007 and 2018, and presents the results of an update to the first canopy assessment study, *Every Tree Counts – A Portrait of Toronto's Urban Forest*, published by the City of Toronto in 2009, and later updated in 2013.

Temporal Land Cover Comparison

To spatially analyze tree cover change between 2008 and 2018, a current automated land cover dataset was created by the City of Toronto Geospatial Competency Lab. This dataset provided a continuous land cover surface, broken down into 8 categories: Tree, Grass, Bare Earth, Water, Building, Road, Other (Impervious) and Shrub (see Figure 53).

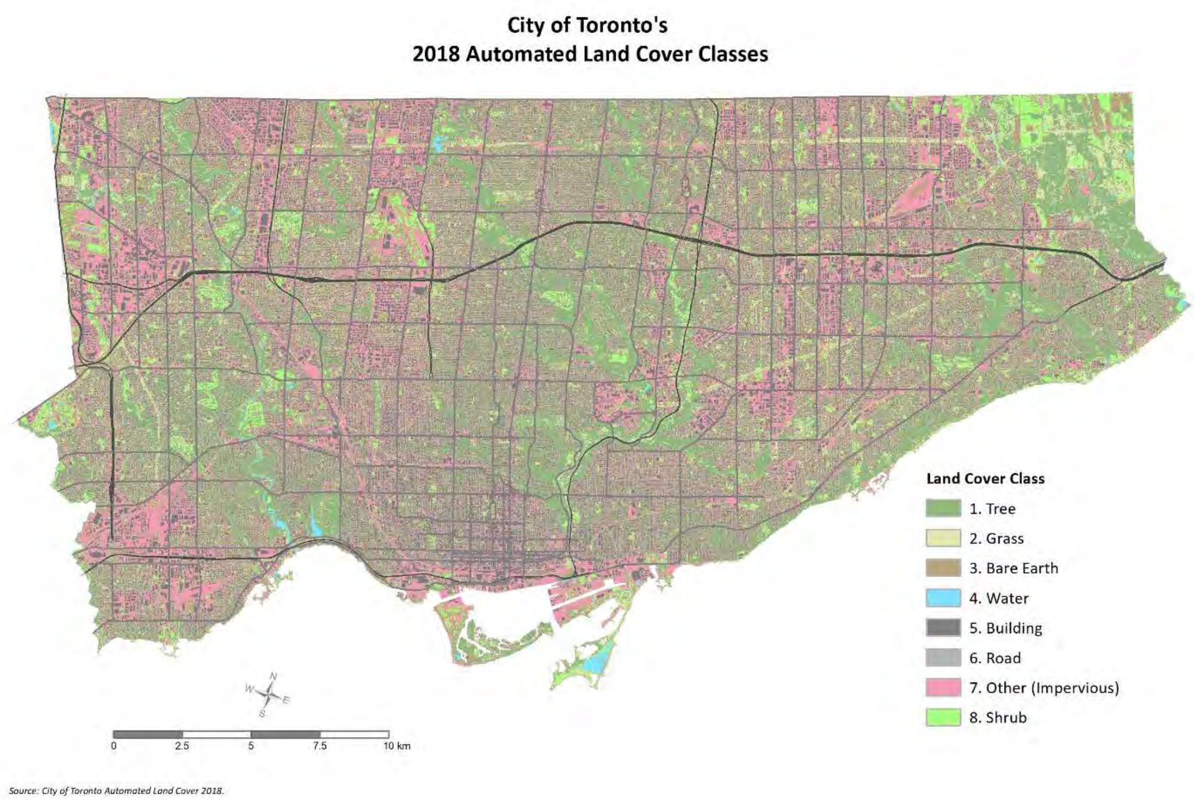


Figure 53: City of Toronto's Automated Land Cover. (Source: City of Toronto 2018 land cover classification)

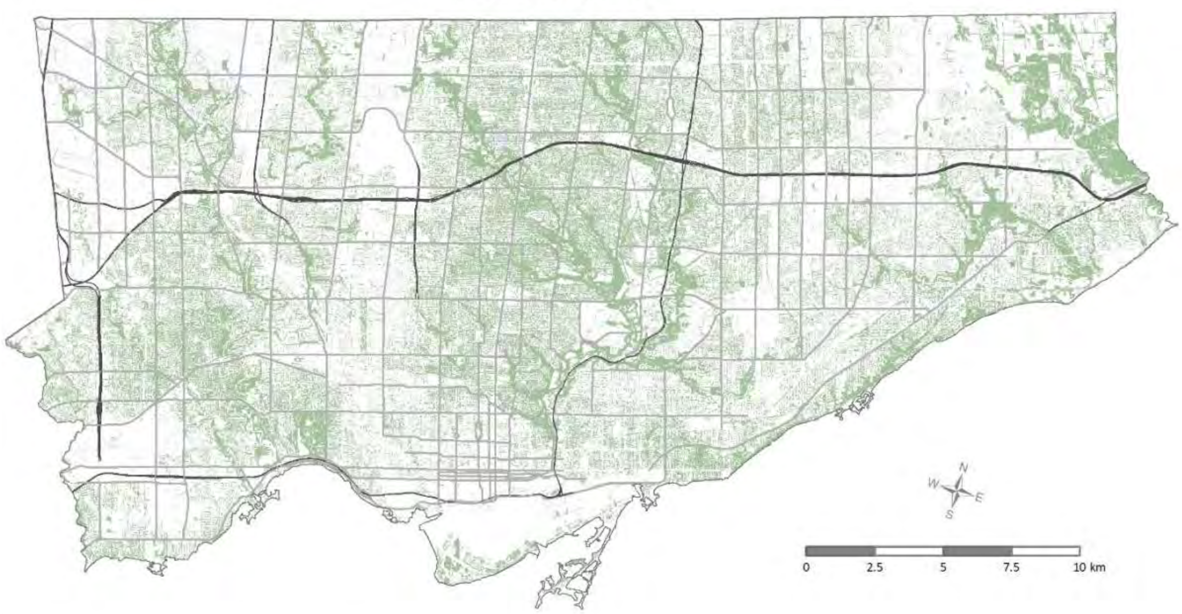
The 2007 Land Cover Classification from the Every Tree Counts – A Portrait of Toronto's Urban forest (2013), created by the University of Vermont's Spatial Analysis Laboratory was used as a baseline to identify change, if any, in the tree cover from 2008 and 2018. The 2007 Land Cover class consisted of Tree Canopy, Grass/Shrub, Bare Earth, Water, Buildings, Roads, Other Paved Surfaces and Agriculture Land cover classes. Both the 2007 and 2018 Land Cover classifications were derived from high resolution satellite imagery. Advanced classification algorithms and processing were applied to produce classified Land Cover datasets. The 2007 Land Cover dataset was subject to a manual quality control, with over 50,000 corrections being made to the classification. The 2018 Automated Land Cover did not complete any post-classification adjustments to the data; rather, it was created through a fully automated process (see the Automated Land Cover Analysis – 2018 Tree Canopy Study Methodology document). The accuracy and completeness of the 2018 Automated Land Cover classification data has not been independently validated by the study team.

Land Cover classification identifying "Tree Canopy" and "Tree" were extracted from both the 2007 and 2018 Land Cover datasets, respectively, to identify the percent of tree cover within the City's boundary. The total amount of tree cover was calculated and divided by the City's Municipal Boundary area to determine the percent tree cover within the city of Toronto. In 2007, the total tree cover was 28%. In 2018 the tree cover decreased by 2% to 26% (see Figure 54). However, when "Tree" and "Shrub" datasets are combined, the total canopy cover increased to 31%.

Tree Cover, 2018

Land Classification	2018 Automated Land Cover (%)	2007 Land Cover (%)	% Change
Tree Cover	26%	28%	-2%

Tree Cover, 2007



Source: 2018 Tree Cover: City of Toronto Automated Land Cover 2018.
2007 Tree Cover: University of Vermont Spatial Analysis Labratory, Toronto 2007 Land Cover.

Figure 54: Tree Cover within Toronto 2018 vs 2008. (Source: City of Toronto 2018 Land Cover classification, 2007 University of Vermont land cover classification).

The 2007 and 2018 Land Cover classification datasets were compared to identify change in pervious versus impervious land cover surface types. Ultimately, the mapping of pervious and impervious surfaces was used to identify and quantify Possible Plantable Areas (PPAs). PPA is a high-level estimate of available planting space, but it does not consider the many possible constraints that can be encountered at the site level. Pervious surfaces that are PPAs included Grass, Shrub, Bare Earth and Agricultural Land Cover classes. Impervious surfaces consisted of Buildings, Roads and Other Land Cover classes. Tree Canopy and Water Land Cover classes were not included in the change detection calculation of areas with pervious and impervious surfaces. The comparison in Land Cover from 2007 to 2018 showed an increase in impervious surfaces of 4% and a decrease of 2% for pervious surfaces (see Figure 55).

Further refinement of the 2018 Land Cover classification dataset involved the removal of sports field and hydro corridor land parcels in acknowledgement that these existing land cover classifications (i.e. recreation and utilities) would preclude the planting of trees now and into the foreseeable future. As a result, when sports fields and hydro corridors were removed from the pervious surfaces aggregated land cover type estimate for 2018, PPA decreased a further 3%, from 25% to 22% (see Figure 56).

Land Cover datasets were processed at the Neighbourhood, Ward and Sub watershed level to identify percent change in tree cover. Geographic Information System (GIS) models were created for each geographic area. Figure 57 below is a graphic representation of the automated 2018 Neighbourhood Land Cover calculation workflow. Calculation models were developed in GIS to automate as well as document the multi-step process for future replication.

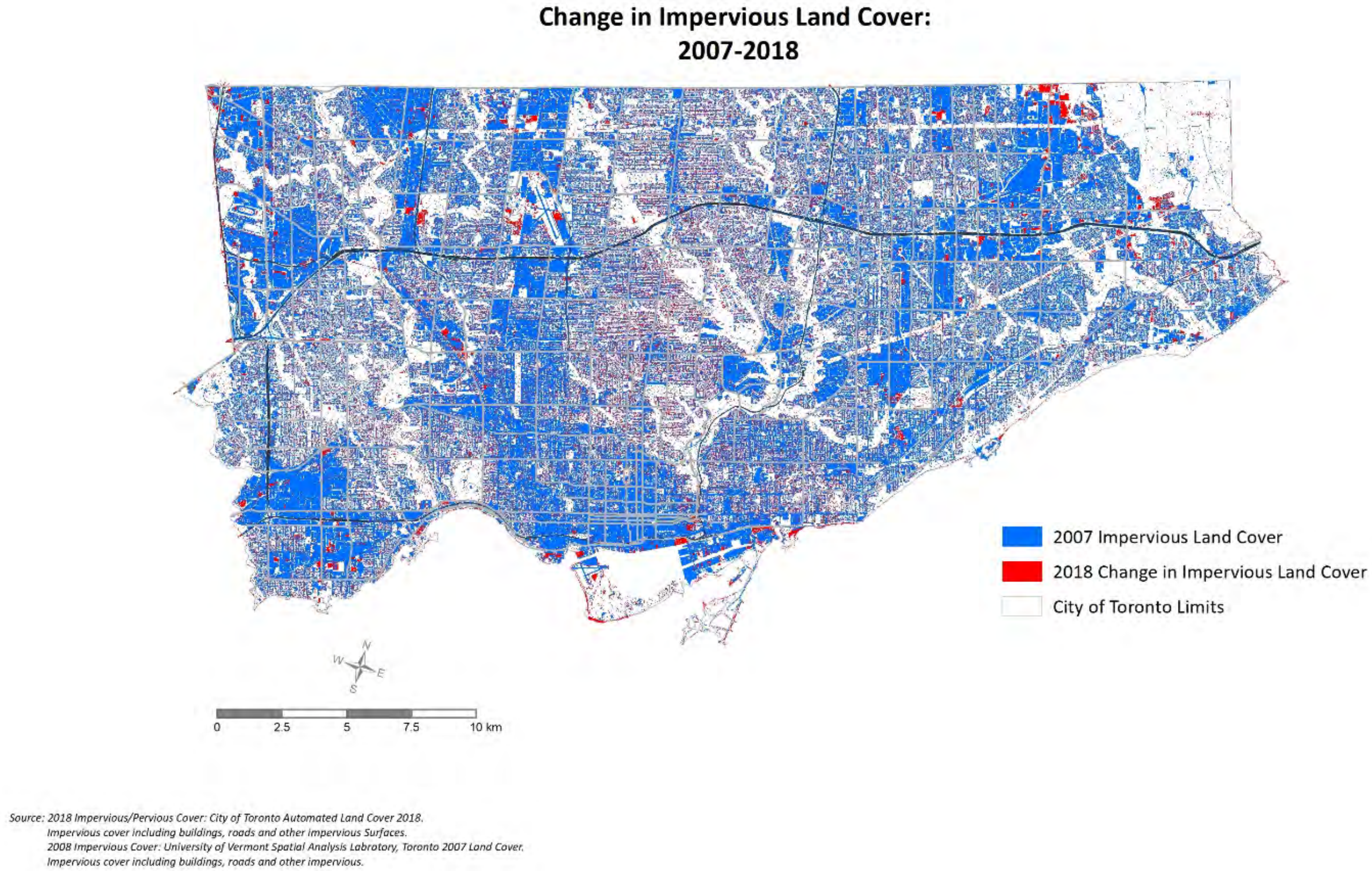


Figure 55: Change in Impervious Land Cover between 2008 and 2018. (Source: City of Toronto 2018 land cover classification, 2007 University of Vermont land cover classification)

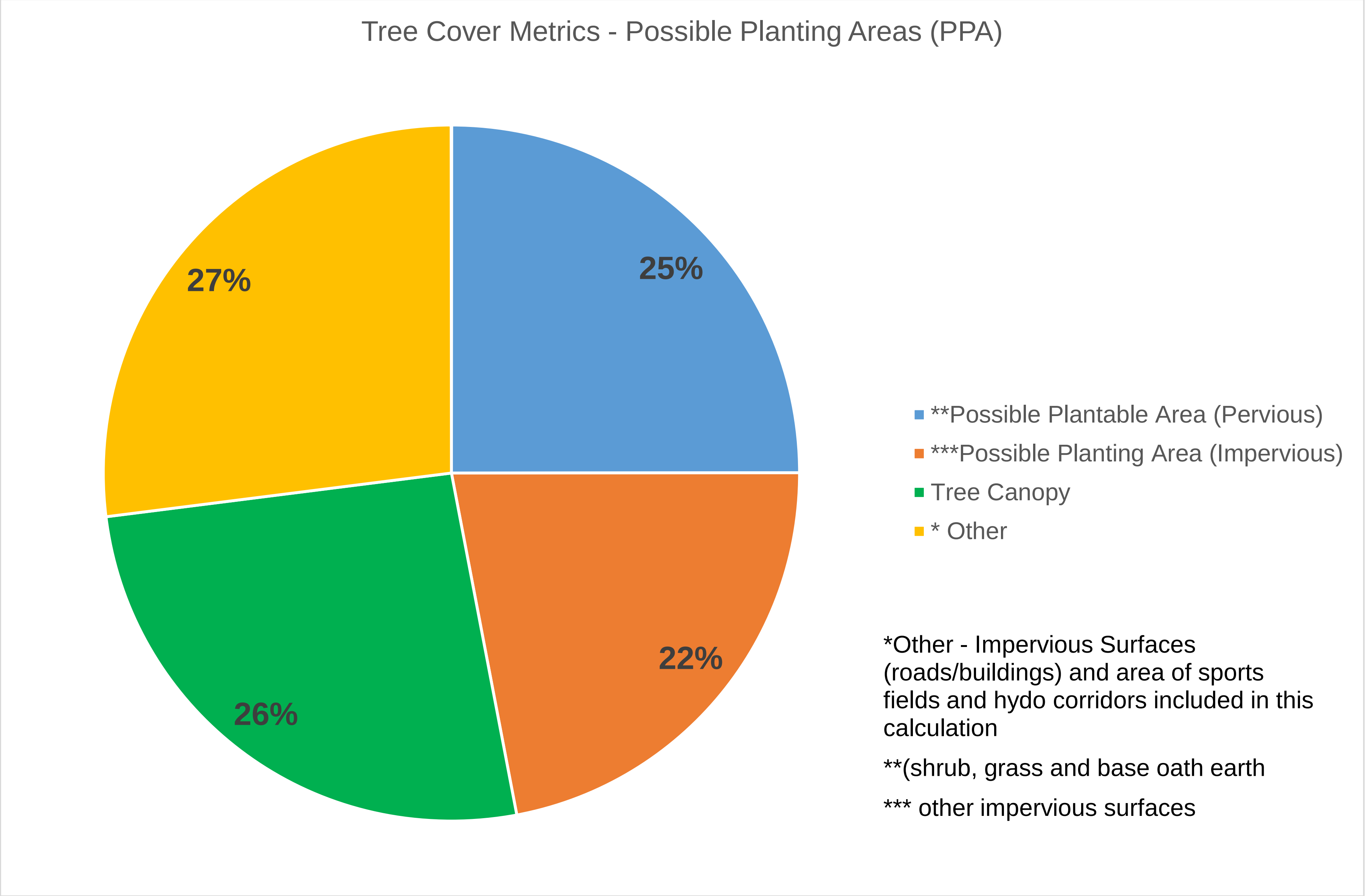

Tree Cover Metrics - Possible Planting Areas (PPA)
25%
22%
26%
27%
**Possible Plantable Area (Pervious)
***Possible Planting Area (Impervious)
Tree Canopy
* Other
*Other - Impervious Surfaces (roads/buildings) and area of sports fields and hydo corridors included in this calculation
**(shrub, grass and base oath earth
*** other impervious surfaces

Figure 56: Tree Cover Metrics – Possible Planting Areas with Sports Fields and Hydro Corridors Removed. (Source: City of Toronto 2018 land cover classification)

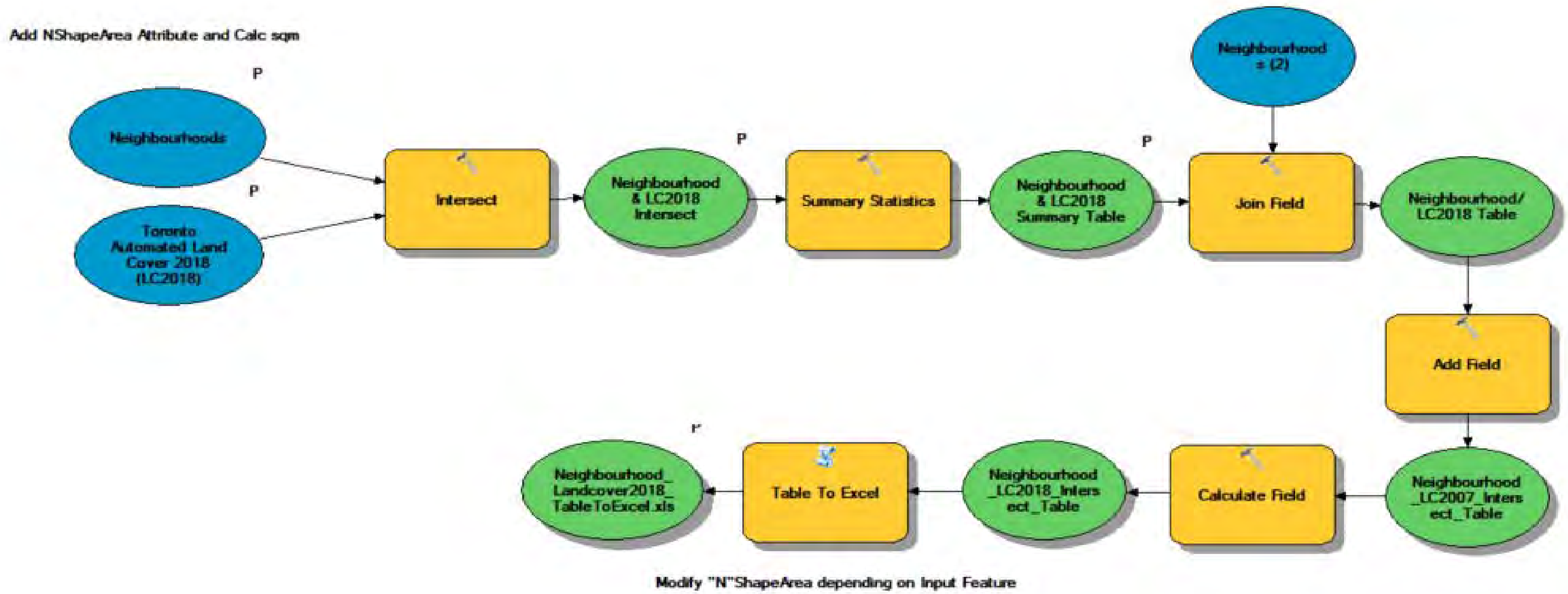


Figure 57: Geographic Information Systems workflow

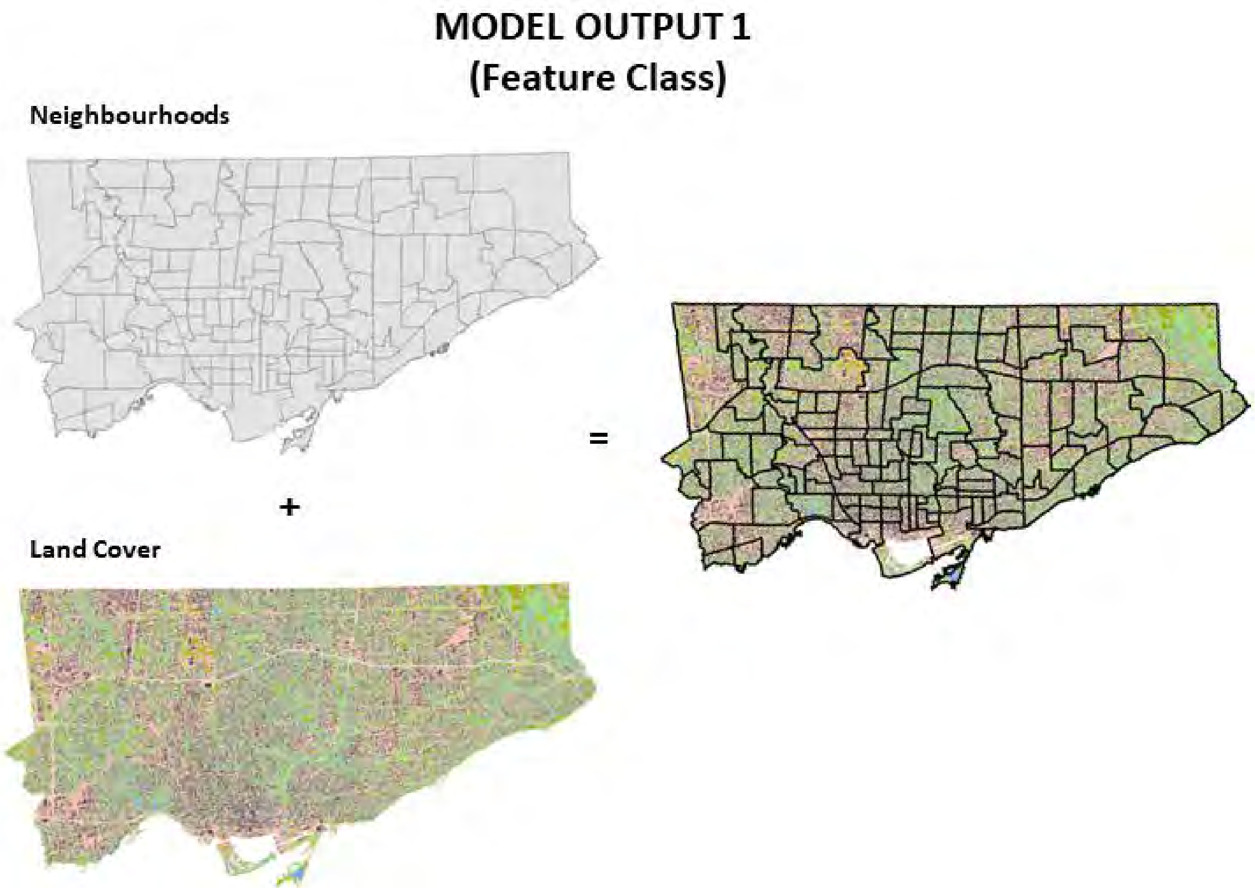


Figure 58: Model Features Classes and Output.

MODEL OUTPUT 2
(Summary Table)

2018 LANDCOVER NAME	NEIGHBOURHOOD NAME	NEIGHBOURHOOD AREA (m²)	TOTAL AREA OF 2018 LANDCOVER WITHIN NEIGHBOURHOOD (m²)	TOTAL PERCENTAGE OF 2018 LANDCOVER WITHIN NEIGHBOURHOOD (%)
Tree	Agincourt North (129)	7262805.226	1263756.957	17.40039719
Grass	Agincourt North (129)	7262805.226	620363.7638	8.541517285
Bare	Agincourt North (129)	7262805.226	1107013.053	15.24222417
Water	Agincourt North (129)	7262805.226	1444.68	0.019891480
Building	Agincourt North (129)	7262805.226	1225827.72	16.87816771
Road	Agincourt North (129)	7262805.226	615303.0333	8.471974866
Other	Agincourt North (129)	7262805.226	2166216.9	29.82617367
Shrub	Agincourt North (129)	7262805.226	262889.1193	3.61966363
Tree	Agincourt South-Malvern West (128)	7874185.228	1429487.208	18.15409781
Grass	Agincourt South-Malvern West (128)	7874185.228	575928.36	7.314132743
Bare	Agincourt South-Malvern West (128)	7874185.228	1175102.851	14.923485
Water	Agincourt South-Malvern West (128)	7874185.228	13524.84	0.171761771
Building	Agincourt South-Malvern West (128)	7874185.228	1494787.32	18.98309037
Road	Agincourt South-Malvern West (128)	7874185.228	633900.6355	10.59001013
Other	Agincourt South-Malvern West (128)	7874185.228	2120940.329	26.93536242
Shrub	Agincourt South-Malvern West (128)	7874185.228	230513.6057	2.927459762
Null	Alderwood (20)	4979780.581	134.4498456	0.002699916
Tree	Alderwood (20)	4979780.581	1056744.331	21.22070068
Grass	Alderwood (20)	4979780.581	333918.2877	6.705481944
Bare	Alderwood (20)	4979780.581	554321.9232	11.13145277
Water	Alderwood (20)	4979780.581	16224.62395	0.325810017
Building	Alderwood (20)	4979780.581	1048806.36	21.06129664
Road	Alderwood (20)	4979780.581	504010.3744	10.12113619
Other	Alderwood (20)	4979780.581	1336379.428	26.83511067
Shrub	Alderwood (20)	4979780.581	129240.8024	2.595311186

Figure 59: Example of Summary Table Output.

Neighbourhood polygon data provided by the City of Toronto was intersected with the 2018 Land Cover (see Figure 58). The intersect tool creates a new feature class that outputs the overlap of Neighbourhoods and Land Cover type codes within the selected Neighbourhood. Statistics were generated to calculate the total area in square metres (sq^m) of each Neighbourhood and the total sum (sq^m) of each Land Cover type within the Toronto Neighbourhoods. A new attribute field was added to calculate the percentage of Land Cover within each Neighbourhood. The final output was a spreadsheet with data summary tables and a feature class of Land Cover Map by Neighbourhood (see Figure 59).

Three (3) Geographic Administrative Areas were selected and run through GIS Models, including: Neighbourhoods, Wards and Sub watersheds. Each of the Geographic Areas were intersected with both the 2007 and 2018 Land Cover datasets. Percent UTC Change from 2007 and 2018 was calculated and mapped for Neighbourhoods, Wards and Sub watersheds (see Figures 60-62).

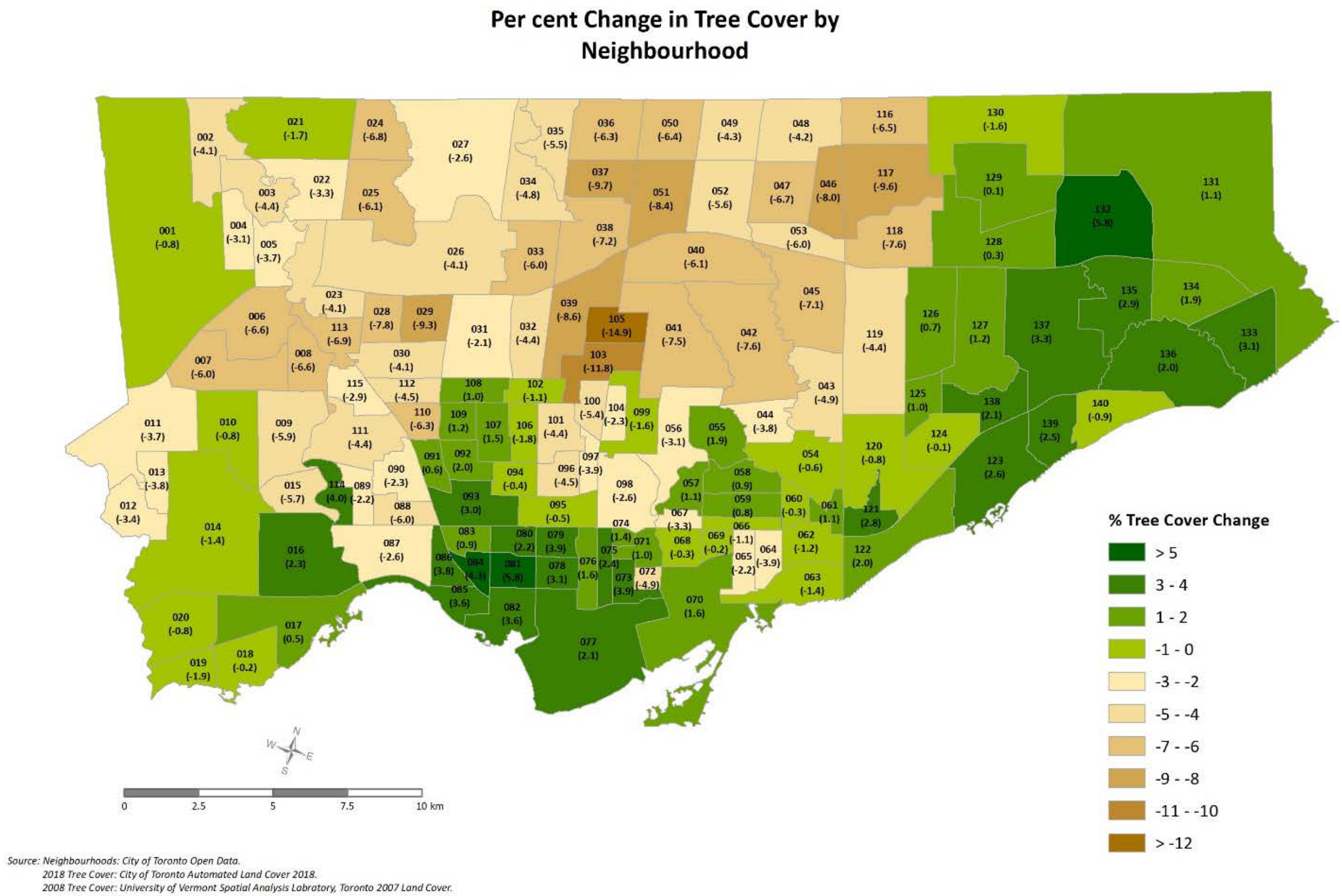


Figure 60: Percent Tree Cover Change by Neighbourhood between 2018 and 2008 (Source: Toronto land cover data, 2008 and 2018).

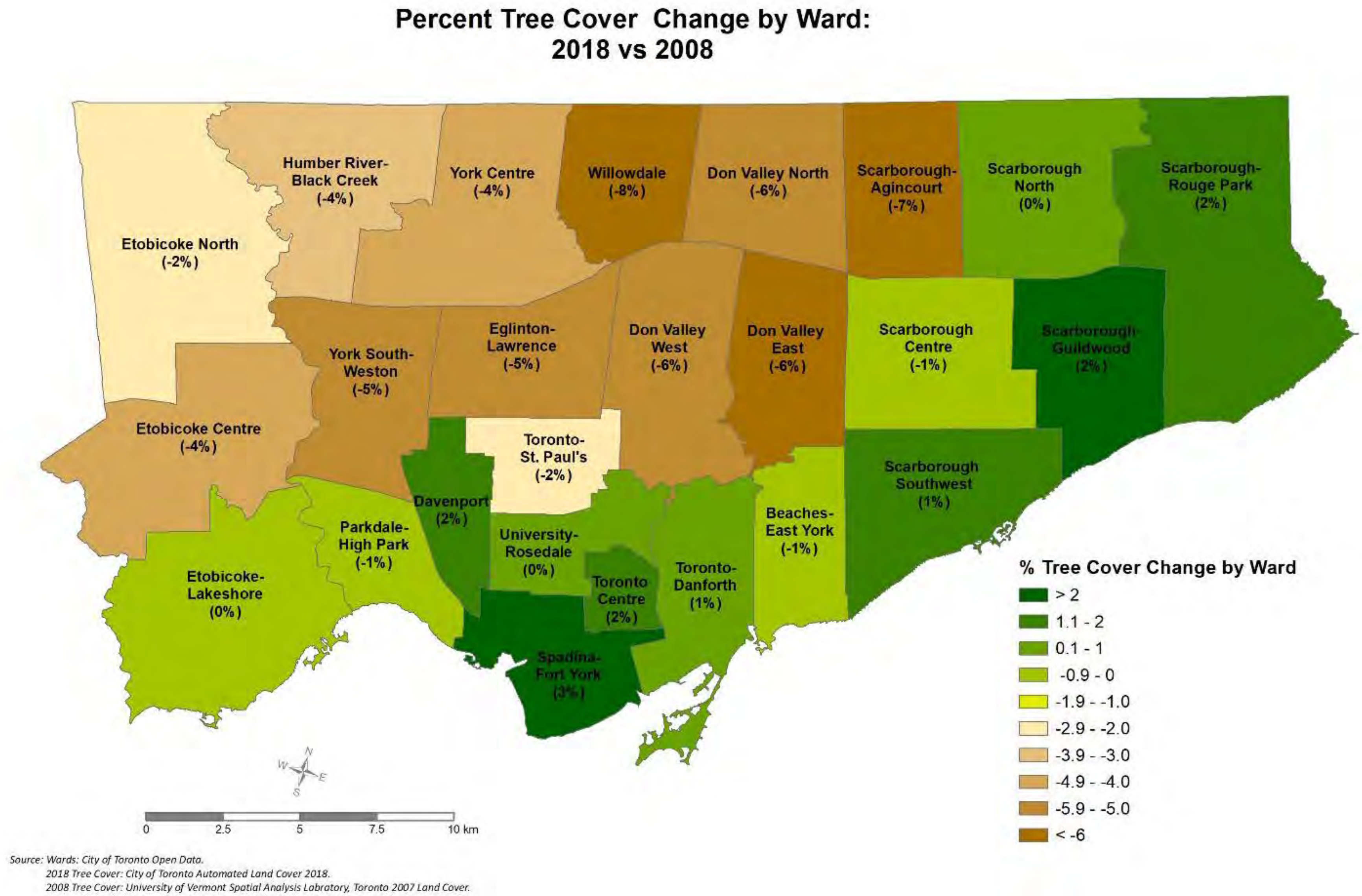


Figure 61: Percent Tree Cover Change by Ward between 2018 and 2008 (Source: Toronto land cover data, 2008 and 2018).

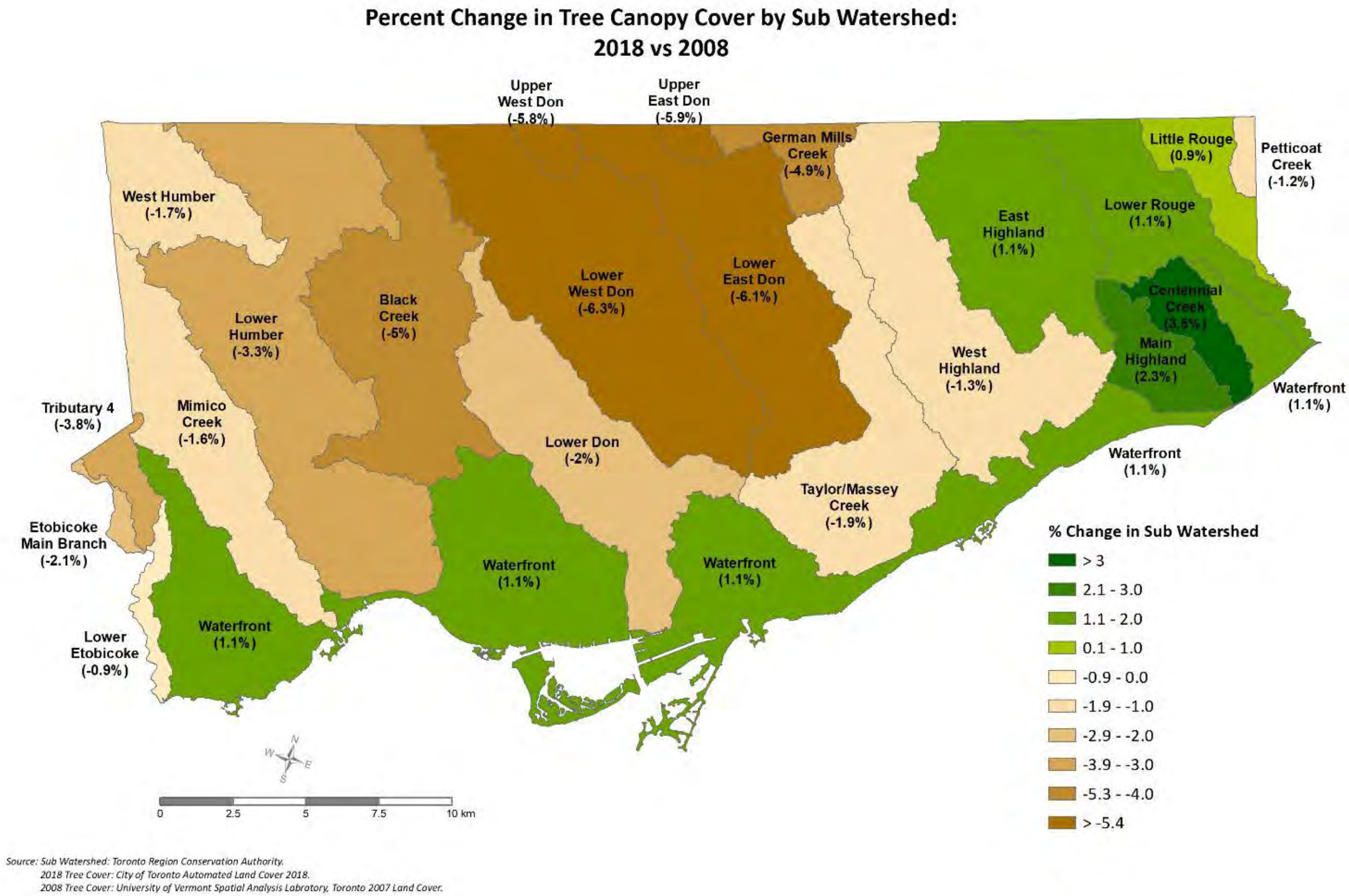


Figure 62: Percent Tree Cover Change by Subwatershed between 2018 & 2008 (Source: Toronto land cover data, 2008 and 2018).

In addition to calculating the percent change in tree cover by Administrative areas, additional analysis was also completed to identify change in tree cover by Land Use. To complete this analysis, 2007[1] Land Cover and 2008[2] Land Use datasets were input into the Model to summarize percent of tree cover within each Land Use type. The same process was applied to the 2018 Land Cover and 2018 Land Use layers provided by the City of Toronto. The 2008 Land Use dataset was derived from Municipal Property Assessment (MPAC) property codes used by MPAC to classify all properties in Ontario according to the following system:

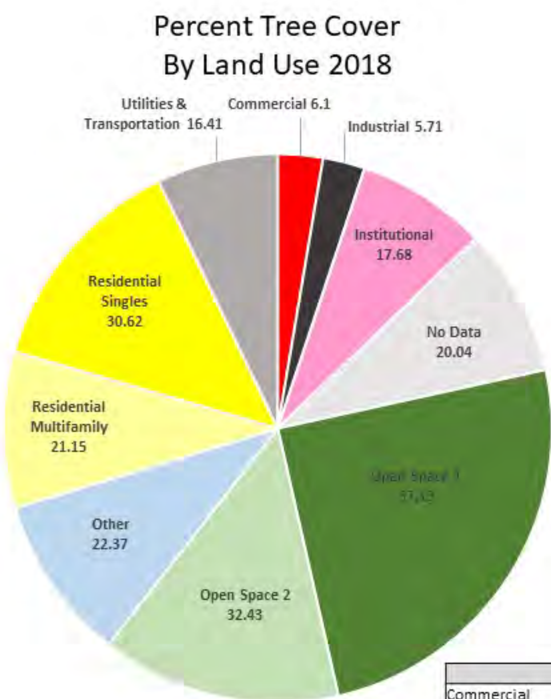
- 100 series – Vacant Land, 200 series – Farm
- 300 series – Residential (340, 341, 352, 361 and 374 - Multi-Residential)
- 400 series – Commercial
- 500 series – Industrial
- 600 series – Institutional
- 700 series – Special & Exempt
- 800 series – Government

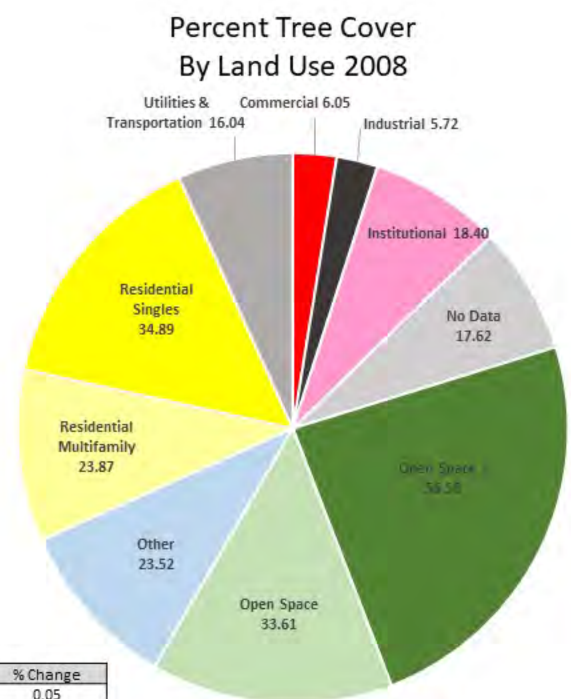
The 2008 Land Use dataset joined MPAC property code classifications associated with land parcel information, and then converted MPAC classifications to the City's zoning land use classification categories. The 2018 Land Use dataset was provided by the City of Toronto (based on their zoning GIS shapefile layer). The accuracy and completeness of the Land Use classification data contained in this report provided by the City of Toronto has not been independently validated by the study team.

The ten land use areas used in the study are derived from the City's zoning, as follows:

1. Commercial
2. Industrial
3. Institutional
4. Open Space 1 (Parks/Toronto and Region Conservation Authority lands e.g., natural areas)
5. Open Space 2 (Commercial Open Space/Recreation/Agriculture)
6. Other (mainly vacant and marinas)
7. Multifamily Residential
8. Single Family Residential
9. Utilities & Transportation
10. No Data (transitional areas that don't have a defined land use)

The key findings were tree cover, which excludes shrubs in the Land Cover classification dataset, has decreased in most land uses, including Single Family Residential land use, which also represents the highest amount of area in the City for planting more trees. Tree cover has increased in the Utility & Transportation, Institutional, Commercial and Open Space (Parks/TRCA lands) land uses, according to the Land Cover classification dataset. The results of the tree canopy cover by Land Use classification modelling are summarized in Figure 63.





*Land Use	% Change
Commercial	0.05
Industrial	-0.01
Institutional	-0.71
No Data	2.42
Open Space 1 (Parks/TRCA lands)	0.55
Open Space 2 (Commercial/Recreation/Agriculture)	-1.18
Other (mainly vacant and marinas)	-1.16
Residential Multifamily	-2.72
Residential Singles	-4.27
Utilities & Transportation	0.37

*2008 Land Use data was used to compare change UTC Land cover from 2007 and 2018

Figure 63: Percent Tree Cover by Land Use 2018 vs 2008 (Source: Toronto Land Cover data, 2008 and 2018, and Toronto Land Use Data 2008 and 2018).

Possible Causes of Tree Cover Decline in Toronto

To identify possible causes of tree cover decline in Toronto, analysis of Emerald Ash Borer (EAB) tree removals, ice storm service calls, Development Applications and building permits was completed. The raw data analyzed is summarized in **Supplement A**.

To identify possible causes of tree cover decline due to EAB, an analysis of ash tree removals on account of EAB documented between 2011 and 2018 was carried out. Data on EAB tree removals were provided within parklands and along streets within the City's Municipal Boundary area (Figure 64). The Kernel Density tool in GIS was used to calculate the density of points per square map unit (heat map). The result of this analysis is a heat map showing hot spots of higher instances of EAB removals within the City (Figure 65). This data can be spatially overlaid with other statistical results to understand possible contributing factors to tree cover loss

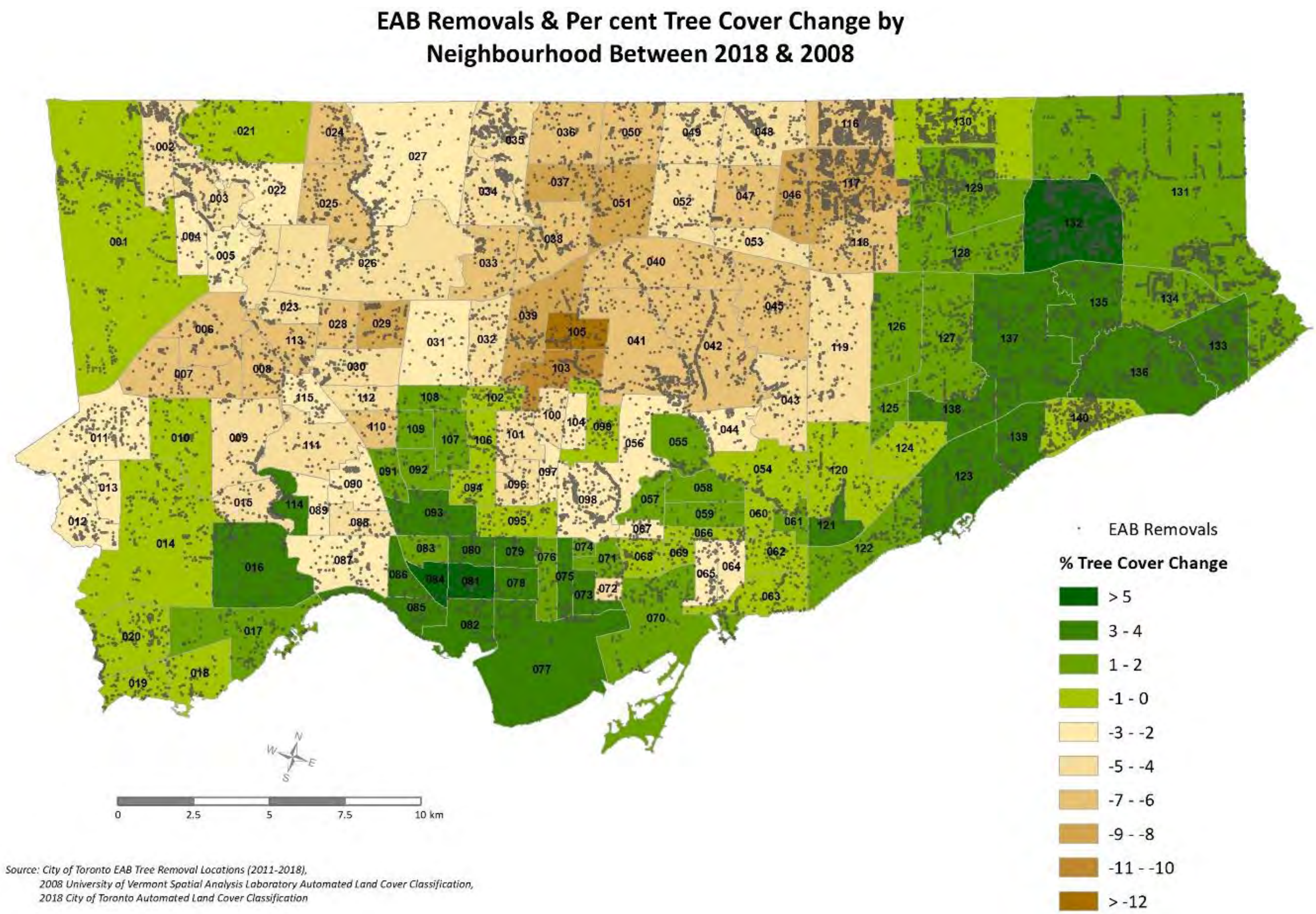


Figure 64: Location of EAB ash tree removals in relation to tree cover change. (Source: Land Cover classification 2008-2018 change assessment overlay with Forestry ash removal location data, 2011-2018, street tree and park data).

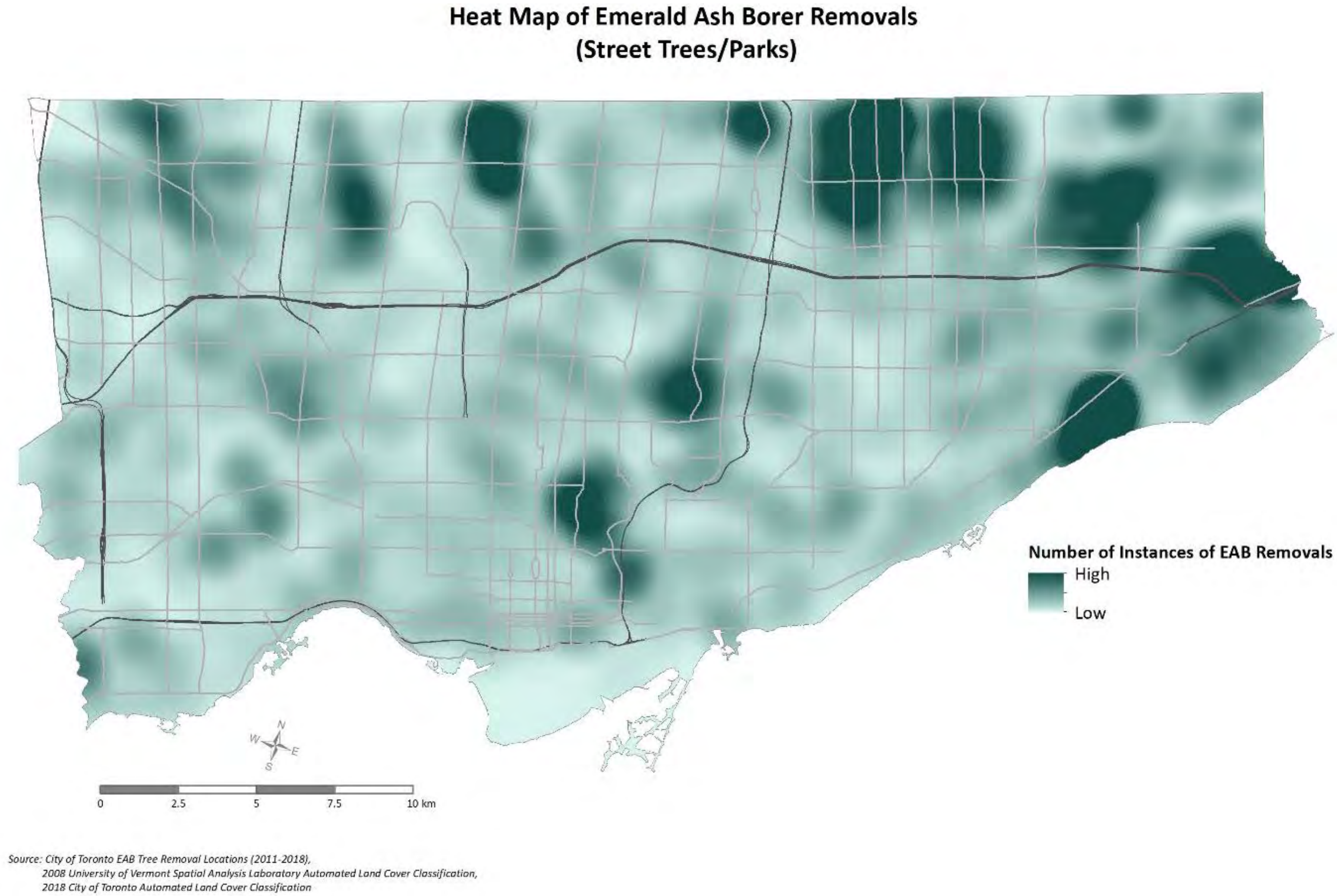


Figure 65: Heat Map of Emerald Ash Borer Removals (Source: Street Trees/Parks).

Analysis was completed at the parcel level to determine if there was a correlation between tree cover loss and parcels identified with an Emerald Ash Borer removal. Tree cover loss was determined by subtracting the 2007 and 2018 tree canopy features. This Feature class was intersected with parcels containing an EAB removal. The Result showed that 89% of parcels with an EAB removal showed a decline in tree canopy, see Figure 66.

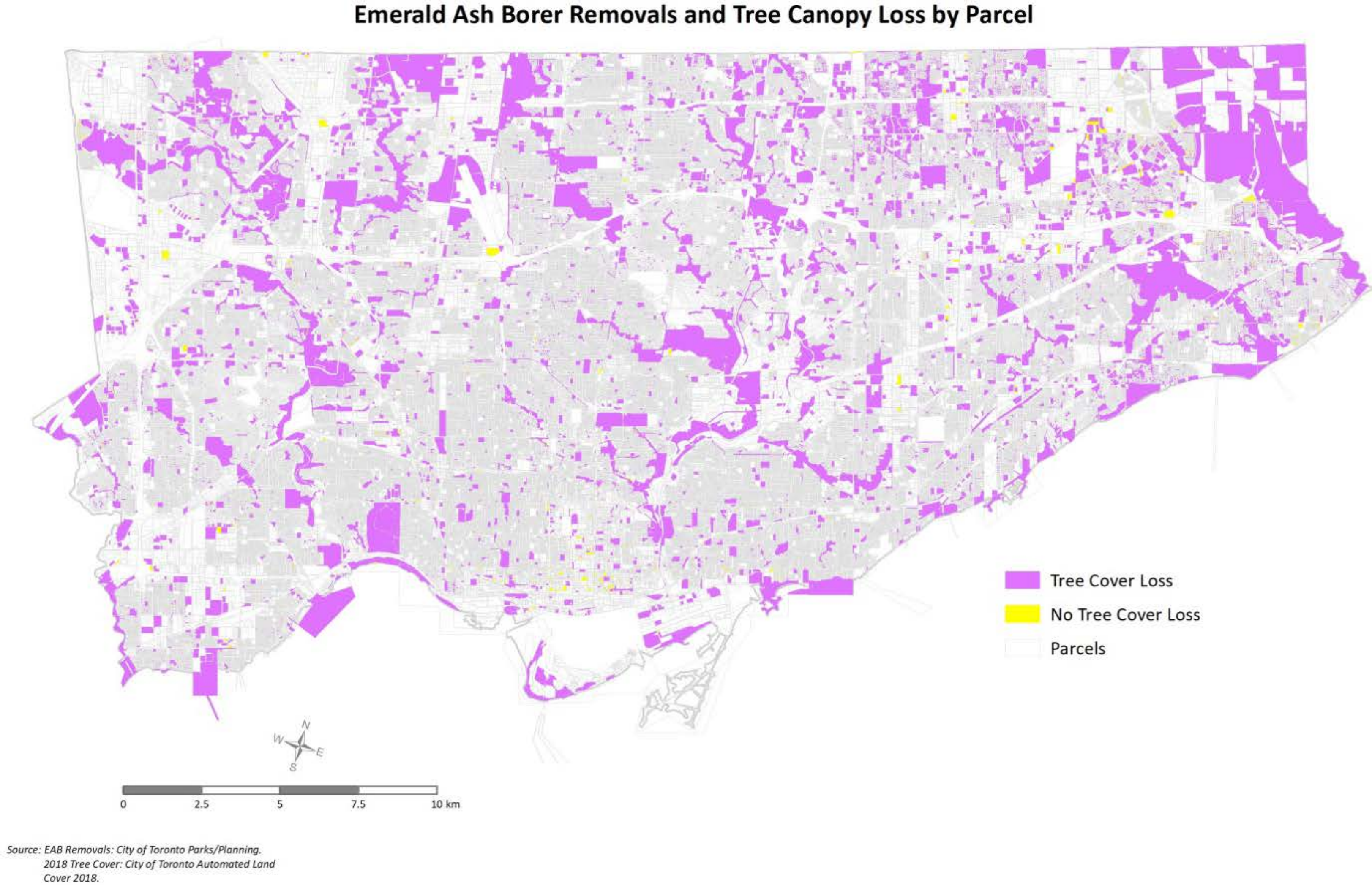


Figure 66: Emerald Ash Borer Tree Removals vs Tree Cover Loss (Parcel Level): 2011 – 2018 (Source: Street Trees/Parks, Toronto land cover data, 2008 and 2018).

To identify possible causes of tree cover decline due to the Ice Storm the City Experienced in 2013, a total of 33,343 service request attributed to damaged or downed trees during the 2013 Ice Storm from December 21, 2013 to December

22, 2013 were analyzed. The Data was mapped at the Neighbourhood scale to show correlations between tree cover loss and the effect of the ice storm (Figure 67). The Kernel Density GIS tool method was applied to create a heat map showing the locations and relative density of the ice storm service requests (Figure 68).

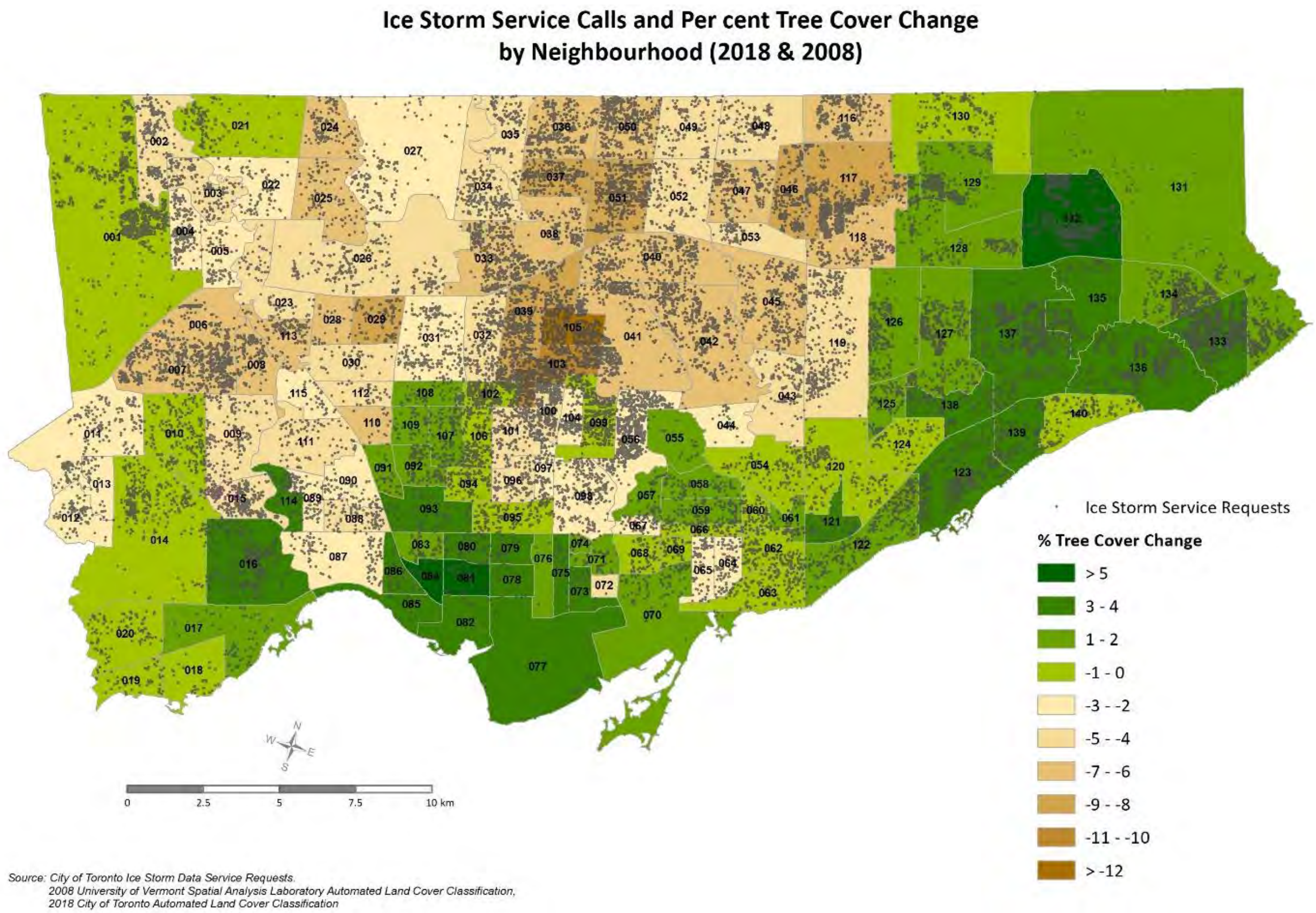


Figure 67: Location of 2013 ice-storm related service requests in relation to tree cover change. (Source: Land Cover classification 2008-2018 change assessment overlay with service request location data from City database).

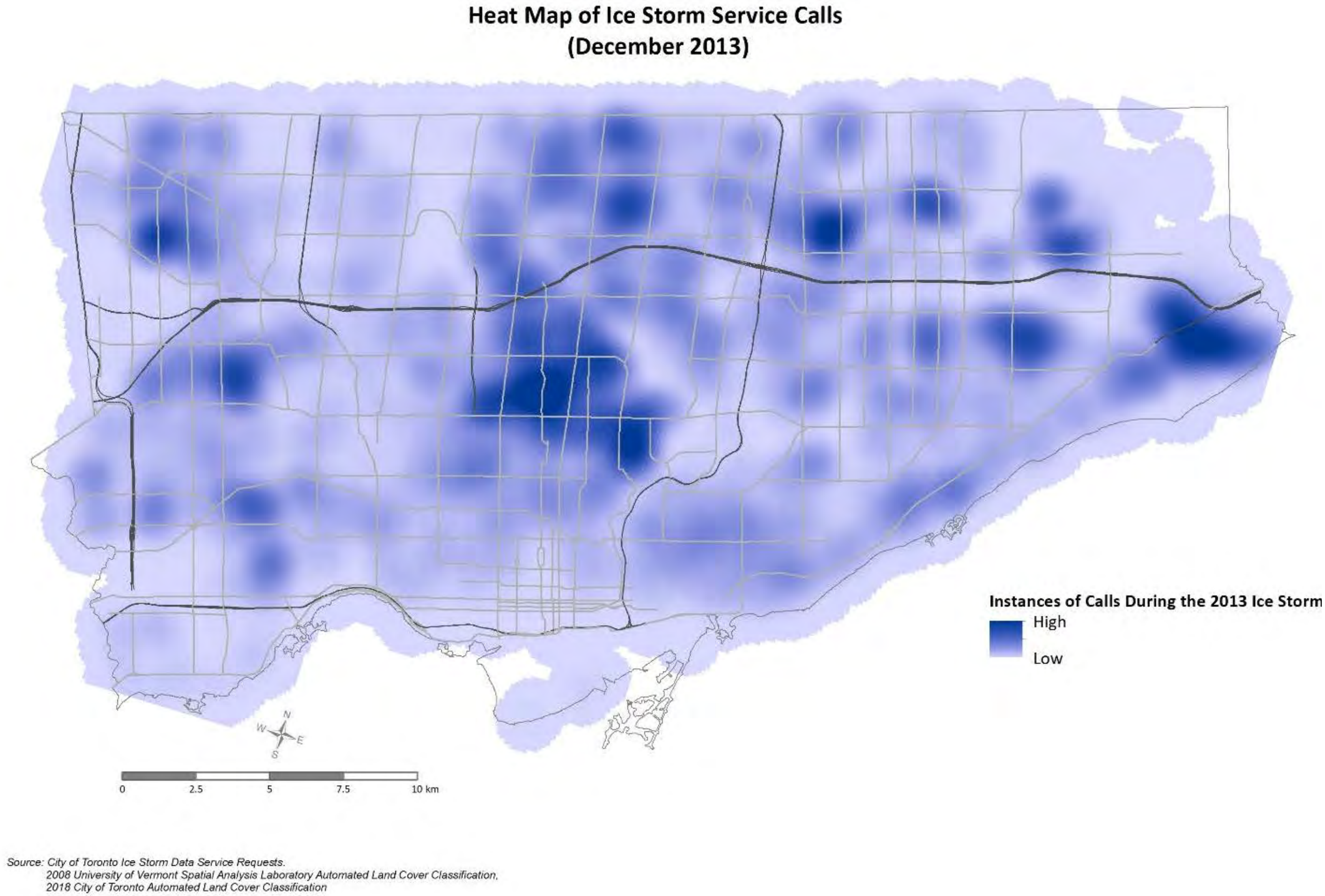


Figure 68: Heat Map of Service Request Calls during the 2013 Ice Storm (Source: service request location data from City database).

Analysis was completed at the parcel level to determine if there was a correlation between tree cover loss and parcels identified with Ice Storm Service Calls. Tree cover loss (identified by subtracting 2007 tree cover by 2018 tree cover) was intersected by each parcel with a service request call. The Analysis showed that 96% of parcels with Ice Storm Service calls experienced a loss in tree cover (Figure 69).

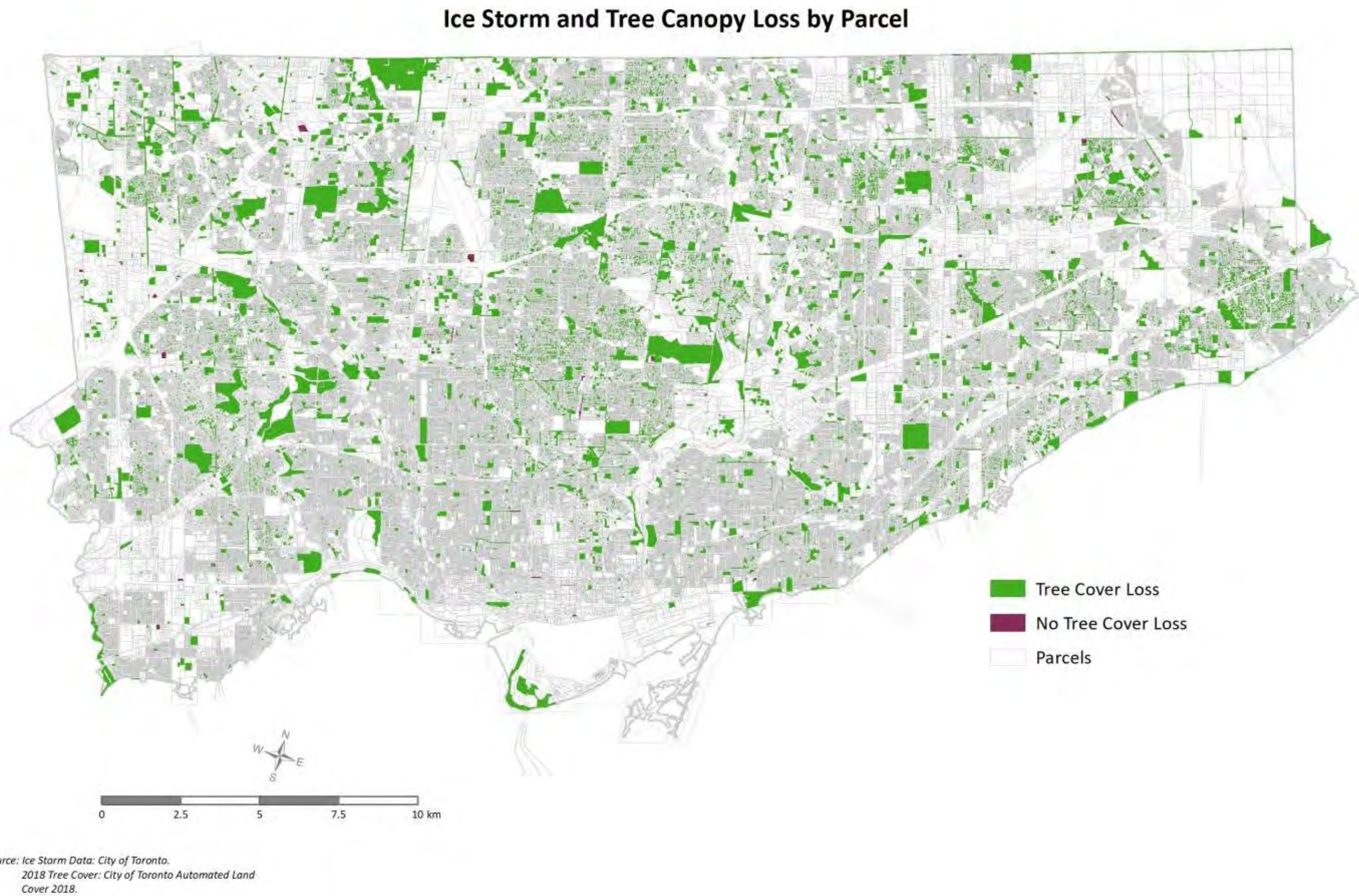


Figure 69. Location of 2013 ice-storm related service requests in relation to tree cover change. (Source: Land Cover classification 2008-2018 change assessment overlay with service request location data from City database).

Development Applications and Building Permit Data

Urban re-development can be viewed as a threat and an opportunity to the urban forests. While it is undeniable that new housing developments in wooded areas lead to tree loss and tree canopy cover decline, it is more challenging to monitor tree loss across the city in already developed areas. To identify correlations between tree canopy loss and urban development, development applications were downloaded from the City of Toronto's open data portal and spatially overlaid on the % Tree Canopy Change by Neighbourhood map. Development Applications dating from 2008 – 2018 were plotted and counts were provided for each neighbourhood (Figure 70).

Analysis at the parcel level was completed to identify possible correlations between tree cover loss and properties with Development Applications. 85% of parcels with an associated development application showed a loss in tree cover (Figure 71).

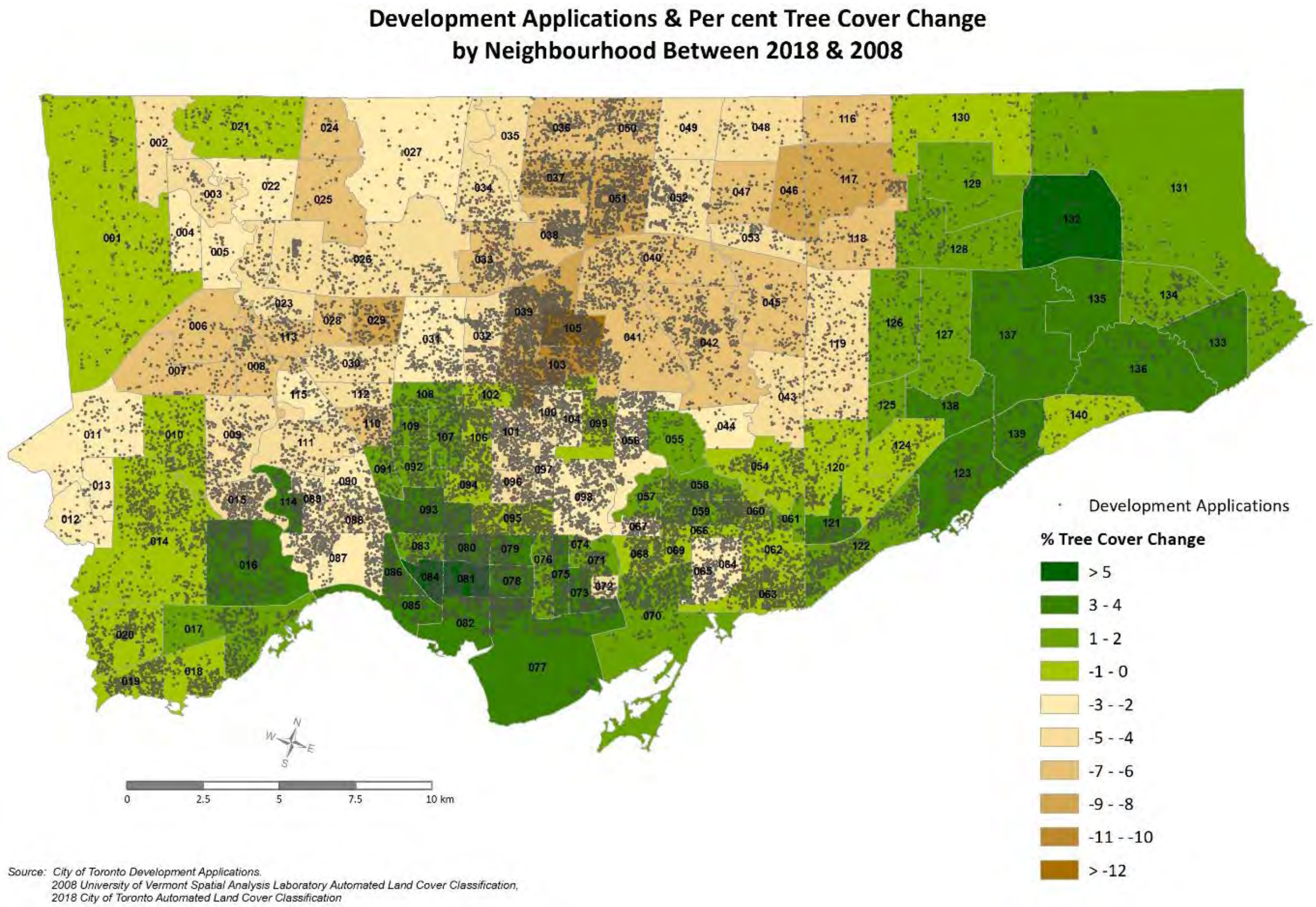


Figure 70: Development Applications and Percent Urban Tree Canopy Change by Neighbourhood Between 2018 and 2008 (Source: Land cover classification 2008-2018 change assessment overlay with Development applications 2008 - 2018).

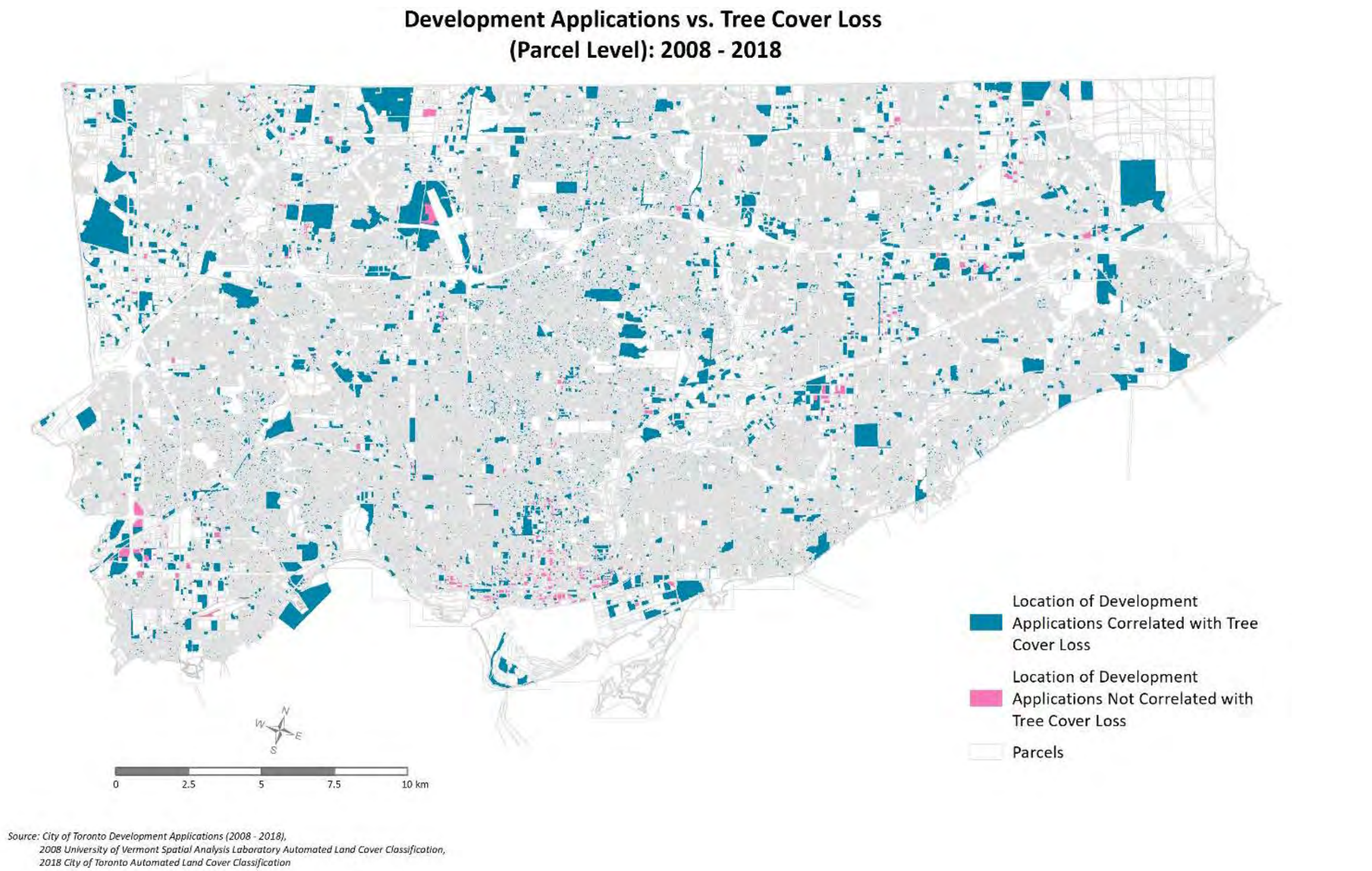


Figure 71: Building permit locations overlaid with areas of tree cover loss for the period 2008-2018 (Source: Land cover classification 2008-2018 change assessment overlay with City of Toronto building permit location data, 2008 - 2018).

Similarly, Permit Applications from 2008 to 2018 that were processed and compiled into point features were overlaid on the % Tree Cover Change by Neighbourhood Map (Figure 72).

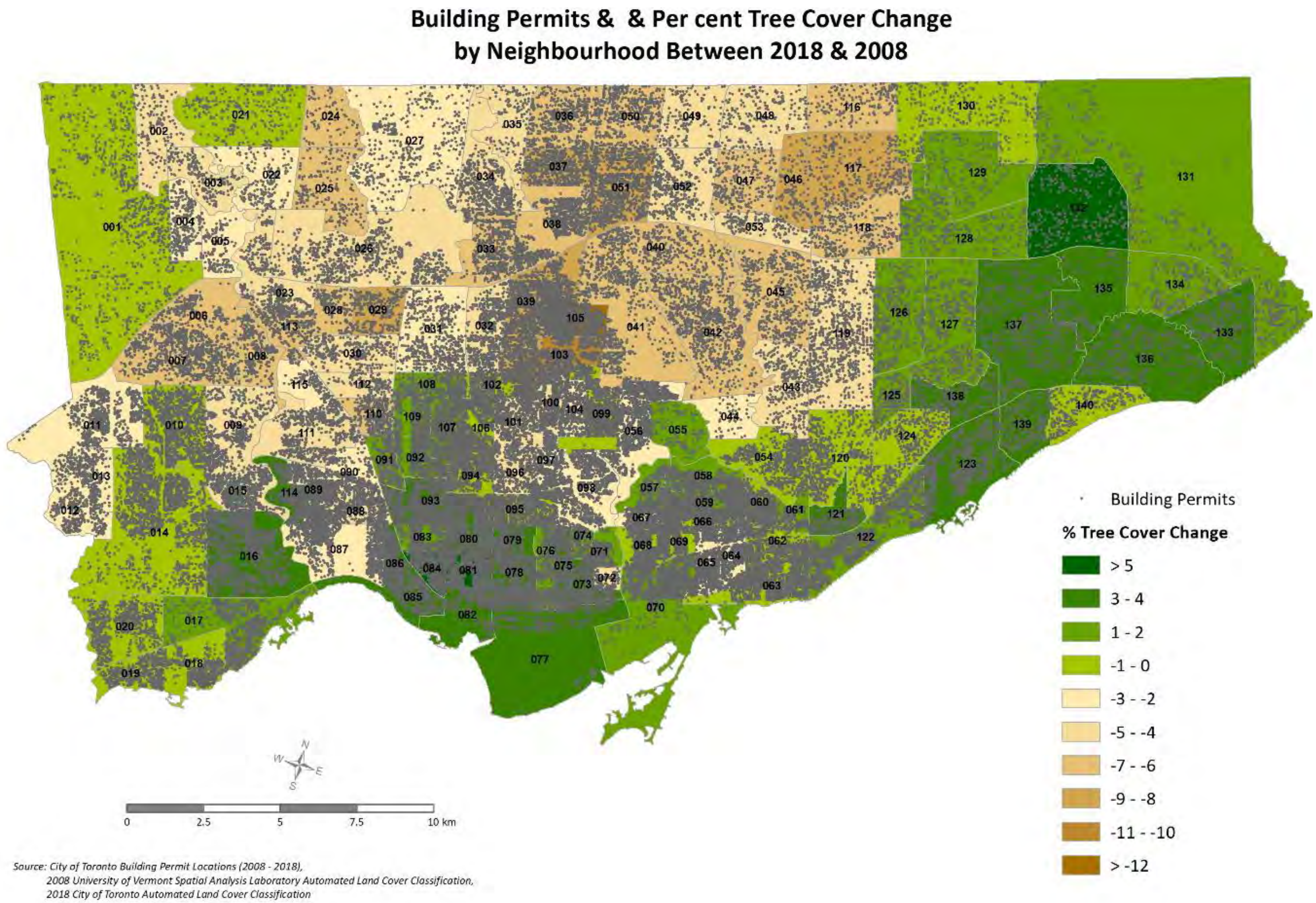


Figure 72: Building Permits and Percent Urban Tree Canopy Change by Neighbourhood Between 2018 and 2008 (Source: Land cover classification 2008-2018 change assessment overlay with Building Permits 2008 - 2018).

Analysis at the parcel level was completed to identify possible correlations between tree cover loss and properties with Building Permits. Similar to Development Applications, 85% of parcels with a building permit associated with it showed a loss in tree cover (Figure 73).

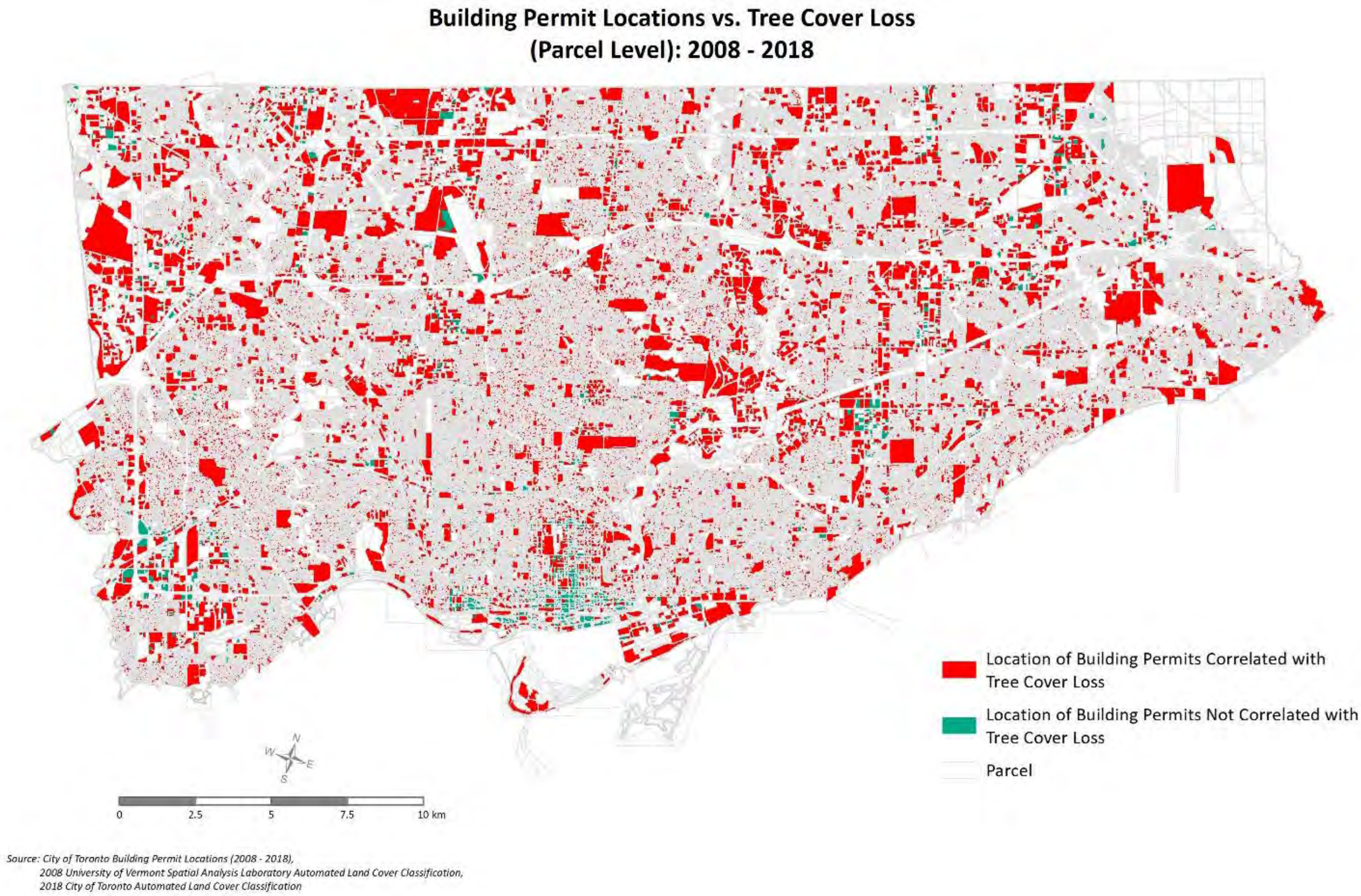


Figure 73: Building Permits vs Tree Cover Loss (Source: Land cover classification 2008-2018 change assessment overlay with Permits 2008 - 2018).

Recent Toronto-based research has shown that tree mortality and tree cover loss are higher in areas where building permits indicate that building renovation activities have occurred (Steenberg et. al., 2018a; 2018b). This research leveraged Toronto's open data program to investigate 15 years of building permit patterns and statistically test whether or not the presence and abundance of permits can be a predict of tree mortality. The findings of these papers suggest that despite some preventative measures, such as tree protection zones, renovation and other urban development and re-development activities can have a negative effect on Toronto's tree population.

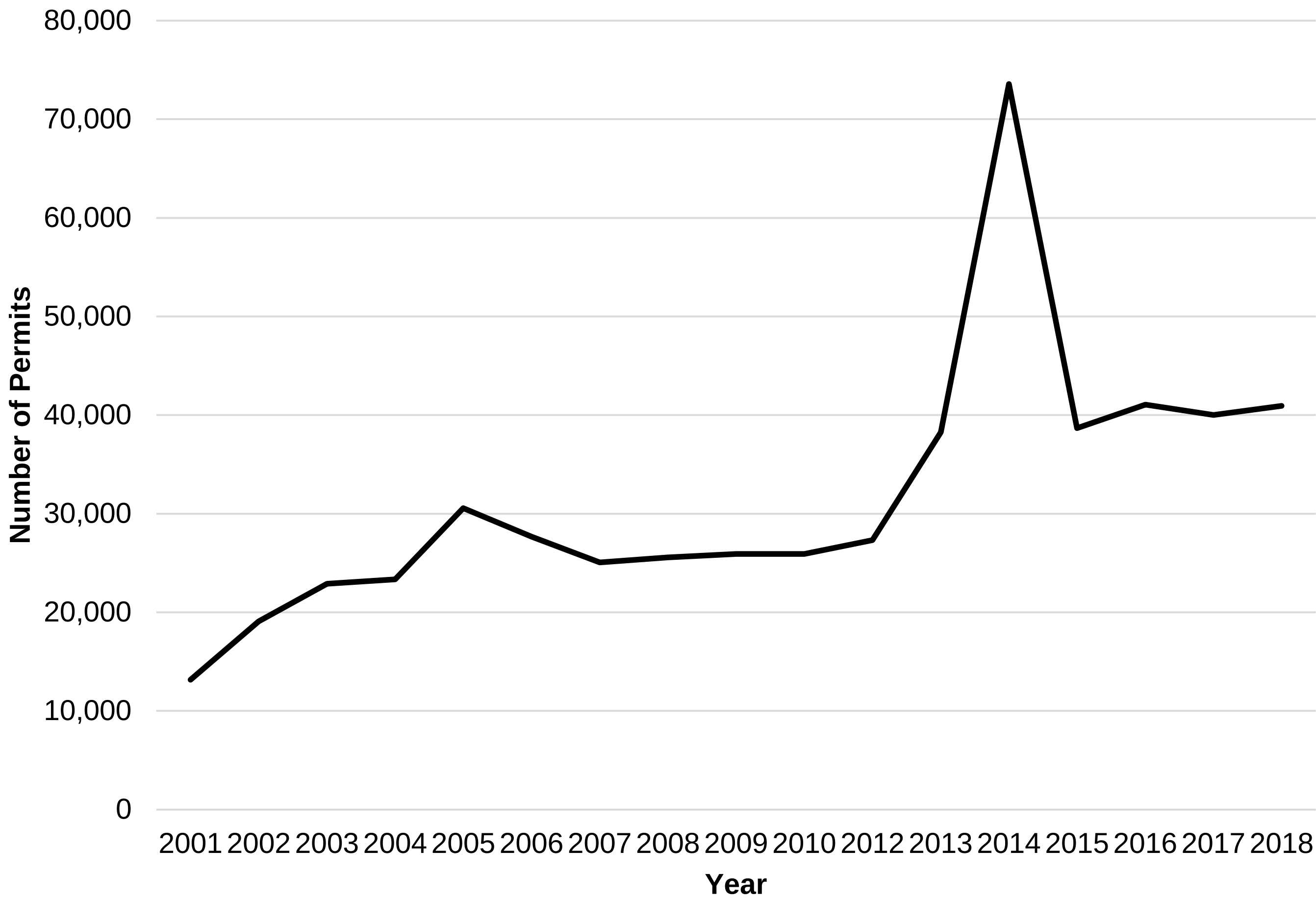


Figure 74: Total number of building permits per year in Toronto from 2001 to 2018.

Supplement A - Summary of Potential Influences on Canopy Cover by Neighbourhood

Table 37: Summary of EAB Removals, Ice Storm Service Calls, Development Applications and Building Permits by Neighbourhood

Neighbourhood	Ash Removals due to EAB	Ice Storm Service Calls	Development Applications	Building Permits (2008-2018)
West Humber-Clairville (1)	854	1047	406	2706
Mount Olive-Silverstone-Jamestown (2)	605	292	28	379
Thistletown-Beaumond Heights (3)	257	219	97	495
Rexdale-Kipling (4)	241	250	36	982
Elms-Old Rexdale (5)	251	125	52	1411
Kingsview Village-The Westway (6)	246	376	95	3349
Willowridge-Martingrove-Richview (7)	163	751	190	1839
Humber Heights-Westmount (8)	148	159	163	953
Edenbridge-Humber Valley (9)	227	210	412	2609
Princess-Rosethorn (10)	163	232	338	272
Eringate-Centennial-West Deane (11)	420	289	178	1920
Markland Wood (12)	162	105	40	602
Etobicoke West Mall (13)	50	48	57	1854
Islington-City Centre West (14)	354	387	1286	500
Kingsway South (15)	197	384	557	1054
Stonegate-Queensway (16)	354	410	1011	446
Mimico (includes Humber Bay Shores) (17)	253	64	626	1587
New Toronto (18)	104	32	288	2451
Long Branch (19)	129	53	700	2015
Alderwood (20)	526	119	608	2214
Humber Summit (21)	285	192	186	773
Humbermede (22)	299	91	48	701
Pelmo Park-Humberlea (23)	248	85	210	1647
Black Creek (24)	266	163	22	175

Neighbourhood	Ash Removals due to EAB	Ice Storm Service Calls	Development Applications	Building Permits (2008-2018)
Glenfield-Jane Heights (25)	505	122	42	2274
Downsview-Roding-CFB (26)	475	283	722	4277
York University Heights (27)	549	161	168	2415
Rustic (28)	76	42	79	2129
Maple Leaf (29)	113	127	189	2395
Brookhaven-Amesbury (30)	208	56	275	962
Yorkdale-Glen Park (31)	76	300	495	3380
Englemount-Lawrence (32)	124	249	1029	315
Clanton Park (33)	163	436	574	1803
Bathurst Manor (34)	859	270	277	1587
Westminster-Branson (35)	801	160	47	1422
Newtonbrook West (36)	227	466	431	1877
Willowdale West (37)	109	333	650	3239
Lansing-Westgate (38)	502	380	969	1106
Bedford Park-Nortown (39)	224	754	1539	5755
St.Andrew-Windfields (40)	328	486	465	5705
Bridle Path-Sunnybrook-York Mills (41)	613	527	627	5843
Banbury-Don Mills (42)	872	558	596	4538
Victoria Village (43)	288	144	120	700
Flemingdon Park (44)	215	34	25	566
Parkwoods-Donalda (45)	224	418	198	2549
Pleasant View (46)	173	278	34	1358
Don Valley Village (47)	180	292	128	1544
Hillcrest Village (48)	670	192	77	1093
Bayview Woods-Steeles (49)	237	143	43	357
Newtonbrook East (50)	201	553	641	1397
Willowdale East (51)	234	729	1361	6027
Bayview Village (52)	175	167	619	2204
Henry Farm (53)	80	77	154	698
Oakridge (121)	242	151	406	646
Thorncliffe Park (55)	146	28	150	1145

Neighbourhood	Ash Removals due to EAB	Ice Storm Service Calls	Development Applications	Building Permits (2008-2018)
Leaside-Bennington (56)	206	937	802	3473
Broadview North (57)	57	58	170	782
Old East York (58)	59	100	415	2144
Danforth East York (59)	26	152	638	3122
Woodbine Corridor (64)	15	99	282	1488
Taylor-Massey (61)	60	63	110	1077
East End-Danforth (62)	96	215	298	1778
The Beaches (63)	216	174	972	4817
Woodbine-Lumsden (60)	56	102	200	1884
Greenwood-Coxwell (65)	103	116	430	489
Danforth (66)	53	115	159	607
Playter Estates-Danforth (67)	39	77	213	1338
North Riverdale (68)	294	77	342	3545
Blake-Jones (69)	54	77	139	1001
South Riverdale (70)	283	110	1015	1134
Cabbagetown-South St.James Town (71)	97	56	206	1102
Regent Park (72)	37	1	181	2610
Moss Park (73)	63	31	550	563
North St.James Town (74)	16	20	164	2300
Church-Yonge Corridor (75)	65	33	691	6242
Bay Street Corridor (76)	57	4	475	19508
Waterfront Communities-The Island (77)	233	34	1534	8771
Kensington-Chinatown (78)	42	12	441	930
University (79)	66	39	266	1863
Palmerston-Little Italy (80)	79	61	615	1761
Trinity-Bellwoods (81)	76	51	716	3810
Niagara (82)	130	7	440	2611
Dufferin Grove (83)	41	56	230	3666
Little Portugal (84)	40	19	380	4181
South Parkdale (85)	198	16	193	1142

Neighbourhood	Ash Removals due to EAB	Ice Storm Service Calls	Development Applications	Building Permits (2008-2018)
Roncesvalles (86)	38	46	330	1574
High Park North (88)	248	131	584	1589
High Park-Swansea (87)	59	114	330	2951
Runnymede-Bloor West Village (89)	15	98	281	3757
Junction Area (90)	128	87	322	7393
Weston (113)	56	41	132	666
Corso Italia-Davenport (92)	40	139	211	1356
Dovercourt-Wallace Emerson-Junction (93)	163	105	739	2684
Wychwood (94)	68	118	327	1966
Annex (95)	71	177	1146	6122
Casa Loma (96)	140	131	504	1563
Yonge-St.Clair (97)	40	122	376	2299
Rosedale-Moore Park (98)	1149	314	739	2059
Mount Pleasant East (99)	111	461	645	391
Yonge-Eglinton (100)	65	455	509	2591
Forest Hill South (101)	114	209	608	1375
Forest Hill North (102)	141	490	231	317
Lawrence Park South (103)	186	919	899	4100
Mount Pleasant West (104)	39	171	727	3503
Lawrence Park North (105)	89	426	819	3627
Humewood-Cedarvale (106)	135	215	452	397
O'Connor-Parkview (54)	64	173	437	725
Briar Hill-Belgravia (108)	60	59	224	894
Caledonia-Fairbank (109)	70	50	268	791
Keelesdale-Eglinton West (110)	46	20	281	2434
Rockcliffe-Smythe (111)	126	112	304	487
Beechborough-Greenbrook (112)	83	46	87	359
Weston-Pellam Park (91)	154	152	239	1233
L'Amoreaux (117)	150	106	295	1671
Mount Dennis (115)	262	52	128	2169
Steeles (116)	2133	312	39	2522

Neighbourhood	Ash Removals due to EAB	Ice Storm Service Calls	Development Applications	Building Permits (2008-2018)
Lambton Baby Point (114)	1740	621	171	2047
Tam O'Shanter-Sullivan (118)	429	481	128	4107
Wexford/Maryvale (119)	252	394	355	2496
Clairlea-Birchmount (120)	239	220	602	5442
Oakwood Village (107)	202	52	263	1966
Birchcliffe-Cliffside (122)	287	369	1030	3885
Cliffcrest (123)	265	447	569	3226
Kennedy Park (124)	45	97	191	1233
Ionview (125)	59	130	38	1889
Dorset Park (126)	199	252	211	1248
Bendale (127)	446	525	117	2072
Agincourt South-Malvern West (128)	460	323	277	1495
Agincourt North (129)	1153	437	61	704
Milliken (130)	1110	182	130	678
Rouge (131)	4464	426	355	5245
Malvern (132)	1767	799	148	1695
Centennial Scarborough (133)	749	1039	219	1054
Highland Creek (134)	526	507	370	1917
Morningside (135)	479	211	109	2920
West Hill (136)	1395	533	308	2459
Woburn (137)	695	946	197	2061
Eglinton East (138)	214	160	76	1701
Scarborough Village (139)	241	147	144	431
Guildwood (140)	2176	173	72	2287

References

City of Toronto, 2018. Automated Land Cover Analysis.

City of Toronto Open Data Portal. Accessed April 2019. (https://www.toronto.ca/city-government/data-research-maps/open-data/)

Steenberg, J. W. N., Robinson, P. J., & Duinker, P. N. (2018). A spatio-temporal analysis of the relationship between housing renovation, socioeconomic status, and urban forest ecosystems. *Environment and Planning B: Urban Analytics and City Science*. In press.

Steenberg, J. W. N., Robinson, P. J., & Millward, A. A. (2018b). The influence of building renovation and rental housing on urban trees. *Journal of Environmental Planning and Management, 61*, 553-567.

University of Vermont Spatial Analysis Laboratory, 2007. Land Cover for the City of Toronto Ontario, (toronto_2007_landvover.img).

Appendix F: Status of Recommendations from 2012 Strategic Forest Management Plan

Table 38: 2012 Strategic Forest Management Plan Status Update

No.	ACTION	STATUS
1	Communicate comprehensive pest management strategies as needed through media, meetings and outreach programs.	ongoing - web updates EAB program winding down
2	Obtain required funding to maintain an appropriate response to EAB, including monitoring and mapping EAB tree removals.	EAB program winding down
3	Maintain consistent funding to city-wide forest health care and pest management programs and initiatives and refine the forest health care strategy going forward based on the effectiveness of current programs and initiatives and industry best practices.	Forest Health Care Threats published and posted on web site in 2017
4	Continue to progressively implement city-wide proactive area tree maintenance, a program which is estimated to bring the average pruning cycle to approximately 7 years.	Implementation of the Area Street Tree Maintenance program towards an average 7-year maintenance cycle is underway
5	Continue implementation of the newly planted tree maintenance program to provide early and proactive maintenance to protect the City's tree planting investment and the potential benefits these trees bring to the community.	Newly Planted Tree Maintenance program ongoing.

No.	ACTION	STATUS
6	Reduce mortality in new street tree plantings by: completing a detailed mortality survey of newly planted street trees with a goal to identifying key factors causing mortality; reviewing and revising stock sourcing procedures to improve planting stock; reviewing and revising planting and early maintenance procedures to improve survival.	Tree Health Assessment study underway, looking at tree health and mortality for trees planted over the last 10 years including street trees, park trees and trees in naturalization areas.
7	Reduce tree service delay for reactive maintenance from the current 6 to 9 months, to 3 to 6 months.	Ongoing; fluctuates based on extreme weather event work orders
8	Develop and implement a parkland tree risk management policy and program city-wide.	Implementation of the Area Park Tree Maintenance program towards a 7-year maintenance cycle
9	Improve public awareness of: proper planting, watering, mulching and tree protection techniques; tree risk situations (e.g., under specified weather conditions, high traffic areas).	New street tree planting materials completed - Every Tree Counts brochure and web site updates
10	Increase compliance with tree protection requirements through interaction with the development industry and enhanced monitoring of tree by-law applications.	TPPR compliance and enforcement unit in place
11	Improve tree by-law effectiveness by tracking and measuring key performance indicators to inform by-law and implementation improvements.	TPPR compliance unit in place
12	Work with the relevant City divisions to complete a review of land use, planning and zoning policies to identify regulatory constraints to achieving canopy expansion and a sustainable urban forest.	Use key findings from 10-year tree canopy study

No.	ACTION	STATUS
13	Utilize all available tree planting locations and where possible strive to improve planting conditions, providing adequate soil, water and oxygen to support mature growth.	Toronto Complete Streets Guidelines done
14	Develop mapping systems that: support planting activities; ensure the currency of data recording; facilitate effective communication of information to stakeholders.	New work and asset management system in development
15	Assess the state of the forest every 10 years through analysis of leaf-on satellite imagery and field sampling to: verify the urban forest species composition; verify the urban forest size composition; monitor change in overall city canopy coverage.	2018 tree canopy study
16	Undertake strategic planting prioritized in the areas of most need, as follows: residential boulevards where trees have been removed; public lands outside of planned infrastructure work areas and within priority storm water management areas identified by Toronto Water; parkland and on streets in neighbourhoods where the canopy is significantly lower than the city average; where ash trees occur in relatively high concentrations; areas of high heat vulnerability (as identified by Toronto Public Health).	Ongoing
17	Collaborate with City divisions and agencies (e.g., TRCA) on opportunities for developing policy related to soil conservation on development sites.	Toronto Green Standard Version 3 includes provisions for soil volume.

No.	ACTION	STATUS
18	Continue to collaborate with Toronto Water and Transportation Services to identify strategic planting areas that: increase storm water management (by providing water uptake by trees); shade streets and bikeways; reduce erosion and improve the stability of ravine slopes through naturalization.	Ongoing
19	Use land cover data in corporation with City Planning, TRCA and other agencies to assess impacts on canopy goals by: tracking land use and forest cover change city-wide; monitoring change in canopy by land use, watershed or neighbourhood.	Ongoing; use key findings from 2018 tree canopy study
20	Centralize tree planting functions and pilot new models for planting services in residential areas, assessing a variety of stock types.	Continuous improvement
21	Market the city's free residential tree planting program for front yards.	New "Every Tree Counts" brochure and web site updates
22	Cultivate new relationships with green community organizations with a focus on realizing canopy targets in communities and neighbourhoods.	Interim actions undertaken in partnership with Toronto Parks and Trees Foundation for community micrograms including subsidies for backyard tree planting
23	Design and implement a pilot study in cooperation with Urban Design, Business Improvement Areas and private businesses to increase tree cover in selected commercial and industrial areas.	Recommendation in Tree Planting Strategy

No.	ACTION	STATUS
24	Continue to work with other agencies (e.g., TRCA, Natural Resources Canada, OMNRF) to highlight and address information gaps with respect to urban forests and climate change (e.g., tree species response to climate change in the urban environment) by: monitoring species composition over time (through the urban forestry database system and i-Tree Eco permanent sample plots); evaluating planting success by species in different settings (e.g., naturalization areas, parks and streets); adapting species mix based on diversity criteria and planting success (as per the monitoring plan); using monitoring data to refine species planting lists; pursuing partnerships with research institutions or other organizations to refine planting lists with a focus on climate change adaptation.	New Tree Diversity Policy and Guidelines; Tree Health Assessment study underway; 2018 Tree Canopy Study; natural area monitoring partnership with University of Toronto
25	Promote new standards for tree planting in hard landscapes that accommodate adequate soil volume and moisture retention, mature tree growth and facilitate required utility access.	Toronto Green Standard Version 3 includes provisions for soil volume requirements
26	Continue to refine watering programs as needed to respond to prolonged droughts that are anticipated in future.	As needed
27	Continue to increase and adapt tree species planting lists to include more species, particularly those that have demonstrated urban resilience to extreme conditions and native species from slightly warmer climates.	New "Every Tree Counts" street tree planting brochure; Tree Diversity Policy and Guidelines
28	Develop a database with mapping of large, robust populations of native species for seed collection and continued biodiversity.	Forests Ontario

No.	ACTION	STATUS
29	Develop policies aimed at restricting inappropriate land uses and preventing further habitat fragmentation in significant natural areas.	Tree Planting Strategy action item; informed by Ravine Strategy and City Biodiversity Strategy
30	Collaborate with the Parks branch and TRCA to create a natural environment framework that identifies, selects and prioritizes natural area management sites, with a focus on improving habitat size and shape, use of native species, and improving linkages between habitats.	Ravine Strategy, Parkland Acquisition, Environmentally Significant Area (ESA) Management Plans in progress
31	Explore options for securing strategic land acquisitions with a view to improve key linkages between parkland sites and protect natural areas from future development.	
32	Continue to develop and implement projects to mitigate invasive species and recreational impacts in cooperation with partner agencies in consideration of these key actions; selecting native species for planting using locally propagated trees and shrubs from native seeds collected within Toronto parkland (e.g., expanding Tree Seed Diversity Project); protecting and managing natural areas through the strategic placement of trail systems, design solutions for resource protection and by-law enforcement; eliminating existing invasive plants utilizing a combination of manual or chemical control methods.	Seed Collection (increase the proportion of locally sourced trees) - ongoing Work in Urban Forest Renewal and Natural Environment Trails Strategy (NETS); ongoing new TPPR compliance unit in place – ongoing Ongoing invasive species removal activities.
33	Use Environmentally Significant Area mapping: to prioritize management of natural areas based on levels of risk/threats; as a basis for future mapping updates (in coordination with City Planning and TRCA).	Updated Environmentally Significant Areas (ESAs) - adopted by City Council 2015 Prioritized natural area management - ongoing

No.	ACTION	STATUS
34	Continue engagement of the public through programs supporting private land and garden naturalization and education by Tree Protection and Plan Review staff.	Ongoing
35	Maintain existing stewardship programs (in particular invasive species management) to support investments in past restoration projects on flagship and other sites. Expand stewardship and work with the Parks branch to enable more volunteer stewardship in public natural areas.	Natural Environment and Community Programs (NECP) - ongoing Stewardship plan for program expansion - underway
36	Increase public education regarding natural area management activities, trail systems and appropriate trail user conduct to protect natural areas. Tools to be investigated for use include: the production of marketing materials; website education; alignment with parks branch communication and education; coordinating with the recreation branch on awareness posters, brochures, and maps in community recreation centres.	Communications activities through social media – Facebook and Twitter feeds Natural Environment Trails Strategy (NETS) implementation - ongoing
37	Proceed with a natural and paved surface trail study and network with other divisions and stakeholders to explore the funding potential for the development and management of a multi-purpose trail system, including: interpretive signage; wayfinding signage; trail enhancement.	Implementation of Natural Environment Trails Strategy (NETS) - ongoing Key stakeholder is TRCA trails strategy development Wayfinding Strategy - pilot study done Cycling Infrastructure - ongoing
38	Explore the potential for fund creation by private partners where there is opportunity for contiguous canopy benefits.	Tree Planting Strategy drafted; going to Committee in June 2019
39	Support staff resources to expand the Community Stewardship Program to meet the demand for stewardship activities	Continued support for current staff resource levels for Community Stewardship Program

No.	ACTION	STATUS
40	Continue to make City street tree data available to individuals and community groups to facilitate neighbourhood studies of local forest conditions.	Ongoing

Appendix G: Automated Land Cover Analysis Methodology

Automated Land Cover Analysis

2018 Tree Canopy Study

Prepared by: Ryan Garnett

City of Toronto

Information and Technology Division

Enterprise Spatial and Digital Services

1 Glossary of Terms

Table 39: Glossary of Terms for Automated Land Cover Analysis

Terms	**Definitions**
Band	A layer of numeric information stored within raster data. Numeric information stored within a band can vary from integers to decimal values, with either positive or negative values.
Feature engineering	A method of creating new information through calculating existing attributes.
Ground sampling distance	A method of measuring geographic data accuracy.
Feature engineering	Generating additional information to a dataset through calculation and/or analytical processes
Land cover	A broad representation of the physical landscape, identifying physical features rather than land usage types.
LiDAR	Light Detecting and Ranging is a technology for collecting geographic information, allowing for accurate horizontal and vertical measurements.
Multispectral	Representing information across a wide range of the electromagnetic spectrum; typically including portions of the visible and infrared spectrum.

Terms	Definitions
NDVI	Normalized difference vegetation index is a method of analyzing the presence of chlorophyll within objects of a satellite or aerial photograph.
Panchromatic	A satellite or aerial photography product consisting of a single band of information represented by the electromagnetic spectrum, which is typically of higher pixel resolution than corresponding multispectral information.
Pixel resolution	A unit for measuring geographic resolution in raster information, such as satellite, aerial photography, elevation, etc.
Raster	A data type consisting of a collection of pixels, represented by a digital number. Raster can have a single layer, or band, or be comprised of multiple bands of information.
Segmentation	An analytical process of identifying statistically similar information within raster data, resulting in a vectorized polygon.
Topographic	Vector information representing physical geographic features collected from high accuracy and aerial photography.
Vector	A data type that can represent different geographic geometries, such as points, lines or polygons, allowing for information to be stored within a corresponding attribute table.

2 Purpose

With the 2018 Tree Canopy Study project there is a requirement to perform a city wide analysis on land cover using an automated process. The automated analysis is to provide a macro level evaluation based on eight different land cover types within the city of Toronto. The findings are to be used for comparative analysis with the results from the 2008 Canopy Study by the project team consultants.

3 Assumptions

The automated land cover classification was developed with the following assumptions:

1. Use existing land cover classes, with the exception of class 8 - agriculture
    a. Agriculture is a land use type, not a form of land cover, it was removed from the analysis
    b. 1 - tree
    c. 2 - grass/shrub
    d. 3 - bare

   e. 4 - water
   f. 5 - building
   g. 6 - road
   h. 7 - other
2. Tree canopy was determined to be the physical extent of a tree, regardless of the known or assumed ground cover (i.e. trees that extended into the street right-of-way were classified as tree)
3. Project area of interest (AOI) is occupied by the current (2018) ward boundaries, excluding non in-land water areas (i.e. Toronto Harbour) previously classified as 4.water
4. Geospatial accuracy is of the highest importance
5. Output dataset to be geospatial raster in .img; to match 2008 analysis

4 Limitations

The following are limitations that were taken into consideration when performing the automated land cover classification:

1. Enterprise geospatial data quality varies in data accuracy, currency and scale
   a. Ward and Neighbourhood administrative boundaries do not share exact geographic distribution
   b. Ward and Neighbourhood administrative boundaries have different creation dates
2. Ward and Neighbourhoods administrative boundaries occupy non in-land water areas (i.e. Toronto Harbour)
3. Topographic features are not all collected in the same calendar year, resulting in currency discrepancies
4. Geospatial accuracy differences between classified land cover data and topographic information
5. Image size limitation within the image classification software, resulting in the creation of image grids for analysis
6. The water class in the 2008 analysis included the Toronto Harbour between Toronto Island and the main shoreline. This area of water was removed from the 2018 analysis as it was not determined to be “in-land water”.
7. Absolute accuracy in the extraction of features through automated analysis
   a. Data similarities between land cover classes
      - Trees and grass/shrub
      - Bare and other
      - Road and other
8. Inability for full automation to provide the desired spatial accuracy

5 Data Sources

The automated land cover analysis utilized a number of different geospatial datasets. To ensure the requirement of obtaining the highest level of accuracy possible, the automated processes leveraged existing authoritative data for the creation of land cover classes, specifically class 4 to class 7 (water, building, roads, other impervious) see Table 40. The remaining classes, class 1, 2, 3 and 8 (tree, grass, bare and shrub) were extracted from multispectral satellite imagery, with the assistance of LiDAR information.

Table 40: Source Data for Land Cover Analysis

Land cover class	Dataset
Tree	Extracted from satellite imagery; assisted with LiDAR
Grass	Extracted from satellite imagery; assisted with LiDAR
Bare	Extracted from satellite imagery; assisted with LiDAR
Water	Government of Canada - National Hydrologic Network
Building	City of Toronto - Topographic database
Road	City of Toronto - Topographic database
Other	City of Toronto - Topographic database
Shrub	Extracted from satellite imagery; assisted with LiDAR

In addition to the data that was used to create the land cover classes, neighbourhood and ward administrative boundaries were utilized for analysis purposes.

6 Methodology

Automated land cover analysis is a process that encompasses a number of different analysis and processes. The following section will outline the methods utilized to generate the automated land cover classes.

The process to automatically classify land cover requires a series of processes that result in a continuous land cover classification for the study area. The process to classify land cover consisted of four main areas: data preparation, image classification, feature engineering, and rasterization. The following sections outline the details of work undertaken within each stage of the classification process.

6.1 Software Requirements

The current automated land cover classification utilized a series of different software applications at different stages of the process. Below is a list of the software and the function it served:

- ArcGIS Pro 2.2.4
  - Polygon to raster transformation
  - Raster mosaic -- combining all land cover class rasters into a single raster file
- PCI Geomatica 2017 - Focus
  - Perform NDVI analysis
- PCI Geomatica 2017 - Object Analyst
  - Image classification
    - Segmentation
    - Feature extraction
    - Model training
    - Classification
- QGIS 3.0
  - Feature engineering of LiDAR statistics
- R x64 3.5.2
  - Used by RStudio 1.1.463
- RStudio 1.1.463
  - Feature engineering
  - Land cover analysis

6.2 Data Preparation

Prior to extracting land cover classes a data preparation exercise was undertaken, a process that is required in all data analysis projects.

1. Project datasets into City of Toronto geographic coordinate reference system
2. Create fifth band with NDVI values
3. Remove non in-land water areas from city-wide administrative boundary polygon
4. Calculate land cover value as new vector attribute for polygon data (topographic, NHN and ward boundary features)
   1. 4 - water
   2. 5 - building
   3. 6 - road
   4. 7 - sidewalk
   5. 7 - city-wide administrative boundary
5. Generate single LiDAR height raster file

6.3 Image Classification

Image classification is the process used to group similar areas of an image (satellite images for this project), with image pixels used to perform the grouping. The automated land cover classification utilized image segmentation to group similar pixels. Two classes were used to train the classification algorithm, pervious and impervious, which were used in the proceeding automation process. The following are the steps and configurations used during the image classification process:

1. Calculate Segmentation
    1. Select raster layer -- NDVI grid raster
    2. Scale = 25
    3. Shape = 0.5
    4. Compactness = 0.5
    5. Export as new file
2. Feature Extraction
    1. Channel statistics = Min, Max, Mean
    2. Geometrical = Compactness, Elongation, Circularity, Rectangularity
3. Training Site Editing
    1. Add two classes
        1. Impervious
        2. Pervious
    2. Add 200 to 600 training samples per class
        1. Geographically distributed
        2. Varying representation for each feature (i.e. single tree, group of trees, grass area, etc.)
        3. Varying segment size and shape
4. Classification
    1. Select the last eight features

6.4 Feature Engineering

Combining additional information with the segmentation polygons allowed for the creation of a classification model to perform the land cover classification. LiDAR height and feature classification were used to provide more information for the land cover classification.

6.4.1 LiDAR Height

LiDAR above ground height information was used to improve the classification between natural land cover classes (tree, grass, shrub, and bare). The addition of height information provides a mechanism to identify features that share similar chlorophyll levels, but have significantly different height properties (i.e. grass vs. tree).

Zonal statistics, a process of extracting numeric values from raster data into polygon vector attributes was performed to add minimum maximum and mean height information.

6.4.2 Feature Classification

Utilizing the LiDAR information, a classification model was developed to generate the land cover classes for tree, grass, shrub, bare, and other. The classification model generated a new attribute column in the polygon layer. The following is the description of the classification model logic:

Land cover tree class = when

LiDAR max height >=1.5; LiDAR mean height >= 0.75 AND NDVI mean > 0.5

Land cover shrub class = when

LiDAR max height < 1.5; LiDAR mean height < 0.75 AND NDVI mean > 0.5

Land cover grass class = when

LiDAR min height = 0; LiDAR mean height < 1 AND NDVI mean >= 0.5

Land cover bare class = when

LiDAR min height = 0; LiDAR mean height < 1 AND NDVI mean between 0.15 & 0.5

Land cover other class = when

LiDAR min height = 0; LiDAR mean height < 1 AND NDVI mean < 0.5

The classified polygons are an input layer for the next stage of the process, rasterization, which requires the data to have a numeric value for each land cover class. The following is the text to numeric re-coding logic:

Land cover value 1 = when

Land cover class = tree

Land cover value 2 = when

Land cover class = grass

Land cover value 3 = when

Land cover class = bare

Land cover value 7 = when

Land cover class = other

Land cover value 8 = when

Land cover class = shrub

6.5 Rasterization

The image classification and feature engineering process provided the content for extracting individual land cover classes. Rasterization was performed to combine all the land cover classes into a single continuous land cover dataset. The following are the source datasets that were used to create a continuous land cover raster dataset:

- Convert topographic features to raster
  - Based on land cover value
- Convert National Hydrologic Network features to raster
  - Based on land cover value
- Convert 2018 ward boundary to raster
  - Based on land cover value
- Convert raster grid segmentation polygon to raster
  - Based on land cover value
- Combine all rasters into a single multi band raster
  - Based on land cover value
  - Combination layering to ensure non-tree land cover did not overlay tree canopy areas; from top to bottom layering:
    - Tree - 1
    - Shrub - 8
    - Building - 5
    - Road - 6
    - Sidewalk - 7
    - Water - 4
    - Grass - 2
    - Bare - 3
    - Other 7

7 Land Cover Analysis

The land cover neighbourhood level analysis was undertaken in RStudio and written as a reproducible code notebook. An R code notebook consists of all libraries, code, and connection to source data required to execute the analysis. R notebooks provide the ability for reproducibility, allowing of the analysis to be re-run at a future date.

8 Change Detection

A common technique in temporal comparative analysis is change detection. Land cover change detection typically is performed to indicate locations where a change has occurred. While this provides useful information, an understanding of what the land cover changed from the baseline conditions in 2008 to what it is now, provides more valuable insights. The change detection analysis will focus on identifying what the land cover class changed into between 2008 and 2018.

8.1 Change Detection Methodology

The change detection analysis is a pixel-to-pixel analysis between the two comparative years (2008 and 2018), however instead of a presence-absence review, the method focused on understanding what the land cover class changed into in 2018. In order to undertake this level of analysis, the land cover data (2008 and 2018) were re-coded from the 1-7 class values, to a range of numeric values at the power of n (1, 2, 4, 8, 16, 32, and 64).

The purpose of the “power of n” data reclassification is to produce a unique numeric value for each change scenario for all seven land cover classes. The re-coding of land cover values were as follows:

- Class 1 to 1
- Class 2 to 2
- Class 3 to 4
- Class 4 to 8
- Class 5 to 16
- Class 6 to 32
- Class 7 to 64

Note that in order for this method to work appropriately, the land cover class value for 2018 shrubs (value 8) was grouped with grass/shrub (value 2) to align with the 2008 land cover classification in order to ensure continuity of the change analysis. This form of change detection results in a range of potential values from -64 to 64 (see Table 41), providing a means to uniquely identifying the original 2008 land cover class and the 2018 land cover class.

Table 41: Change Detection Matrix.

	2018		**Tree**	**Grass / shrub**	**Bare**	**Water**	**Bldg**	**Road**	**Other**
		Value	**1**	**2**	**4**	**8**	**16**	**32**	**64**
2008	*Tree*	1	0	-1	-3	-7	-15	-31	-63
	Grass / shrub	2	1	0	-2	-6	-14	-30	-62
	Bare	4	3	2	0	-4	-12	-28	-60
	Water	8	7	6	4	0	-8	-24	-56
	Bldg.	16	15	14	12	8	0	-16	-48
	Road	32	31	30	28	24	16	0	-32
	Other	64	63	62	60	56	48	32	0

8.2 Change Detection Scenarios

The change detection between the 2008 and 2018 land cover classification had the potential for 49 unique outcomes, with some of the changes being of less value in the discussion of change.

The change analysis was focused on three scenarios:

1. 2008 tree land cover areas changing to impervious land cover features (building, roads, and other impervious)
2. 2008 pervious (grass/shrub, and bare) land cover areas to tree land cover
3. 2008 pervious (grass/shrub, and bare) land cover to impervious land cover features (building, roads, and other impervious)

8.2.1 Scenario 1 - Tree to impervious features

This scenario looked at 2008 tree land cover areas that changed to impervious features (building, road or other impervious). Within this scenario there were three different potential changes:

1. From tree to building 1 minus -16 = -15
2. From tree to road 1 minus -32 = -31
3. From tree to other 1 minus -64 = -63

8.2.2 Scenario 2 - Pervious to tree

This scenario looked at 2008 pervious land cover areas (grass/shrub and bare) that changed to tree land cover features. Within the scenario there were two different potential changes:

1. From grass/shrub to tree 2 minus 1 = 1
2. From bare to tree 4 minus 1 = 3

8.2.3 Scenario 3 - Pervious to impervious features

This scenario looked at 2008 pervious land cover areas (grass/shrub and bare) that changed to impervious land cover features (building, road or other impervious) features. Within this scenario there were six different potential changes:

1. From grass/shrub to building 2 minus -16 = -14
2. From grass/shrub to road 2 minus -32 = -30
3. From grass/shrub to other 2 minus -64 = -62
4. From bare to building 4 minus -16 = -12
5. From bare to road 4 minus -32 = -28
6. From bare to other 4 minus -64 = -60

9 Future Considerations

The City of Toronto has undertaken a land cover classification twice in the past ten years, once in 2008 and again in 2018. During that time period there have been technological advancements, improvements in automated algorithms, and greater data availability. For these reasons it can be difficult to perform a true comparison between two time periods separated by a decade. Throughout the 2018 automated land cover classification process ideas related to improving the end goal of understanding the physical makeup of the city, specifically how it relates to tree coverage has been considered. The final section of this report outlines considerations for improving the understanding of tree coverage in Toronto as it relates to automated land cover classification.

9.1 Reporting Period

Currently the automated land cover process occurs every ten years, as recommended in *Sustaining and Expanding the Urban Forest: Toronto's Strategic Forest Management Plan 2012-2022*. From a policy perspective this may appear to be a good timeframe to analyze change, but for technology a decade is a long time period that experiences significant change, especially in the field of location intelligence. Technology, including hardware, software, algorithms, and data, are currently changing at an unprecedented rate that can make it difficult to replicate the methodologies of a study that occurred ten years prior.

A more pragmatic approach would be to perform a portion of the study every two to three years. The modified study time frame could utilize a different data source and focus on a more targeted subsection of the land cover classes, such as pervious and impervious features; or focus on identifying tree coverage two to three times in a ten year period thereby reducing the gap in technological change, helping to control the methodological variation that occurs during the ten year gap between studies.

9.2 Source Data

The traditional method for automatically classifying land cover is to perform image analysis techniques on remotely sensed data. The major limitation of this approach is the difficulty in identifying the difference between features that share similar chlorophyll levels (i.e. trees, shrubs and grass). While chlorophyll levels are important in categorizing land cover classes other properties can provide great information, specifically height. The combination of chlorophyll levels with height above ground significantly improves the accuracy of identifying features like trees, shrubs and grass. The addition of LiDAR data provides a mechanism for obtaining above ground height information. Additionally, newer LiDAR sensors collect multispectral and elevation information in a single dataset, resulting in an exceptional data source for performing automated land cover classification.

9.3 Reproducible Process

An overlooked aspect of longitudinal studies, such as with the 2018 Tree Canopy Study, is the ability to reproduce the same results at any point between study periods (i.e. between 2008 and 2018, or 2018 and 2028, etc.). The current study had a strong desire to mimic the original 2008 methodology, resulting in a process that has limited reproducibility. The 2008 method was built around software processes, rather than a code-based reproducible method. There are various potential reasons for the original methodological direction, including algorithmic availability, production scalability, human resource ability, etc. However, the previously stated limitations are no longer barriers. Modern data analytics algorithms and technology provide a pathway for developing a reproducible license independent (open source) approach that can be undertaken, improved, and audited at any point in the future. It is recommended that future automated land cover classifications be developed in a manner that allows for complete reproduction of the analysis using available modern approaches which are available in current data analytics domains like Python (i.e. Jupyter Notebook) or R (i.e. R Notebook).

9.4 Third Dimension Analysis

- Move from top down land cover analysis where classes add up to 100%
- Individual class analysis -- may add up to over 100%

Appendix H: Land Use Definitions

General Definitions based on City of Toronto land use types

Commercial – retail, services and office uses

Industrial – manufacturing and associated uses

Institutional – hospitals, schools, places of worship and associated uses

Multifamily Residential – a building or structure meant to house several different families in separate housing units such as duplexes, triplexes and apartment buildings

No Data – current land use is transitional and not yet confirmed

Open Space 1 – parks, natural areas, recreation and community centres

Open Space 2 – golf courses, marinas and cemeteries

Single Family Residential – a detached or semi-detached home occupied by one family

Utilities and Transportation – public utilities and transportation uses

Appendix I: Canopy Change by Neighbourhood 2009-2018

Table 42: Canopy change by neighbourhood 2009-2018. (Source: 2009 and 2018 leaf-on point sample data)

Neighborhood	Percent Canopy 2018	Standard Error Percent	Percent Canopy 2009	Standard Error Percent	Change
Agincourt North (129)	24.00	3.82	15.70	3.50	8.30
Agincourt South-Malvern West (128)	19.83	3.63	24.40	3.90	-4.57
Alderwood (20)	26.83	4.89	24.70	4.70	2.13
Annex (95)	21.05	7.44	19.40	6.60	1.65
Banbury-Don Mills (42)	30.77	3.55	36.20	3.90	-5.43
Bathurst Manor (34)	34.41	4.93	32.40	5.70	2.01
Bay Street Corridor (76)	4.35	4.35	6.70	4.60	-2.35
Bayview Village (52)	51.72	5.36	43.80	5.80	7.92
Bayview Woods-Steeles (49)	43.59	5.61	37.50	6.10	6.09
Bedford Park-Nortown (39)	40.00	5.48	39.60	4.80	0.40
Beechborough-Greenbrook (112)	34.78	12.30	23.30	7.70	11.48
Bendale (127)	28.23	4.04	26.50	4.10	1.73
Birchcliffe-Cliffside (122)	36.96	5.03	31.00	5.00	5.96
Black Creek (24)	18.18	5.20	14.70	4.30	3.48
Blake-Jones (69)	20.00	14.14	26.70	8.10	-6.70
Briar Hill-Belgravia (108)	17.39	8.70	11.10	5.20	6.29
Bridle Path-Sunnybrook-York Mills (41)	47.14	4.22	55.60	4.10	-8.46
Broadview North (57)	29.41	13.15	37.80	8.00	-8.39
Brookhaven-Amesbury (30)	18.97	5.15	17.90	4.70	1.07

Neighborhood	Percent Canopy 2018	Standard Error Percent	Percent Canopy 2009	Standard Error Percent	Change
Cabbagetown-South St.James Town (71)	33.33	11.11	46.70	9.10	-13.37
Caledonia-Fairbank (109)	18.52	8.28	26.70	8.10	-8.18
Casa Loma (96)	37.50	12.50	36.70	8.80	0.80
Centennial Scarborough (133)	36.56	4.99	23.00	4.50	13.56
Church-Yonge Corridor (75)	25.00	12.50	16.70	6.80	8.30
Clairlea-Birchmount (120)	17.71	3.90	15.00	3.60	2.71
Clanton Park (33)	31.67	6.01	11.10	3.70	20.57
Cliffcrest (123)	36.22	4.27	38.20	5.20	-1.98
Corso Italia-Davenport (92)	21.88	8.27	30.00	8.40	-8.13
Danforth (66)	16.67	9.62	23.30	7.70	-6.63
Danforth East York (59)	23.68	7.89	23.50	7.30	0.18
Don Valley Village (47)	36.51	6.07	30.20	5.00	6.31
Dorset Park (126)	14.81	3.42	12.20	3.50	2.61
Dovercourt-Wallace Emerson-Junction (93)	17.39	6.15	16.10	4.70	1.29
Downsview-Roding-CFB (26)	13.39	2.14	13.30	2.30	0.09
Dufferin Grove (83)	9.38	5.41	30.00	8.40	-20.63
East End-Danforth (62)	25.64	6.99	37.10	8.20	-11.46
Edenbridge-Humber Valley (9)	46.24	5.17	41.90	5.30	4.34
Eglinton East (138)	23.53	5.94	13.40	4.20	10.13
Elms-Old Rexdale (5)	33.33	7.03	30.60	7.70	2.73
Englemount-Lawrence (32)	34.78	7.02	32.70	6.70	2.08
Eringate-Centennial-West Deane (11)	25.98	3.89	20.50	3.50	5.48

Neighborhood	Percent Canopy 2018	Standard Error Percent	Percent Canopy 2009	Standard Error Percent	Change
Etobicoke West Mall (13)	31.43	7.85	20.00	7.30	11.43
Flemingdon Park (44)	33.33	8.61	30.00	7.20	3.33
Forest Hill North (102)	30.00	10.00	50.00	9.10	-20.00
Forest Hill South (101)	40.63	8.68	51.20	7.80	-10.58
Glenfield-Jane Heights (25)	18.52	4.32	21.40	4.50	-2.88
Greenwood-Coxwell (65)	37.50	12.50	30.00	8.40	7.50
Guildwood (140)	47.14	5.97	39.20	6.80	7.94
Henry Farm (53)	19.44	7.35	33.30	7.00	-13.86
High Park North (88)	51.72	9.28	36.70	8.80	15.02
High Park-Swansea (87)	65.22	4.97	46.90	5.10	18.32
Highland Creek (134)	32.22	4.93	30.00	5.10	2.22
Hillcrest Village (48)	29.35	4.75	17.90	4.30	11.45
Humber Heights-Westmount (8)	40.48	7.57	28.20	7.20	12.28
Humber Summit (21)	15.83	3.33	8.80	3.00	7.03
Humbermede (22)	18.18	4.75	15.50	4.80	2.68
Humewood-Cedarvale (106)	46.43	9.43	34.40	8.40	12.03
Ionview (125)	7.41	5.24	21.90	7.30	-14.49
Islington-City Centre West (14)	15.73	2.23	15.40	2.30	0.33
Junction Area (90)	15.00	6.12	6.70	4.60	8.30
Keelesdale-Eglinton West (110)	23.53	8.32	17.60	6.50	5.93
Kennedy Park (124)	13.04	5.33	35.10	7.80	-22.06
Kensington-Chinatown (78)	25.00	11.18	20.00	7.30	5.00

Neighborhood	Percent Canopy 2018	Standard Error Percent	Percent Canopy 2009	Standard Error Percent	Change
Kingsview Village-The Westway (6)	23.88	5.21	25.70	5.10	-1.82
Kingsway South (15)	42.55	7.21	46.90	7.10	-4.35
L'Amoreaux (117)	28.04	4.34	28.90	8.60	-0.86
Lambton Baby Point (114)	62.96	9.29	33.30	4.20	29.66
Lansing-Westgate (38)	47.06	5.41	48.10	5.60	-1.04
Lawrence Park North (105)	46.34	7.79	37.50	7.70	8.84
Lawrence Park South (103)	40.35	6.50	39.60	7.10	0.75
Leaside-Bennington (56)	39.66	6.42	47.90	5.80	-8.24
Little Portugal (84)	6.25	6.25	10.00	5.50	-3.75
Long Branch (19)	15.00	6.12	26.50	7.60	-11.50
Malvern (132)	27.87	4.06	25.90	3.70	1.97
Maple Leaf (29)	39.53	7.46	22.00	5.90	17.53
Markland Wood (12)	31.82	7.02	28.80	6.30	3.02
Milliken (130)	13.16	2.74	8.10	2.10	5.06
Mimico (includes Humber Bay Shores) (17)	16.49	3.77	13.40	3.50	3.09
Morningside (135)	52.69	5.18	53.80	5.60	-1.11
Moss Park (73)	5.56	5.56	13.30	6.20	-7.74
Mount Dennis (115)	39.29	9.23	25.60	7.00	13.69
Mount Olive-Silverstone-Jamestown (2)	25.71	5.22	31.60	5.30	-5.89
Mount Pleasant East (99)	44.90	7.11	54.80	7.70	-9.90
Mount Pleasant West (104)	30.00	12.25	30.00	8.40	0.00
New Toronto (18)	15.25	5.08	8.70	4.20	6.55

Neighborhood	Percent Canopy 2018	Standard Error Percent	Percent Canopy 2009	Standard Error Percent	Change
Newtonbrook East (50)	33.33	5.44	28.60	5.70	4.73
Newtonbrook West (36)	27.71	4.91	24.70	4.60	3.01
Niagara (82)	15.09	5.34	16.70	5.10	-1.61
North Riverdale (68)	21.05	10.53	26.50	7.60	-5.45
North St.James Town (74)	12.50	12.50	13.30	6.20	-0.80
O'Connor-Parkview (54)	50.00	5.81	35.00	7.70	15.00
Oakridge (121)	14.29	8.25	23.30	6.80	-9.01
Oakwood Village (107)	17.14	7.00	16.70	5.30	0.44
Old East York (58)	45.71	8.42	23.30	6.40	22.41
Palmerston-Little Italy (80)	10.53	7.44	20.00	7.30	-9.47
Parkwoods-Donalda (45)	38.39	4.60	35.90	4.70	2.49
Pelmo Park-Humberlea (23)	31.08	5.38	18.00	4.90	13.08
Playter Estates-Danforth (67)	11.76	8.32	36.70	8.80	-24.94
Pleasant View (46)	22.22	7.86	26.30	7.10	-4.08
Princess-Rosethorn (10)	39.19	5.67	38.70	6.20	0.49
Regent Park (72)	18.20	3.88	20.00	7.30	-1.80
Rexdale-Kipling (4)	30.56	7.68	19.40	6.60	11.16
Rockcliffe-Smythe (111)	29.41	4.94	30.30	4.90	-0.89
Roncesvalles (86)	7.41	5.24	13.30	6.20	-5.89
Rosedale-Moore Park (98)	44.93	5.99	61.80	5.90	-16.87
Rouge (131)	37.98	1.98	33.10	1.80	4.88
Runnymede-Bloor West Village (89)	48.57	8.45	26.70	8.10	21.87

Neighborhood	Percent Canopy 2018	Standard Error Percent	Percent Canopy 2009	Standard Error Percent	Change
Rustic (28)	31.58	7.54	30.00	8.40	1.58
Scarborough Village (139)	31.37	6.50	44.70	7.30	-13.33
South Parkdale (85)	25.64	6.99	20.50	6.50	5.14
South Riverdale (70)	27.56	3.58	21.20	3.30	6.36
St. Andrew-Windfields (40)	36.04	4.56	38.30	4.30	-2.26
Steeles (116)	19.28	4.33	13.20	3.90	6.08
Stonegate-Queensway (16)	43.40	4.81	32.20	4.40	11.20
Tam O'Shanter-Sullivan (118)	24.73	4.47	28.40	4.80	-3.67
Taylor-Massey (61)	50.00	17.68	40.00	8.90	10.00
The Beaches (63)	48.00	7.07	40.30	6.20	7.70
Thistletown-Beaumond Heights (3)	38.18	6.55	36.00	6.80	2.18
Thorncliffe Park (55)	18.33	5.00	18.40	5.50	-0.07
Trinity-Bellwoods (81)	28.57	10.10	33.30	8.60	-4.73
University (79)	7.69	7.69	30.00	8.40	-22.31
Victoria Village (43)	22.22	5.24	21.50	4.60	0.72
Waterfront Communities-The Island (77)	10.43	2.10	13.90	2.40	-3.47
West Hill (136)	41.79	4.26	42.30	4.00	-0.51
West Humber-Clairville (1)	13.17	1.57	10.30	1.40	2.87
Westminster-Branson (35)	42.19	6.17	21.20	5.70	20.99
Weston (113)	29.27	7.11	34.80	7.00	-5.53
Weston-Pellam Park (91)	17.86	7.99	23.30	7.70	-5.44
Wexford/Maryvale (119)	16.56	3.02	12.20	2.40	4.36

Neighborhood	Percent Canopy 2018	Standard Error Percent	Percent Canopy 2009	Standard Error Percent	Change
Willowdale East (51)	34.57	5.28	28.40	5.20	6.17
Willowdale West (37)	17.95	6.78	30.20	6.30	-12.25
Willowridge-Martingrove-Richview (7)	30.51	5.99	37.20	5.20	-6.69
Woburn (137)	22.10	3.08	25.80	3.20	-3.70
Woodbine Corridor (64)	36.36	12.86	43.30	9.00	-6.94
Woodbine-Lumsden (60)	47.37	15.79	23.30	7.70	24.07
Wychwood (94)	38.89	14.70	26.70	8.10	12.19
Yonge-Eglinton (100)	28.13	9.38	43.30	9.00	-15.18
Yonge-St.Clair (97)	32.00	11.31	50.00	9.10	-18.00
York University Heights (27)	16.58	2.68	13.50	2.30	3.08
Yorkdale-Glen Park (31)	12.63	3.41	11.00	3.50	1.63

Appendix J: Land Cover 2018

Table 43: Land cover 2018 (Data Sources: 2009 point sample (from 2013 Assessing Urban Forest Effects and Values report), 2018 point sample data, and 2008 land use (from Every Tree Counts report)

Note: "No Data" and "Other" land use category removed for summary

Land cover 2018 by land use 2008	Commercial	Industrial	Institutional	Open Space 1	Open Space 2	Multifamily Residential	Single Family Residential	Utilities & Transportation
Agriculture	0	0	0	0	8.6957	0	0	3.1941
Building	27.5912	31.7096	15.7971	0.974	1.7013	21.4165	23.8729	3.9312
Grass	7.8832	11.5809	26.2319	24.1342	36.1059	17.5379	14.9965	29.7297
Impervious other	41.0219	37.3162	25.5072	5.7359	10.9641	24.1147	17.1455	33.6609
Road	14.8905	7.4449	8.1159	5.1948	4.9149	12.3103	9.8809	6.3882
Soil	0.438	3.125	1.8841	2.1645	2.6465	0.8432	0.8643	4.4226
Tree/shrub	8.0292	8.7316	22.029	58.3333	33.0813	23.7774	33.1698	17.6904
Water	0.146	0.0919	0.4348	3.4632	1.8904	0	0.0701	0.9828

Table 44: Detailed SAS (Statistical Analysis Software) Table Output

Land Use (2008)	Frequency Count	Percent of Total Frequency	Confidence Interval 95	Upper 95 Confidence Interval	Lower 95 Confidence Interval	Upper Accuracy	Lower Accuracy	Standard Error Percent
Grass	3	5.0847	0.05606	0.1069	-0.00521	0.07945	0.02225	2.93568
Impervious other	4	6.7797	0.06415	0.13195	0.00365	0.10053	0.03507	3.38983
Road	1	1.6949	0.03294	0.04989	-0.01599	0.03375	0.00014	1.69492
Soil	2	3.3898	0.04618	0.08008	-0.01228	0.05746	0.01034	2.39697
Tree/shrub	4	6.7797	0.06415	0.13195	0.00365	0.10053	0.03507	3.38983
Water	45	76.2712	0.10855	0.87127	0.65416	0.8181	0.70733	5.5385

Land Use (2008)	Frequency Count	Percent of Total Frequency	Confidence Interval 95	Upper 95 Confidence Interval	Lower 95 Confidence Interval	Upper Accuracy	Lower Accuracy	Standard Error Percent
Building	189	27.5912	0.03347	0.30939	0.24244	0.29299	0.25883	1.7078
Grass	54	7.8832	0.02018	0.09901	0.05865	0.08913	0.06854	1.02962
Impervious other	281	41.0219	0.03684	0.44705	0.37338	0.42901	0.39143	1.87935
Road	102	14.8905	0.02666	0.17556	0.12225	0.16251	0.1353	1.36019
Soil	3	0.438	0.00495	0.00932	-0.00057	0.0069	0.00186	0.25285
Tree/shrub	55	8.0292	0.02035	0.10064	0.05994	0.09067	0.06991	1.03828
Water	1	0.146	0.00286	0.00432	-0.0014	0.00292	0	0.14599
Building	345	31.7096	0.02765	0.34475	0.28944	0.3312	0.30299	1.41078
Grass	126	11.5809	0.01901	0.13482	0.09679	0.12551	0.10611	0.97013
Impervious other	406	37.3162	0.02874	0.4019	0.34442	0.38782	0.3585	1.46626
Road	81	7.4449	0.0156	0.09005	0.05885	0.08241	0.06649	0.79582
Soil	34	3.125	0.01034	0.04159	0.02091	0.03652	0.02598	0.52749
Tree/shrub	95	8.7316	0.01677	0.10409	0.07054	0.09587	0.07876	0.85584
Water	1	0.0919	0.0018	0.00272	-0.00088	0.00184	0	0.09191
Building	109	15.7971	0.02721	0.18518	0.13076	0.17186	0.14409	1.38844
Grass	181	26.2319	0.03282	0.29514	0.2295	0.27907	0.24557	1.67465
Impervious other	176	25.5072	0.03253	0.2876	0.22255	0.27167	0.23848	1.65945
Road	56	8.1159	0.02038	0.10154	0.06078	0.09156	0.07076	1.0396
Soil	13	1.8841	0.01014	0.02899	0.0087	0.02402	0.01366	0.5176
Tree/shrub	152	22.029	0.03092	0.25121	0.18937	0.23607	0.20451	1.57775
Water	3	0.4348	0.00491	0.00926	-0.00056	0.00685	0.00184	0.25102
Building	10	7.6923	0.04581	0.12273	0.03112	0.10029	0.05355	2.33709
Grass	53	40.7692	0.08447	0.49217	0.32322	0.45079	0.36459	4.30991
Impervious other	18	13.8462	0.05937	0.19783	0.07909	0.16875	0.10817	3.02922

Land Use (2008)	Frequency Count	Percent of Total Frequency	Confidence Interval 95	Upper 95 Confidence Interval	Lower 95 Confidence Interval	Upper Accuracy	Lower Accuracy	Standard Error Percent
Road	14	10.7692	0.05329	0.16098	0.0544	0.13488	0.0805	2.7188
Soil	1	0.7692	0.01502	0.02271	-0.00733	0.01535	0.00003	0.76923
Tree/shrub	30	23.0769	0.07243	0.3032	0.15834	0.26772	0.19382	3.69527
Water	4	3.0769	0.02969	0.06046	0.00108	0.04592	0.01562	1.53846
Building	9	0.974	0.00633	0.01607	0.00341	0.01297	0.00651	0.32468
Grass	223	24.1342	0.02759	0.26893	0.21375	0.25542	0.22727	1.40768
Impervious other	53	5.7359	0.01499	0.07235	0.04237	0.06501	0.04971	0.76496
Road	48	5.1948	0.01431	0.06626	0.03764	0.05925	0.04465	0.73007
Soil	20	2.1645	0.00938	0.03103	0.01226	0.02643	0.01686	0.47873
Tree/shrub	539	58.3333	0.03179	0.61512	0.55154	0.59955	0.56711	1.62187
Water	32	3.4632	0.01179	0.04642	0.02284	0.04065	0.02862	0.60152
Agriculture	46	8.6957	0.02401	0.11097	0.06294	0.09921	0.07471	1.22509
Building	9	1.7013	0.01102	0.02803	0.00599	0.02264	0.01139	0.56711
Grass	191	36.1059	0.04093	0.40199	0.32013	0.38194	0.34018	2.08829
Impervious other	58	10.9641	0.02663	0.13627	0.08302	0.12323	0.09606	1.35844
Road	26	4.9149	0.01842	0.06757	0.03073	0.05855	0.03975	0.93991
Soil	14	2.6465	0.01368	0.04014	0.01279	0.03344	0.01949	0.69789
Tree/shrub	175	33.0813	0.0401	0.37091	0.29072	0.35127	0.31036	2.04568
Water	10	1.8904	0.01161	0.03051	0.0073	0.02482	0.01298	0.59211
Agriculture	2	0.3252	0.0045	0.00775	-0.00125	0.00555	0.00096	0.22995
Building	39	6.3415	0.01926	0.08268	0.04415	0.07324	0.05359	0.98272
Grass	138	22.439	0.03297	0.25736	0.19142	0.24121	0.20757	1.68223
Impervious other	127	20.6504	0.03199	0.2385	0.17451	0.22283	0.19018	1.6323
Road	76	12.3577	0.02601	0.14959	0.09757	0.13685	0.11031	1.32705

Land Use (2008)	Frequency Count	Percent of Total Frequency	Confidence Interval 95	Upper 95 Confidence Interval	Lower 95 Confidence Interval	Upper Accuracy	Lower Accuracy	Standard Error Percent
Soil	24	3.9024	0.01531	0.05433	0.02372	0.04683	0.03122	0.78088
Tree/shrub	152	24.7154	0.03409	0.28125	0.21306	0.26455	0.22976	1.7394
Water	57	9.2683	0.02292	0.1156	0.06976	0.10438	0.08099	1.16934
Building	127	21.4165	0.03302	0.24718	0.18115	0.23101	0.19732	1.68466
Grass	104	17.5379	0.03061	0.20599	0.14477	0.191	0.15976	1.56167
Impervious other	143	24.1147	0.03443	0.27558	0.20672	0.25871	0.22358	1.75668
Road	73	12.3103	0.02644	0.14955	0.09666	0.1366	0.10961	1.34921
Soil	5	0.8432	0.00736	0.01579	0.00107	0.01219	0.00468	0.37708
Tree/shrub	141	23.7774	0.03427	0.27204	0.20351	0.25526	0.22029	1.74822
Building	1022	23.8729	0.01277	0.2515	0.22596	0.24524	0.23221	0.65155
Grass	642	14.9965	0.0107	0.16066	0.13927	0.15542	0.14451	0.54568
Impervious other	734	17.1455	0.01129	0.18275	0.16016	0.17722	0.16569	0.57605
Road	423	9.8809	0.00894	0.10775	0.08987	0.10337	0.09425	0.45607
Soil	37	0.8643	0.00277	0.01142	0.00587	0.01006	0.00723	0.14147
Tree/shrub	1420	33.1698	0.0141	0.3458	0.31759	0.33889	0.3245	0.71959
Water	3	0.0701	0.00079	0.00149	-0.00009	0.00111	0.0003	0.04046
Agriculture	13	3.1941	0.01708	0.04902	0.01486	0.04066	0.02322	0.87162
Building	16	3.9312	0.01888	0.05819	0.02043	0.04894	0.02968	0.96329
Grass	121	29.7297	0.04441	0.3417	0.25289	0.31995	0.27464	2.2656
Impervious other	137	33.6609	0.04591	0.38252	0.2907	0.36003	0.31319	2.34234
Road	26	6.3882	0.02376	0.08764	0.04012	0.076	0.05176	1.21215
Soil	18	4.4226	0.01997	0.0642	0.02425	0.05442	0.03403	1.01911
Tree/shrub	72	17.6904	0.03707	0.21398	0.13983	0.19582	0.15799	1.89146
Water	4	0.9828	0.00958	0.01941	0.00024	0.01472	0.00494	0.4914

Appendix K: 2018 Baseline Land Cover by 2018 Land Use (Zoning)

Table 45: 2018 Baseline land cover by 2018 land use (Zoning). (Sources: 2018 Land Use, 2018 leaf-on point sample (10,000 points) satellite imagery)

2018 Land Use	# of Points	Cover Types 2018	Percent of Total Frequency	Confidence Interval 95	Upper 95 Confidence Interval	Lower 95 Confidence Interval	Standard Error %
Commercial	505	Building	31.49	0.04	0.36	0.27	2.07
Commercial	505	Grass	5.35	0.02	0.07	0.03	1.00
Commercial	505	Impervious other	37.82	0.04	0.42	0.34	2.16
Commercial	505	Road	15.84	0.03	0.19	0.13	1.62
Commercial	505	Soil	1.58	0.01	0.03	0.00	0.56
Commercial	505	Tree/shrub	7.92	0.02	0.10	0.06	1.20
Industrial	1355	Agriculture	0.22	0.00	0.00	0.00	0.13
Industrial	1355	Building	29.89	0.02	0.32	0.27	1.24
Industrial	1355	Grass	10.85	0.02	0.13	0.09	0.84
Industrial	1355	Impervious other	42.14	0.03	0.45	0.40	1.34
Industrial	1355	Road	7.68	0.01	0.09	0.06	0.72
Industrial	1355	Soil	2.73	0.01	0.04	0.02	0.44
Industrial	1355	Tree/shrub	6.35	0.01	0.08	0.05	0.66
Industrial	1355	Water	0.15	0.00	0.00	0.00	0.10
Institutional	205	Building	16.10	0.05	0.21	0.11	2.57
Institutional	205	Grass	31.22	0.06	0.38	0.25	3.24
Institutional	205	Impervious other	30.73	0.06	0.37	0.24	3.22
Institutional	205	Road	6.83	0.03	0.10	0.03	1.76
Institutional	205	Soil	0.98	0.01	0.02	0.00	0.69
Institutional	205	Tree/shrub	14.15	0.05	0.19	0.09	2.43
No data	424	Building	12.26	0.03	0.15	0.09	1.59

2018 Land Use	# of Points	Cover Types 2018	Percent of Total Frequency	Confidence Interval 95	Upper 95 Confidence Interval	Lower 95 Confidence Interval	Standard Error %
No data	424	Grass	25.24	0.04	0.29	0.21	2.11
No data	424	Impervious other	33.49	0.04	0.38	0.29	2.29
No data	424	Road	8.96	0.03	0.12	0.06	1.39
No data	424	Soil	5.66	0.02	0.08	0.03	1.12
No data	424	Tree/shrub	12.50	0.03	0.16	0.09	1.61
No data	424	Water	1.89	0.01	0.03	0.01	0.67
Open space 1	1104	Agriculture	5.16	0.01	0.06	0.04	0.67
Open space 1	1104	Building	0.27	0.00	0.01	0.00	0.16
Open space 1	1104	Grass	19.66	0.02	0.22	0.17	1.20
Open space 1	1104	Impervious other	3.53	0.01	0.05	0.02	0.56
Open space 1	1104	Road	2.99	0.01	0.04	0.02	0.51
Open space 1	1104	Soil	2.81	0.01	0.04	0.02	0.50
Open space 1	1104	Tree/shrub	62.23	0.03	0.65	0.59	1.46
Open space 1	1104	Water	3.35	0.01	0.04	0.02	0.54
Open space 2	656	Building	1.68	0.01	0.03	0.01	0.50
Open space 2	656	Grass	44.66	0.04	0.48	0.41	1.94
Open space 2	656	Impervious other	11.13	0.02	0.14	0.09	1.23
Open space 2	656	Road	3.66	0.01	0.05	0.02	0.73
Open space 2	656	Soil	1.83	0.01	0.03	0.01	0.52
Open space 2	656	Tree/shrub	36.13	0.04	0.40	0.32	1.88
Open space 2	656	Water	0.91	0.01	0.02	0.00	0.37
Other	6	Grass	16.67	0.30	0.46	-0.13	16.67
Other	6	Impervious other	33.33	0.38	0.71	-0.04	23.57
Other	6	Tree/shrub	50.00	0.40	0.90	0.10	28.87
Multifamily residential	860	Building	23.49	0.03	0.26	0.21	1.45

2018 Land Use	# of Points	Cover Types 2018	Percent of Total Frequency	Confidence Interval 95	Upper 95 Confidence Interval	Lower 95 Confidence Interval	Standard Error %
Multifamily residential	860	Grass	18.14	0.03	0.21	0.16	1.31
Multifamily residential	860	Impervious other	22.91	0.03	0.26	0.20	1.43
Multifamily residential	860	Road	11.51	0.02	0.14	0.09	1.09
Multifamily residential	860	Soil	0.70	0.01	0.01	0.00	0.28
Multifamily residential	860	Tree/shrub	23.26	0.03	0.26	0.20	1.44
Single family residential	4251	Building	23.59	0.01	0.25	0.22	0.65
Single family residential	4251	Grass	15.01	0.01	0.16	0.14	0.55
Single family residential	4251	Impervious other	17.48	0.01	0.19	0.16	0.58
Single family residential	4251	Road	9.55	0.01	0.10	0.09	0.45
Single family residential	4251	Soil	0.78	0.00	0.01	0.01	0.13
Single family residential	4251	Tree/shrub	33.55	0.01	0.35	0.32	0.72
Single family residential	4251	Water	0.05	0.00	0.00	0.00	0.03
Utility and transportation	526	Agriculture	0.19	0.00	0.01	0.00	0.19
Utility and transportation	526	Building	1.33	0.01	0.02	0.00	0.50
Utility and transportation	526	Grass	35.17	0.04	0.39	0.31	2.08
Utility and transportation	526	Impervious other	21.86	0.04	0.25	0.18	1.80
Utility and transportation	526	Road	24.33	0.04	0.28	0.21	1.87
Utility and transportation	526	Soil	3.23	0.02	0.05	0.02	0.77

2018 Land Use	# of Points	Cover Types 2018	Percent of Total Frequency	Confidence Interval 95	Upper 95 Confidence Interval	Lower 95 Confidence Interval	Standard Error %
Utility and transportation	526	Tree/shrub	13.69	0.03	0.17	0.11	1.50
Utility and transportation	526	Water	0.19	0.00	0.01	0.00	0.19

Appendix L: Canopy by Ward (2018)

Table 46: Canopy by ward (2018). (Source: 2018 leaf-on point sample)

Ward	% Tree Canopy (Tree and Shrub)	Standard Error %
Beaches-East York	40.71	3.09
Davenport	15.08	2.54
Don Valley East	29.45	2.46
Don Valley North	36.73	2.43
Don Valley West	41.58	2.25
Eglinton-Lawrence	28.73	2.40
Etobicoke Centre	33.93	2.01
Etobicoke North	19.37	1.46
Etobicoke-Lakeshore	22.13	1.67
Humber River-Black Creek	20.25	1.83
Parkdale-High Park	48.46	3.10
Scarborough Centre	19.60	1.86
Scarborough North	19.11	1.81
Scarborough Southwest	27.56	2.21
Scarborough-Agincourt	22.38	2.19
Scarborough-Guildwood	33.99	2.34
Scarborough-Rouge Park	40.52	1.68
Spadina-Fort York	12.93	1.96
Toronto Centre	14.94	3.82
Toronto-Danforth	28.09	2.60

Ward	% Tree Canopy (Tree and Shrub)	Standard Error %
Toronto-St. Paul's	36.98	3.48
University-Rosedale	26.59	3.36
Willowdale	32.32	2.58
York Centre	23.65	1.77
York South-Weston	27.16	2.21