2023 King Township Forest Study: Technical Report

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Acknowledgements

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Executive Summary

The Regional Municipality of York (York Region) along with the Township of King (King) are committed to assessing the distribution, structure, and function of King's forest every ten years through a forest study. A forest study employs a combination of remote sensing, GIS tools, and plot-based field surveys to characterize the forest across the entire Township and examines factors that may impact its health and function, including invasive species, soil condition, and climate change.

The Region in partnership with King retained Toronto and Region Conservation Authority (TRCA) to undertake the King Township Forest Study. This technical report summarizes the Study and examines the distribution of canopy cover by Municipal Property Assessment Corporation (MPAC) land use type, available planting opportunities, tree size, species composition, the structural and ecosystem services value of the forest, condition of the forest, and soil properties. Additionally, the report explores the potential future state of the forest and climate vulnerability. Data for the assessments were collected in 2022, but the study is known as the *2023* Forest Study.

King's forest has an estimated 9,588,224 trees with an estimated structural value of $2.3 billion. The gross carbon sequestration of trees in King is approximately 28,490 tonnes of carbon per year, with an associated annual value of $29.7 million. Considering loss of carbon from decomposition of dead trees, net sequestration is 12,790 tonnes per year (46,899 tonnes CO_2 per year) with a value of $13.3 million. Trees store 1,017,851 tonnes of carbon valued at $1.06 billion. King's forest removes 468 tonnes of air pollution annually; the benefit of this ecosystem service is valued at $359,486 annually. In King the forest reduces the annual energy consumption of residential homes and low-rise apartments by approximately 16,768 MWH, with an associated annual financial savings of approximately $439,311.

Canopy cover in King is at thirty-four percent, driven by tree planting, natural regeneration, and growth of existing trees and forest cover. A total of sixty-three percent (20,928 ha) of the Township's land area could theoretically support additional canopy. However, much of this area is contained within active agricultural areas, most of which is not suitable for tree establishment beyond the planting of hedgerows. The greatest opportunity to plant trees outside of agricultural areas is in low density residential areas with a potential space available of 2,282 hectares.

King's forest is relatively young, and sixty-eight percent of the trees are in fair to excellent condition. Approximately, sixty-one percent of all trees are less than 15.2 cm diameter at breast height (DBH) – these trees will grow in future years, increasing both canopy cover and benefit provision. The top three most commonly occurring species, sugar maple, eastern white cedar, and white ash, make up 31 percent of the tree population. These are common forest species for this ecoregion and their dominance is to be expected. Furthermore, King's forest is more diverse than nearby urban municipalities. However, by fostering a greater species diversity, the resilience of the forest to impacts of climate change, pests, and diseases could be increased. Tree planting programs should consider species selection and diversity to account for climate change and invasive species impacts. Over the past decade emerald ash borer beetle (EAB) has significantly impacted ash trees causing high tree mortality across the Township, which has slowed the Townships' efforts to increase canopy cover.

Soil and climate change impact the health of the forest – soil on private properties was found to have better condition than public properties, having lower compaction, salinity, and pH. Thirteen out of the top twenty species in King are expected to be highly to extremely vulnerable to climatic changes that would occur by the 2050s, according to the Intergovernmental Panel on Climate Change's Representative Concentration Pathway (RCP) 8.5 (business-as-usual scenario).

Summary of Results

Through regular monitoring, this information can be used to track progress towards established goals, measure the effectiveness of efforts to maintain a healthy forest, and guide future management decisions.

Tree Cover and Leaf Area

King's 9,588,224 trees (±1,179,056) provide the Township with 34 percent canopy cover. The high canopy cover across King is primarily driven by natural growth of trees, particularly in forested/woodland areas. Natural growth has outpaced losses from urbanization. There is a need to maintain tree planting requirements and restoration plans as King urbanizes to ensure that canopy growth continues despite development and construction.

Leaf area, the total surface area of one side of all tree leaves in King, is approximately 91,956 hectares across a municipal area of 33,656 hectares. Average tree density in King is 285 trees/ha, which is above the average of the Greater Toronto Area at 202 trees/ha and similar to results found by the Whitchurch-Stouffville Forest Study (2024) of 289 trees/ha. In theory, 63 percent (20,928 ha) of the Township's land area could support additional canopy. However, much of this area is contained within active agricultural areas, most of which in practice cannot be planted.

Seventeen percent (±5.0%) of the tree population occurs on public lands (such as municipal parks, rights-of-ways (ROWs), and protected areas, including conservation authority lands), and eighty-three percent (±11.7%) of trees are privately owned. Therefore, working with private landowners is an essential component of maintaining and enhancing the Township's forest.

Species Composition

Table i: Top three species in terms of most abundant tree species and percent leaf area in 2023

Species	Percent of Population (%)	Species	Percent of Leaf Area (%)
Sugar maple (*Acer saccharum*)	13	Sugar maple	29
Eastern white cedar (*Thuja occidentalis*)	10	American basswood (*Tilia americana*)	8
White ash (*Fraxinus americana*)	8	White spruce (*Picea glauca*)	6

The top three most abundant tree species made up 31 percent of the total population in 2023. Sugar maple, eastern white cedar and white ash are common forest species for Ecoregion 6E (Lake Simcoe-Rideau). Their proportion of the tree population is within an acceptable range for natural forest populations. Overall, the tree population in King is heterogeneous, although it is still important to cultivate and support tree diversity where possible.

With respect to percent of total leaf area, the dominant tree species in King in 2023 were sugar maple, American basswood, and white spruce. Sugar maple represents both the largest proportion of leaf area and tree population in King and is the key forest species across the Township.

Tree Size

Sixty-one percent of all trees have a diameter at breast height (DBH) smaller than 15.2 cm and just over 13 percent of the tree population has a DBH of 30.6 cm or greater. Across all MPAC land uses the trend is similar, with the smallest diameter classes containing the large majority of trees, while fewer trees (3.8%) are found in the large (>45.7 cm) diameter classes. The average tree diameter in King is 16.4 cm which is greater than neighboring municipalities. Because most of the trees in King are young, they have the potential to add significantly to the canopy in the future. Active planting needs to continue, particularly in urban spaces, and trees of all sizes require protection to ensure that there are younger trees to replace older trees as they die. Older and larger trees provide significantly more ecosystem service benefits than smaller trees and it takes decades to replace them with new plantings.

Condition and Tree Health

All trees measured in the field were assigned a condition rating based on the proportion of dieback in the canopy. The majority of trees are in good to fair condition with approximately 68 percent of trees in King estimated to be in either excellent, good or fair condition. However, the percent of trees in poor condition, critical, dying, or dead should be monitored by land use stratum. As shown in Figure i below, *Open Space – Natural Cover* (37.6%) has the greatest proportion of dead trees, followed by *Other – Institutional* (33.9%), *Other urban* (26.0%) and *Agriculture* (23.7%) land use categories*.* This partly reflects ash (*Fraxinus* spp.) on some of these sites, many of which have died, but also is indicative of the woodlot cover present across majority of these land use strata. In natural areas, it is beneficial to leave some dead and dying trees which provide additional habitat and resources, and do not pose a risk to public safety, whereas in residential areas and rights-of-ways (ROWs), it is important to remove dead or dying trees which can fall and potentially cause damage to infrastructure and/or injure people.

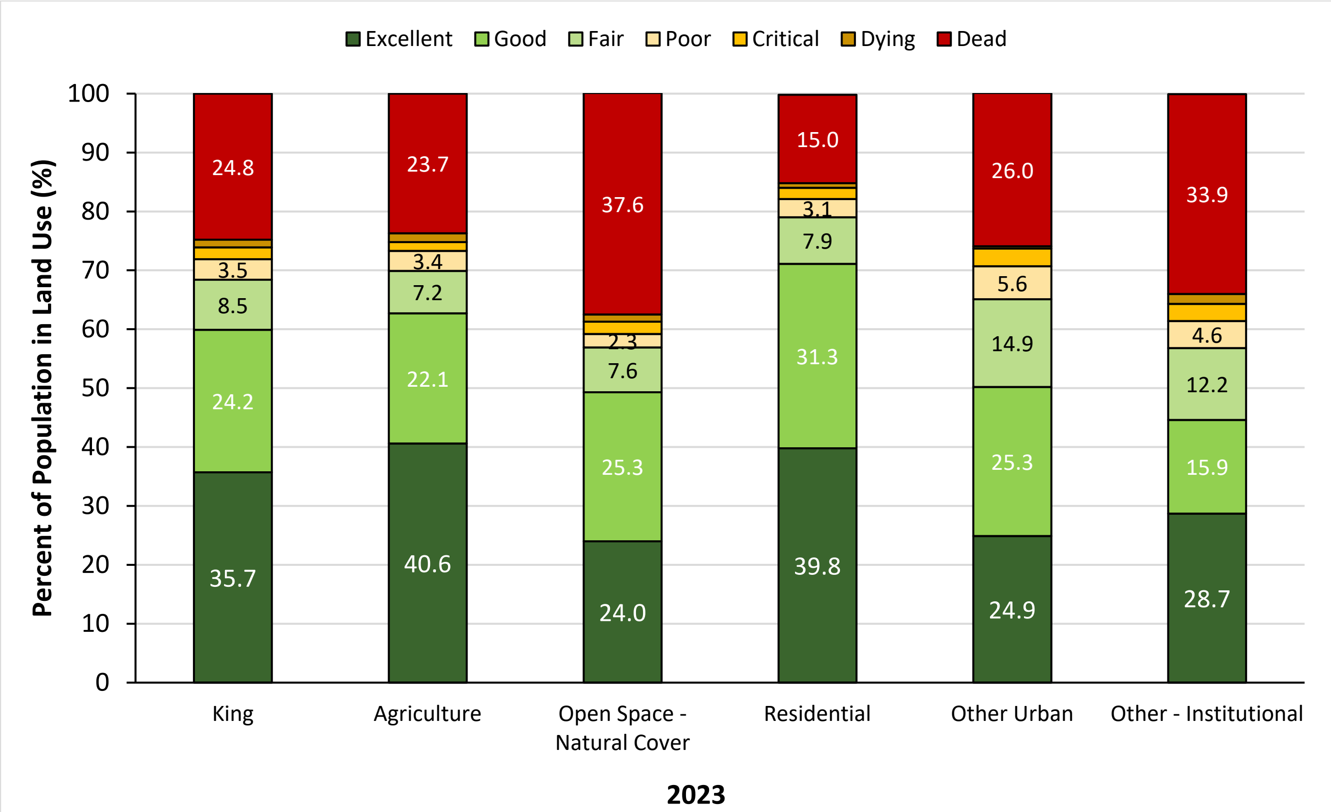

Figure i: The proportion of trees in each condition category across King MPAC land uses

Structural Value of Trees

The estimated structural value of all trees (both public and private) in King in 2023 is approximately $2.3 billion. Most of this value is found on private lands where 83% of trees occur. The structural value does not represent the ecological or societal value of the forest, but rather provides an estimate of total tree replacement cost. This value is based on the Council of Tree and Landscape Appraisers (CTLA) Trunk Formula method (Nowak, 2020) and considers species, DBH, condition, and location.

Ecosystem Service Benefits

Carbon Storage and Sequestration

As a tree grows, it removes carbon dioxide from the atmosphere; this process is referred to as *gross carbon sequestration*, which is expressed as an annual rate of removal. Carbon is then stored in the woody biomass of the tree; this can be expressed as total *carbon storage*. When a tree dies, much of the stored carbon is released back to the atmosphere through decomposition. The difference between gross carbon sequestration and decomposition is known as *net sequestration.* Trees in King sequester approximately 28,490 tonnes of carbon per year, with an associated annual value of $29.7 million and store 1,017,851 tonnes of carbon, valued at $1.06 billion. Taking into account decomposition, the net carbon sequestration of King's forest is 12,790 tonnes per year (46,899 tonnes CO_2 per year) with a value of $13.3 million.

Air Pollution Removal

The forest can improve local air quality by absorbing and intercepting airborne pollutants. King's forest removes 468 tonnes of air pollution annually; the benefit of this ecosystem service is valued at $359,486 annually.

- Ozone: 396.02 tonnes
- Particulate matter (2.5 microns): 23.60 tonnes
- Nitrogen dioxide: 39.90 tonnes
- Sulfur dioxide: 3.99 tonnes
- Carbon monoxide: 4.73 tonnes

Residential Energy Savings

Trees reduce local air temperature due to shading effects, wind speed reductions, and the release of water vapor through evapotranspiration. In King, the forest reduces the annual energy consumption of residential homes and low-rise apartments by approximately 16,768 MWH, with an associated annual financial savings of approximately $439,311.

Hydrological Benefits

The forest helps to prevent rainwater from entering the stormwater system, known as avoided runoff, by capturing rainwater, evapotranspiration, and facilitating the infiltration of water into the soil. Using 2019 rainfall data from Pearson International Airport, it was determined that 139,991 m^3 of precipitation were prevented from entering the stormwater system in 2019 with an associated value of $325,228 per year.

Soil

Soil quality is a vital component and indicator of forest health. Important components of soil health include compaction with impacts the ability of roots and water to penetrate the soil, as well as salinity and pH, which impact growing conditions. In general, higher levels of salinity are harmful to plant growth as well as pH levels outside of an ideal range of 6 to 7. Soil in plots occurring in built or developed land uses (*Residential – Other Urban*) had worse soil health than plots occurring in less developed land uses. *Residential* and *Other Urban* land uses had a lower proportion of uncompacted plots, higher median salinity, and a higher median pH (see Table ii).

Table ii: Soil properties across King

Soil Quality	Open Space – Natural Cover & Other – Institutional	Agriculture	Residential – Other Urban
Percent of uncompacted plots (%)	53	50	24
Median salinity (µS/cm)	106.5	100.8	129.3
Median pH	6.2	6.3	7.2

Invasive Species

Plants

Out of the 193 plots surveyed for this study, 48 percent of plots had at least one invasive plant species present. Invasive plant species were most prevalent in the *Residential* land use stratum (78% of plots), followed by *Other – Institutional* (62.5%) and *Open Space – Natural Cover* (52.2%). The most commonly found invasive species in terms of the percentage of plots affected were European buckthorn (*Rhamnus cathartica*; 26%), Manitoba maple (*Acer negundo*; 15%), non-native honeysuckle (*Lonicera spp*.; 13.5%), garlic mustard (*Alleria petiolate*; 10%), and dog-strangling vine (*Cynanchum rossicum;* 6%).

Pests and Diseases

The presence and/or symptoms of spongy moth (*Lymantria dispar dispar*) were observed at 31 percent of plots surveyed in King, while signs of emerald ash borer were observed at 18 percent of plots. Dutch elm disease and beach bark disease were quite widespread across the Township impacting elm and beach trees, respectively. Both disease are likely to kill their host trees within a few years of infestation.

Climate Vulnerability

Thirteen of the twenty most abundant tree species in King are highly or extremely vulnerable to climate change (under the RCP 8.5 scenario), including three of the top five species, i.e., eastern white cedar, white ash, and white spruce. These thirteen species make up 47 percent of the total population of trees across the King forest. Only two of the top twenty species were assigned a low vulnerability score, namely, Manitoba maple and American elm, the former is not recommended for planting due to their invasive properties. Five species were given a moderate vulnerability score. It is essential to maintain the diversity of resilient native and non-native non-invasive plant species – especially those expected to have low or moderate vulnerability to the impacts of climate change like sugar maple, eastern hop-hornbeam (*Ostrya virginiana*), black gum (*Nyssa sylvatica)*, and honeylocust (*Gleditsia triacanthos*) – and carry out best management practices to support the urban forest in a changing climate.

Summary of Recommendations

The following recommendations were developed based on the results of the report, the current municipal context (i.e. existing programs, plans, policies, etc.), and the capacity and priorities of the Township of King. The recommendations presented have been developed in alignment with King's existing planning and management documents, including the Township of King Official Plan, Strategic Plan, Term of Council Service Excellence Strategic Plan, and the Tree Management Plan. Some recommendations are included in multiple sections as the recommended actions are cross-applicable. These are indicated with an asterisk (*).

Recommendations identified in the discussion are summarized below. In addition, they are assigned a priority or suggested time horizon for completion. Recommendation Priority:

- **Short-term (ST):** Next one to two years
- **Medium-term (MT):** Next two to five years
- **Long-term (LT):** Next five to ten years

Existing and Possible Urban Forest Distribution

Recommendation 1 – MT: Finalize the Township's Tree Management Plan in 2025 which will address: local canopy targets, species diversity, and forest health, maintenance, and monitoring.

As part of the Tree Management Plan update, reassess tree care and maintenance practices for trees in highly urbanized areas. Consider indicators associated with street tree mortality, including plant hardiness and tolerances to harsher urban conditions, tree pit enhancements, direct tree care/stewardship, and assessing local traffic, and building conditions. Develop a post-tree planting management and monitoring procedure to complement King's tree maintenance program to ensure tree survivorship and mitigate common stressors in the urban environment.

Consider the inclusion of a naturalization and restoration procedure section within King's Tree Management Plan to bolster planting inputs in the natural heritage system and other naturalized areas.

Recommendation 2 – MT: The Township should strongly consider alignment with targets for canopy cover outlined in the York Region Forest Management Plan.

Recommendation 3 – MT: Develop canopy cover targets for land use types within the Official Plan.

Recommendation 4 – ST: Work with York Region to customize and utilize the Region's tree planting prioritization tool for King to improve equitable canopy cover distribution, the maximization of ecological benefits and ecosystem services, and target areas impacted by invasive pests.

Recommendation 5 – MT: Develop mechanisms and education programs to encourage and support private landowners (particularly of commercial, industrial, and agricultural spaces, and property developers) to plant, protect and enhance trees and employ best practices for tree maintenance.

Recommendation 6 – LT: Continue assessing forest structure, function, and distribution every ten years through the Forest Studies and canopy cover every five years through the York Region Canopy Cover Assessment.

Recommendation 7 – LT: Consider developing an understory planting program targeting natural forest woodlands and historically managed woodlots or plantations.

Tree Species Effects

Recommendation 8 – LT: In line with current practices, continue to establish a diverse tree population in intensively managed urban areas, in which no species represents more than five percent of the tree population, no genus represents more than ten percent of the tree population, and no family represents more than twenty percent of the intensively managed tree population.

Recommendation 9 – MT: Consider the development of a campaign focused on educating private landowners and the public about the ecosystem benefits across the Township's forest and the importance of species diversity for a resilient forest, particularly in the context of climate change. Incentivize private landowners to plant a greater diversity of native species to increase the functional diversity of species planted in King and encourage private landowners to plant alternatives to eastern white cedar given its high vulnerability to climate change.

Recommendation 10 – MT: Utilize native and appropriate non-native, non-invasive planting stock in both intensively and extensively managed areas. Increase genetic diversity of tree populations by using the guidance provided by the Ontario Tree Seed Transfer Policy. This policy is intended to help managers source seed based on the projected changes in climate to increase the likelihood of producing trees well-adapted to current and future conditions.

Tree Size Effects

Recommendation 11 – LT: Evaluate and develop the strategic steps required to maintain the number and proportion of medium and large trees across King's forest including in the natural heritage system, street and park trees, and trees on private lands, where feasible.

Recommendation 12 – MT: Review and enhance tree preservation requirements in municipal guidelines and regulations for sustainable streetscape and subdivision design standards to support tree establishment and eliminate conflict between natural and grey infrastructure. Continue to apply ThinKING Green to ensure sustainability of new developments.

Recommendation 13 – ST: Continue to apply Section 2.3, Natural Environment: Tree Canopy of the Sustainable King: Green Development Standards Program – Single Family Dwellings to maintain the mature tree population in new residential developments and incorporate enhancement plantings where appropriate. Track canopy cover losses associated with corporate plantings projects, development applications and residential site alterations. Consider incorporating site alteration applications for residential dwellings (e.g. pool permit applications).

Recommendation 14 – ST: Host an annual knowledge sharing meeting between the Region and Township to educate staff on by-laws, particularly the Forest Conservation Bylaw, to improve awareness about the applicability of York bylaws for the Township.

Effect on Air Quality

Recommendation 15 – LT: Where appropriate, select and plant long lived, low maintenance, and low volatile organic compound (VOC) emitting tree species.[1]

Recommendation 16 – LT: Bolster the evergreen tree population across the municipality to improve year-round pollution removal services.

Recommendation 17 – MT: Engage in strategic tree planting in high emissions zones.

Effect on Stormwater Runoff

Recommendation 18 – ST: Continue to apply subsurface (Silva) cells on a project-by-project basis and other enhanced rooting environment techniques for street trees, particularly in constrained spaces such as intensification areas. Explore incorporating this recommendation into King's Green Development Standards.

Recommendation 19 – MT: Explore the opportunity to utilize the Sustainable Technology Evaluation Program Treatment Train Tool to evaluate and quantify the stormwater benefits of planting trees. See: Low Impact Development Treatment Train Tool.

[1] Some evergreen species emit high levels of VOCs, however this should not preclude them from planting programs. When possible and appropriate, consider planting low VOC emitting species.

Climate Change Mitigation and Adaptation

Recommendation 20 – LT: Following the Township of King's Official Plan recommendation to encourage tree planting to reduce summer heat (see Section 3.2.1 of the OP), consider including the potential of trees to provide energy savings when developing planting guidelines or standards. Also, consider including the potential of tree-based energy savings under the green infrastructure component of the Sustainable King: Green Development Standards Program.

Recommendation 21 – MT: Consider including species' capacity for carbon storage and sequestration and tolerance to future projected climates when developing planting lists or guidelines and future (urban) forest management plans.

Recommendation 22 – LT: Ensure best practices for healthy soils are implemented in King's public and private urban areas in the planning of planting programs from site selection and appropriate soil volume considerations to assessment of species selection. Sustainable King: Green Development Standards Program provides guidelines for soil quality and quantity that should be applied.

Recommendation 23 – MT: Educate private homeowners and industrial and commercial landowners about planting trees and shrub species based on soil types.

Invasive Plant Species, Pests and Diseases

Recommendation 24 – LT: Promote the implementation of natural buffers along the edges of urban woodlots to protect against the encroachment of invasive species.

Recommendation 25 – MT: Continue targeted removal of high priority invasive plant species at high priority sites following best management practices recommended by the Ontario Invasive Species Council[2].

Recommendation 26 – MT: Explore the development and implementation of a municipal-led invasive plant, pest, and disease education and volunteer program to enhance awareness of invasive plants, pests, and pathogens and proper removal practices. Develop a monitoring and action strategy for invasive species, pests, and diseases, and continue taking proactive approaches to address new and emerging invasive species, such as hemlock woolly adelgid and oak wilt.

Recommendation 27 – MT: Investigate the utility and potential application of pest vulnerability tools, such as the Pest Vulnerability Matrix (PVM) during species selection for municipal tree and shrub planting.

Climate Vulnerability and Resilience

Recommendation 28 – MT: Increase proactive, long-term monitoring of species identified as highly and extremely vulnerable to climate change to assess and evaluate the condition of the at-risk species as incremental climate change impacts advance.

[2] Refer to Ontario Invasive Plant Council's Best Management Practices series: zhttps://www.ontarioinvasiveplants.ca/resources/best-management-practices/

Recommendation 29 – ST: Assess the Township's current recommended planting list based on the climate vulnerability of each species. Shift recommendations to native and appropriate non-native, non-invasive species that have a higher tolerance and lower vulnerability to climate change impacts.

Recommendation 30 – LT: Assisted range expansion and assisted migration of trees should be investigated. The Township should undertake systematic testing of species from warmer ecodistricts that could be suitable to replace the thirteen highly vulnerable and extremely vulnerable species that are at the greatest risk due to climate change.

Urban Forestry and Asset Management

Recommendation 31 - ST: Consider integrating forests and individual trees into the asset management planning process, starting with the development of a natural asset inventory

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1.0 INTRODUCTION

In the Township of King (King or the Township), the forest is fundamental to social, economic, public, and environmental health and resilience. All the trees, shrubs, and woodlands located on public and private property make up the Township's forest and provide vital services to the community. A healthy forest cleans the air, reduces stormwater run-off, moderates extreme heat, sequesters carbon, provides habitat for local wildlife, and makes a community more attractive and livable. The value of these services increases exponentially as healthy trees grow and thrive. King is a rural Township driven by historical and current agricultural practices. A large proportion of the land is covered by crop farming; however, remnant forest communities continue to contribute to an impressive canopy cover across King.

The capacity of King's forest to support a healthy and resilient community is under threat. Stressors such as climate change, urban development, human population growth, invasive species, and difficult growing and soil conditions challenge the health of the forest. If the forest is to continue to provide the many ecosystem services and benefits on which the community depends, King and its partners must address these challenges in a cost-effective, coordinated way. Planning, management, and stewardship are required to ensure that King's forests are maintained, replaced, and successfully integrated into built and agricultural environments. This requires a comprehensive understanding of the forest's distribution, structure, and function.

1.1 Purpose

This Forest Study is a resource for Township and Regional staff to help track and evaluate progress towards established goals, adapt goals and strategies as needed, and make informed management decisions about the forest. The York Region Forest Management Plan (2016) has a regional target of achieving 40 percent canopy cover by 2051 and recommends a canopy cover range of 36 percent to 41 percent for King.

The first Township-wide analysis of King's forest was conducted through a collaboration between King, York Region, TRCA, and LSRCA. Data was collected in 2016 and the results were published in the Upper York Region: Urban Forest Study (LSRCA, 2016). However, due to some data collection inaccuracies, the 2016 study will be omitted as the baseline against which change can be assessed. Refer to the *T*ownship of King Forest Study Change Assessment: Data Inaccuracies report for some additional context. In lieu of a change assessment, the 2023 Forest Study will serve as a baseline against which future studies may assess change. In addition, this report also serves as an opportunity to analyze issues that were emerging in 2016 and have become more crucial to assess in the intervening years. Specifically, this study will include more detailed information on tree health, invasive plant species, pest and disease presence, soil quality, and climate vulnerability for King's forest.

To track progress, study partners committed to conducting sample-based field surveys every ten years and a GIS-based canopy cover assessment every five years. These timelines have been formally established in the York Region Forest Management Plan and are in line with Official Plan targets. A canopy cover assessment was completed in 2020 and the field data for this study was collected in 2022. Note that despite data being collected in 2022, this report refers to the 2023 Forest Study.

1.2 Objectives

The objectives of the 2023 Forest Study are to:

- Assess canopy cover distribution and track progress towards canopy cover goals for King;
- Quantify the current species composition, size, and condition of King's forest;
- Quantify ecosystem services and benefits provided by the forest;
- Analyze key factors relating to forest health, specifically soil health, tree health, invasive plant cover, and presence of invasive pests and diseases;
- Conduct an i-Tree Forecast assessment to estimate tree planting needed to maintain existing canopy cover and to meet the recommended canopy cover goals; and
- Assess climate change risks and forest vulnerability.

2.0 CONTEXT

2.1 Demographic and Ecological Context

The Township of King is a lower-tier municipality within the Regional Municipality of York. The Township is comprised of the three villages of King City, Nobleton, and Schomberg, the seven hamlets of Ansnorveldt, Graham Sideroad, Kettleby, Laskay, Lloydtown, Pottageville, and Snowball, and a vibrant countryside. Population growth in King has continued to increase in the past five years, increasing by 11.5 percent between 2016 and 2021 compared to a 23.2 percent increase between 2011 and 2016, and a 2.1 percent increase from 2006 to 2011 (Township of King, 2021, Statistics Canada, 2021). The current growth rate of population change is larger than the provincial average of 5.8 percent and the national average of 5.2 percent. In light of increasing population growth, intensification and infill development has continued across the municipality. Based on the 2021 census the total population in King is 27,333 and the population density is approximately 82 people per square kilometre (Statistics Canada, 2021). The population is expected to increase to 34,900 by 2031 (Township of King, 2019).

Approximately 66 percent of the municipality is located within the Oak Ridges Moraine Physiographic Region and is situated within the designated protected areas. The remaining 33 percent of the Township falls within the Provincial Greenbelt. The Green Belt Plan designated lands within the Township as Protected Countryside, and the Township is unique in that it contains the Holland Marsh, a wetland and specialty crop area within the Greenbelt, which is considered some of the most fertile crop lands in the country. The Moraine is an irregular ridge stretching west from the Trent River to the Niagara Escarpment. This landform supports significant ecological and hydrological features, including post-glacial kettle lakes and aquifers. The abundance of wetland communities supports a rich diversity of flora and fauna, including a high density of species of regional concern. Headwater features of the West Holland River and East Holland River are located within the municipality.

King is located within Plant Hardiness Zone 5a and 5b according to the Natural Resources Canada Plant Hardiness Zone Map. The northern half of King is situated in Ecodistrict 6E-6 in the Lake Simcoe – Rideau Ecoregion which corresponds to the Great Lakes – St. Lawrence Forest Region. This ecoregion is characterized by coniferous species like eastern white pine (*Pinus strobus*), eastern hemlock (*Tsuga canadensis*), and red pine (*Pinus resinosa*), and deciduous species, such as sugar maple (*Acer saccharum*) and red oak (*Quercus rubra*). While King lies just north of the Carolinian forest region that covers the southernmost portion of Ontario, some tree species representative of that region, such as tulip tree (*Liriodendron tulipifera*) and American sycamore (*Platanus occidentalis*), have been cultivated and planted in the Township.

Prior to European settlement, King, like most of southern Ontario was covered by forests and wetlands. Agricultural conversion, urbanization, and industrial activity have led to the loss of pre-European settlement natural cover in the region, as well as the degradation of the remaining natural systems due to changes to local hydrology and soil quality. However, it should be noted that despite the intensive shift in land use to predominately agricultural land uses, remnant woodlots and woodlands remain the largest contributors to tree cover in the municipality. Concurrent with the relevant loss of natural cover has been the loss of valuable ecosystem services, including water management and climate regulation.

Today, one of the most pressing challenges facing the natural systems in King is the impact of climate change. In addition, future developments threaten the retention of trees and may reduce the space available to plant trees in urban areas. The effects of climate change are already being felt in King and are expected to threaten the health and sustainability of the natural environment. Recognizing these challenges, King is taking proactive steps to protect and enhance the Township's natural systems and mitigate and adapt to climate change.

2.2 Policy, Planning, and Management Context

A Healthy Environment and Healthy Economy, Canada's Strengthened Climate Plan

- A Healthy Environment and a Healthy Economy is the updated federal climate change plan that includes nature-based climate solutions as one of five pillars of action. Nature-based solutions include: the 2 billion trees program; enhancing carbon sequestration by enhancing wetlands, peatlands, and agricultural lands; and establishing a Natural Climate Solutions for Agriculture Fund.

Canadian Urban Forest Strategy (2019 – 2024)

- The Canadian Urban Forest Strategy was developed in partnership by the Canadian Urban Forest Network, Tree Canada, and municipal, provincial, and federal representatives. In recognition of increasing urbanization and resulting pressures on Canada's urban forest, the Strategy was developed to support the protection and enhancement of sustainable, biodiverse, healthy urban forests across the country.

Ontario *Planning Act*, 1990

- The province provides an overarching framework to guide land use planning and development through the *Planning Act*, passed in 1990. The legislation sets out rules for land use planning in Ontario, providing the basis for natural resource management, Provincial Policy Statements, the preparation of municipal Official Plans, and the control of land use through zoning by-laws.

Greenbelt Plan, 2017

- The Greenbelt plan identifies where urbanization should not occur in order to provide permanent protection to the agricultural land base and the ecological and hydrological features/functions of our landscape.
- As identified in the Green Belt Plan, the Township of King contains designated Protected Countryside, Oak Ridges Moraine Area and the Holland Marsh which is a unique specialty crop area within the Green Belt and is considered some of the most fertile crop lands in the country.

Lake Simcoe Protection Plan, 2009

- This comprehensive plan serves as a basis towards the protection and restoration of the ecological health of Lake Simcoe and its watershed. The plan addresses long term environmental issues in Lake Simcoe and its watershed by promoting immediate action to address threats to ecosystem, targeting new and emerging causes of stress, protecting, and restoring important ecologically sensitive lands.

A Place to Grow: Growth Plan for the Greater Golden Horseshoe, 2020

- A Place to Grow is the Ontario government's initiative to plan for growth and development in a way that supports economic prosperity, protects the environment, and helps communities achieve a high quality of life. This plan established a framework for implementing Ontario's vision for building stronger, prosperous communities by better managing growth in this region. It established the long-term framework for where and how the region will grow, while recognizing the realities facing our cities and smaller communities and acknowledging what governments can and cannot influence.

Oak Ridges Moraine Conservation Plan, 2017

- The purpose of the Oak Ridges Moraine Conservation Plan is to provide land use and resource management planning direction to provincial ministers, ministries, and agencies, municipalities, landowners, and other stakeholders on how to protect the Moraine’s ecological and hydrological features and functions.

Provincial Policy Statement, 2020

- Under Section 3 of the *Planning Act*, the province can issue directions for municipalities in the form of the Provincial Policy Statement. The current Provincial Policy Statement came into effect in 2020 and supports the provincial goals to increase housing and protect the environment, while also reducing barriers and costs for development.

York Region Official Plan, 2022

- The York Region Official Plan provides planning direction for all of York Region. This plan requires that all local municipalities develop an Urban Forest Management Plan (Section 3.4.29) and establishes a minimum woodland cover target of at least 25 percent for the region and a minimum canopy cover target of 40%. York Region has updated the Official Plan to provide direction for managing growth and development over the coming decades and to align with revised Provincial Plans.

York Region Forest Management Plan, 2016

- The York Region Forest Management Plan was adopted by York Regional Council in 2016 and covers the time period from 2016 to 2026. The plan directs the municipality to undertake the Forest Studies and provides recommendations on the monitoring of canopy and woodland cover. Additionally, long-term canopy cover and woodland cover targets for the entire region and local municipalities, including King, are recommended in the plan. Recommended ranges for King include 26-28 percent woodland cover and 36-41 percent total canopy cover by 2051. It also outlines strategic goals and actions for forest management in York Region.

York Region Green Infrastructure Asset Management Plan, 2017, 2022 update

- York Region published its second Green Infrastructure Asset Management Plan in 2022 to ensure the management of regional green infrastructure assets in a way that effectively balances costs, risks, and benefits to ensure ongoing sustainable service delivery related to the Region's green infrastructure. The assets within the plan include part of the urban forest (street trees, landscape planting, supporting infrastructure on roadways), York Regional Forest, and the Bill Fisch Forest Stewardship and Education Centre in Whitchurch-Stouffville.

York Region's Greening Strategy, 2022

- Over the last 10 years, York Region's Greening Strategy has helped to secure 1,500 hectares of land for conservation purposes and plant over 2 million trees. While the Greening Strategy has a focus on enhancing natural areas, private land stewardship is also promoted through planting programs for residents or best practices to support farmers on agricultural lands.

York Region's Climate Change Action Plan, 2020

- Most alignment of this Study and the York Region Draft Climate Change Action Plan relates to community resilience actions such as conducting a vulnerability assessment on natural systems and integrate adaptive actions into watershed planning as well as assessing the role natural systems play in mitigating and adapting to climate change.

York Region Forest Conservation Bylaw, 2013-68

- This bylaw prohibits and regulates the destruction and injuring of trees in woodlots and woodlands in the Regional Municipality of York. It applies to all woodlands and woodlots in those lower-tier municipalities which have delegated their power to the Region according to subsection 135(2) of the *Municipal Act, 2001.*
- According to the 2020 Woodland Cover Assessment by York Region the area of woodlot and woodland cover on public and private property in King was 8,797 hectares (North-South Environmental, 2021).

The subsequent list provides an overview of the municipal policies, programs, and plans that are currently applied in the governance or management of the forest in King.

***Municipal Act*, 2001**

- The *Municipal Act* of *2001* empowers municipalities to be accountable for their own jurisdiction and provides the power to pass and adopt by-laws.

King Corporate Strategic Plan 2023 – 2026

- The Township of Kings' Corporate Strategic Plan (CSP) is a collaborative and inclusive community planning tool that identifies the desired future for the community, function and the general vision for the Township's future. The CSP is created based on Council's identified priorities for the existing term, which reflect the changing needs of their constituents. The CSP sets the context for guiding the Township's long-term goals within the medium period term and clearly defines obligations and commitments of the Township to its citizens and the public. The CSP outlines priorities, objectives and key results as the goal-setting framework, and recognizes the role of the green spaces and the tree canopy for the Township's future.

King Official Plan, 2019, approved 2020

- The Official Plan (OP) establishes a comprehensive, long-term vision for the Township as a whole and provides a detailed policy framework to guide growth in the Township. The Official Plan was adopted by Council in 2019 and approved by the Region in 2020. The OP currently directs land use planning to 2031. The Township has initiated a review of the OP to respond to changes in Provincial and Regional policy, and to guide growth in the Township to the year 2051. The OP recognizes the important role of the Township's natural heritage system, including trees, woodlands and woodlots, in improving conservation, air quality, and reducing the urban heat island effect (Section 4, Our Pristine Environment). The Plan promotes land conservation and outlines key environmental features, supports public engagement, and includes policies related to maintaining the forest.

King Community Climate Action plan, pending Council approval, 2024

- The King Community Climate Action Plan (KCCAP) was developed around the vision of a low carbon community that continues to encapsule the rural culture of King. We are a community of communities, intertwined with technology, community action, and resiliency, we will be able to bring King into the 21st century and de-carbonize our Township.

King Recreation and Community Master Plan, 2020

- The King Township Recreation and Community Master Plan sets out specific recommendations for the next (5) years based on 5 goals identified in the Framework for Recreation in Canada. These recommendations are aimed at increasing the ability of residents to live active and healthy lifestyles through King's inclusive recreation, community engagement, environmental education, and stewardship services. The Recreation and Community Master Plan sets priorities for the Township to provide physical activity, inclusive services, and nature connection through recreation and strong community partnerships. In developing the recommendations for this plan, the Township considered feedback from citizens, demographic characteristics of the community, trends, and best practices when providing recreation and community services. This plan builds upon existing strategic and master plans previously developed.

King Trails Master Plan, 2015

- The Trails Master Plan was created with the upmost respect and promotion of the Township's natural heritage, scenic beauty, and rural traditions. The goal of this plan was to address route planning, trail standards, and the development of a prioritization and phasing strategy. The plan will benefit the Township in areas including health and fitness, transportation, economy, and tourism as well as the environment.

King Tree Management Plan, update in 2024

- The King Tree Management Plan (TMP) provides the Township with a comprehensive document that outlines the programs, protocols, and guidelines associated with managing, sustaining, and guaranteeing the growth of the Township's trees in a safe and cost-effective manner.

2.3 Study Background

The first study of King's forest was conducted in 2016. LSRCA and the United States Department of Agriculture (USDA) Forest Service completed an i-Tree Eco analysis (formerly known as UFORE) using land use mapping in conjunction with field data collected at sample plots across King to determine the species composition, condition, size class distribution, and measures of ecological services and value. However, due to inaccuracies present in the data collected, this original assessment has been excluded from this iteration's change assessment. Instead, the current Forest Study will serve as the baseline from which future studies may compare results and track trends.

The 2023 Forest Study is intended to assess the current state of the forest by employing the i-Tree Eco protocol and software tool. In addition, new assessments have been incorporated to better understand biotic factors pertinent to forest change, namely, invasive plant, pest, and disease species, holistic tree health, soil properties, and climate vulnerability. The analysis and recommendations presented in this report have been aligned with the guidance of King's existing and new policies and frameworks.

3.0 METHODOLOGY

This study utilized several complementary approaches, datasets, and analysis tools:

1) Canopy cover mapping and spatial analysis
2) i-Tree Eco and Forecast
3) Assessment of forest structure, composition, and function
4) Quantitative analysis of soil, holistic tree health, and invasive species data
5) Climate vulnerability assessment of dominant tree species

Each analysis tool is explained in more detail in the following sections. Taken together, these analyses provided a broad understanding of King's forest. While the i-Tree Eco and the canopy cover analyses each represent stand-alone assessments capable of supporting a forest management plan, experience from other concurrent Forest Studies demonstrated the value of combining both approaches. By incorporating data collected in the field, the i-Tree Eco analysis allowed the quantification of critical attributes such as tree species and tree height, as well as ecosystem services such as carbon storage and sequestration. In contrast, the canopy cover analysis relied on the mapping of land cover based on high-resolution satellite imagery and LiDAR data. This allowed a detailed and accurate assessment of the quantity and distribution of canopy cover and potential planting space across King. I-Tree Forecast allowed an estimate of future canopy cover and ecosystem services given current planting plans, while additional data collected on soil, tree health, and invasive species, in combination with a climate vulnerability assessment, provided the basis for obtaining a more detailed understanding of the health and vulnerabilities of the forest in King.

3.1 Canopy Cover Analysis

In 2020, the Spatial Analysis Laboratory at the Rubenstein School of the Environment and Natural Resources at University of Vermont (UVM) completed land cover and canopy cover assessments for the whole of York Region. Detailed methods and results can be found in the 2021 York Region Canopy Cover Assessment Technical Report (Timmins & Sawka, 2022). Advanced automated processing techniques utilizing high-resolution WorldView-2 imagery acquired in the summer of 2019, in combination with high-resolution LiDAR data, and ancillary datasets were used to map land cover for the entire Township in King in such detail that single trees were detected. The following land cover classes were mapped: tree canopy, grass/shrub, bare soil, water, buildings, roads/railroads, and other paved/impervious surfaces. The overall accuracy of the land cover map was 97 percent.

Using the land cover data, several canopy cover metrics were computed for King: existing canopy, potential vegetated canopy, potential impervious canopy, and not suitable (see *Table 1* for a description of each metric). Canopy cover metrics were summarized as the total area in hectares, and as a percent of *land area.*

Table 1: Existing and potential canopy cover categories

Category	Description
Existing Tree Canopy	The amount of tree canopy present when viewed from above using imagery.
Potential Vegetated Tree Canopy	Grass or shrub area that is theoretically available for the establishment of tree canopy.
Potential Impervious Tree Canopy	Asphalt, concrete, or bare soil surfaces, excluding roads and buildings, are theoretically available for establishment of tree canopy.
Not Suitable	Areas where it is highly unlikely that new tree canopy could be established (buildings and roads).

For this report, existing and possible canopy cover were also summarized for ten land use categories derived from the Municipal Property Assessment Corporation (MPAC) codes assigned to each property in King. MPAC is an independent body established by the *Ontario Property Assessment Corporation Act, 1997,* which administers a uniform, province-wide property assessment system based on current value assessment. MPAC data were obtained for the canopy cover assessment in 2019 and was last updated in 2016. However, thousands of parcels were of unknown land use (6.1% of York Region's land area) due to problems with joining the land use codes to the parcel boundaries via the roll or parcel ID number. This was corrected where possible, however, there are likely to be errors in the land use codes.

Each original MPAC code or description was grouped into one of ten generalized categories based on similarities in ownership and management type (see Appendix A for the list of MPAC classes in each land use category). Road rights-of-ways (ROWs) were added to the land use layer by UVM by filling in the gaps between the MPAC parcel boundaries and constitute an eleventh land use category.

3.2 i-Tree Eco

i-Tree Eco, a software application, model, and protocol, was chosen as the primary tool for the York Region Forest Studies, including King. I-Tree Eco is an adaptation of the Urban Forest Effects (UFORE) model, which was developed by the U.S. Forest Service Northern Research Station (NRS), the USDA State and Private Forestry's Urban and Community Forestry Program and Northeastern Area, the Davey Tree Expert Company, and SUNY College of Environmental Science and Forestry. UFORE and i-Tree Eco have been used in many other municipalities in the Greater Toronto Area over the past 15 years. The built-in i-Tree Eco models are continually improved upon by its developers. Version 6.0.32 was used for this assessment.

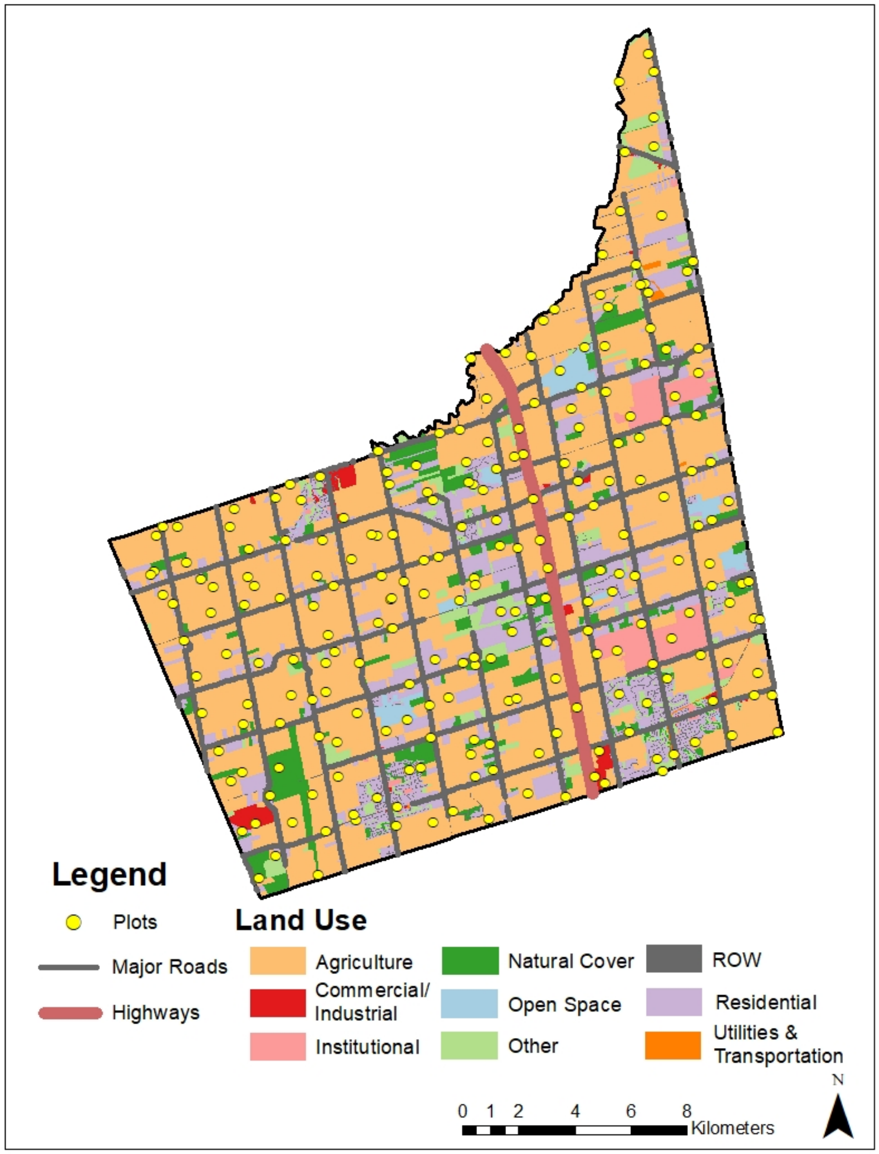
3.2.1 Study Design

The study area boundary was defined by the municipal boundary of King. Two-hundred-and-sixteen randomly generated plot centres created for the 2016 King Urban Forest Study were reused for the 2023 study. However, due to an inability to access all of the previous plots, an additional twenty plots were added to increase sample size. By doing this, the number of plots surveyed provided an acceptable level of standard error when weighed against the time and financial costs associated with additional field data collection. As a rule of thumb, 200 plots allocated within a stratified random design will yield a standard error of approximately 10 percent (USDA, 2021). In the past, large cities such as New York and Baltimore used 200 sample plots and obtained accurate results with acceptable levels of standard error. In accordance with standard i-Tree Eco protocols, plots were circular and had an area of 0.0404 hectares.

i-Tree Eco was used to statistically extrapolate data to estimate totals and standard errors for the entire study area for tree population, leaf area, species composition, size distribution, and condition, as well as carbon storage and sequestration, avoided runoff, air pollution removal, and building energy savings. i-Tree Eco was also used to provide a structural value for the forest using a simplified CTLA Trunk Formula method (Nowak, 2020) and a valuation for ecosystem service benefits.

3.2.2 Study Area Stratification by Land Use

The study area was stratified into smaller units according to land use types (e.g., residential, commercial and industrial, etc.) to better understand variations in the structure of the forest. The randomly distributed plots were post-stratified according to the MPAC land use category in which they fell. The post-stratification approach was selected to enable the monitoring and assessment of change over time at the same plots, as well as the ability to report on trends within land use categories. Using this approach, permanent sample plots are not dependent on a static land use distribution.



For this study, plots were stratified into five land use categories based on 2016 MPAC land use data acquired for the canopy cover assessment. The MPAC land use categories were last updated in 2016 and the next iteration was scheduled for completion in 2020 but delayed due to the COVID-19 pandemic. TRCA's GIS team filled parcels with unknown/unspecified land uses based on other existing datasets. It is likely that errors exist in the dataset due to changes in land use and this filling process.

i-Tree Eco developers recommend that strata are set up to have a minimum of 15 to 20 plots within each stratum to ensure a reasonable accuracy. Unfortunately, there were insufficient plots in the land use categories, *Commercial, Industrial, Institutional, Open Space, Other*[3], *Residential Medium / Residential High,* and *Utilities*

[3] *Other* is comprised predominately of vacant residential land, but also includes non-buildable land such as stormwater management ponds and recreational sports complexes.

and Transportation. Consequently, the aforementioned categories were grouped into broader categories with other similar land use types based on similarities in vegetation cover and management needs to create a total of six land use categories or stratum as shown in *Table 2*. Appendix A contains a detailed description of the land use types. *Figure 1* shows the distribution of land use types and plots across King. *Utilities – Transportation* includes plots that fall predominantly on rights-of-way (ROWs).

Table 2: Land use categories used for i-Tree Eco stratification

Stratum	Area (ha)	No. of Plots
Agriculture	20,728.16	110
Residential	5,722.33	49
Open Space – Natural Cover	2,648.53	27
Other – Institutional	2,621.63	20
Other – Urban	1,920.83	30
Total	**33,641.48**	**236**

3.2.3 Landowner Contact

Permission to access plots located on private property was obtained primarily through written and verbal communication. Prior to entry, property owners received a request for access form in addition to a letter outlining the scope and duration of the study. In the case of businesses, telephone numbers and email addresses that could be found online were used to contact owners. If it was not possible to contact the owner or no response was given, field staff requested permission to access the property in person via cold knock. In those cases where permission was not granted, access was restricted due to physical barriers, or the site was deemed unsafe, the plot was not assessed.

3.2.4 Field Data Collection

Field data collection was conducted by a two-member field crew[4] during the summer leaf-on season of 2022. Plot centres were found by using a combination of handheld GPS units, and high-resolution aerial orthoimagery on a mobile device that illustrated the location of plot centre and plot boundaries for each plot. At each plot, field staff recorded the distance and direction from plot centre to permanent reference objects, where possible, so that plots could be relocated for future re-measurement. Once plot centre had been located, detailed vegetation information was recorded in accordance with the i-Tree Eco field manual specifications. The following general plot data were recorded in the i-Tree Eco web interface via a mobile device:

- percent tree cover
- percent shrub cover

[4] TRCA hired field assistants and crew leads with a combination of educational and work experience in forestry, arboriculture, and/or environmental science to undertake the inventory.

- land use
- percent of plot within the land use
- percent ground cover
    - building
    - cement
    - tar-blacktop/asphalt
    - soil
    - rock
    - duff/mulch
    - herbaceous (exclusive of grass and shrubs)
    - maintained grass
    - wild/unmaintained grass
    - water

For each tree with the centre of its stem in the plot and a minimum diameter at breast height (DBH) of 2.5 cm, except in forested areas[5], where the DBH minimum was increased to 5cm, the following information was recorded:

- species
- number of stems
- diameter at breast height
- tree height
- live tree height
- height to base of live crown
- crown width in east-west direction
- crown width in north-south direction
- percent canopy missing[6]
- percent dieback[7]
- distance and direction (clockwise degrees from True North) from the building (for trees ≥ 6.1m in height and located within 18.3m of a residential building)

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[5] Plots were defined as forested areas if 10% of the plot area was covered by natural canopy. Land was considered forested if it was not subject to use(s) preventing normal tree regeneration and succession, such as regular mowing, intensive grazing, or recreation activities. In some cases, plots with less than 10% canopy cover could qualify as a forested area if trees were harvested, died, or were otherwise removed but the land was expected to naturally regenerate to at least 10% cover.

[6] Percent canopy missing is the percent of the crown volume that is missing foliage. It is assessed within the measured live crown width and height and requires imagining a typical crown outline that is full of live foliage.

[7] Percent dieback is the percent of the crown that is composed of dead branches.

Given access constraints, it was possible to collect data at a total of 193 out of the 236 plots. Prior to visiting plots in the field, plots were inspected using current orthoimagery and Google Street View. Those which fell 98 to 100 percent on impervious surfaces or agricultural fields and had no trees, were assessed using orthoimagery and Google Street View. The remainder were visited in the field as summarized in *Table 3. Table 4* summarizes the number of plots with complete i-Tree Eco data per land use stratum.

Table 3: Data collected for plots

Description	Plots Completed
Field visits	102
Orthophoto/Google Street View	91
Total plots	**193**

Table 4: Number of plots completed per stratum

Stratum	Number of Plots with Complete i-Tree Eco data	Total Number of Plots
Agriculture	87	110
Residential	41	49
Open Space – Natural Cover	23	27
Other – Institutional	16	20
Other – Urban	26	30
Total	**193**	**236**

Research conducted by i-Tree Eco developers indicated that 200 plots (of 0.0404 ha each) in a stratified random sample will have a standard error of approximately 10 percent for the municipality and around 13 percent for 180 plots (USDA, 2021). The relationship between the number of plots and standard error is non-linear, with the biggest gains in accuracy obtained in the first 80 to 90 plots. Therefore, the number of plots and plots per stratum that had complete data to run the i-Tree Eco model was deemed sufficient.

3.2.5 Data Analysis

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

1) Urban Forest Structure: quantifies urban forest structure (e.g., species composition, tree density, tree health, leaf area, and leaf and tree biomass) based on field data.

2) Biogenic Emissions: quantifies 1) hourly urban forest volatile organic compound (VOC) emissions (isoprene, monoterpenes, and other VOC emissions that contribute to ozone (O_3) formation) based on field and meteorological data, and 2) O_3 and carbon monoxide (CO) formation based on VOC emissions.

3) Carbon Storage and Annual Sequestration: calculates total stored carbon, and gross and net carbon sequestered annually by the urban forest based on field data.

4) Air Pollution Removal: quantifies the hourly dry deposition of ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter ($PM_{2.5}$) by the urban forest and associated percent improvement in air quality throughout a year. Pollution removal is calculated based on local pollution and meteorological data.

5) Building Energy Effects: estimates the effects of trees on building energy use as a result of heating and cooling.

3.2.6 Weather and Pollution Data, and i-Tree Eco Parameters

Weather and Pollution Data

Weather and pollution datasets are integrated into i-Tree Eco for use in modelling. It is not possible for the user to directly upload their own data into the application. Hourly precipitation data is utilized to calculate avoided runoff and improve the accuracy of estimating the removal of $PM_{2.5}$ by trees and shrubs. Weather data also impacts the calculation for emissions of volatile organic compounds. Toronto Pearson Airport meteorological station is the closest weather station to York Region and provides weather data from 2010 to 2020. Data from 2019 was selected for analysis as this was the most recent year where pollution data was also available for 2019. Hourly 2019 pollution concentrations of sulphur dioxide (SO_2) and carbon monoxide (CO) were obtained from the Ontario Ministry of Environment, Conservation and Parks' Toronto West station, and ozone (O_3), nitrogen dioxide (NO_2) and $PM_{2.5}$ data were obtained from their Newmarket station for the same year.

Calculation of Energy Savings

The Energy Savings model component of i-Tree Eco is designed specifically for the U.S., making its application to other countries potentially less suitable. International users receive energy results that are based on the characteristics of the user-defined U.S. climate region, typical construction practices and building characteristics, and energy composition (i.e., type of and amount used). Therefore, the developers caution that results could be less reliable as they assume that the building types and energy use of the U.S. are the same as those internationally (Nowak, 2020)). The only local values used in the estimates outside the United States are electricity and fuel costs. The remainder of the estimation is based U.S. conditions from the assigned climate zone. Details on local energy values and the comparisons between international areas and U.S. climate zones is given in Nowak, 2020, Appendix 9). However, given the similarities between heating, cooling, and building structures and the similar climatic region between both countries, the model should be fairly reasonable for southern Ontario.

Value of Air Pollution Removal

The default values of i-Tree Eco were used to estimate the value of air pollution removal services (there is no option to update these values). The associated economic value of the health benefits from the removal of pollutants NO_2, SO_2, O_3, and $PM_{2.5}$ is based on U.S. median externality values from the U.S. EPA's Environmental Benefits Mapping and Analysis Program (BenMAP) model (Nowak, 2020). Based on BenMAP, various standardized health impacts and dollar values (value/person/pollutant) were calculated in i-Tree Eco. The standardized values were calculated using local pollution and population data. These values are multiplied by the corresponding local population total and pollution concentration change due to the effects of trees and other vegetation in the study area to determine health impacts and associated dollar values. For international estimates, regression equations (Nowak et al. 2014) based on population density are employed to estimate a dollar value per ton of pollution removal (Table 5).

Table 5: Value per tonne of air pollutant removed

Pollutant	Unit value
Carbon monoxide (CO)	$ 0 / tonne
Nitrogen dioxide (NO2)	$ 0.04 / tonne
Sulphur dioxide (SO2)	$ 0.02 / tonne
Ozone (O_3)	$ 0.29 / tonne
Particulate matter <2.5 microns ($PM_{2.5}$)	$ 10.26 / tonne

i-Tree Eco parameters

The i-Tree Eco model requires the user to select a variety of parameters to support model runs. Parameters used for the 2023 King Township Forest Study are summarized in *Table 6*.

Table 6: i-Tree Eco parameters

Variable/Parameter/ Dataset	Value/Source	Comments
Weather	2019 Pearson International Airport	Closest station and corresponds to date of air pollution data.
Air pollution	2019 Newmarket and Toronto West data / Ministry of Environment, Conservation and Parks, Ontario	Most recent and closest station data
Census Subdivision and Population Size	Study area type = urban Population (2021) = 202,022 Population Density = 1,990.7	From Statistics Canada (2021)
Electricity in Can$ (CAD)/kWh	$0.11 / Ontario Energy Board	This is used to calculate the cooling benefit of trees due to less air conditioner use. While air-conditioners may be used most in the day during peak hours, many people continue to use air-conditioners at night[8]. In addition, many people turn their air-conditioners off when they are not at home, which is more likely during the day. Therefore, an average electricity price was used as shown below.

[8] According to archived research from Statistics Canada, 48 percent of people with an air-conditioner in Ontario kept their air-conditioner on when away from home in 2009. Only 29 percent of Canadian households with an air-conditioner turned it off while sleeping.

Variable/Parameter/ Dataset	Value/Source	Comments
		Ontario (oeb.ca – 2023-07-30) rates for electricity: Time of Use Costs: o Off-peak: 7.4 c/kWh o Mid-peak: 10.2 c/kWh o On-peak: 15.1 c/kWh o Average: 10.9 c/kWh
Heating in Can$ (CAD)/therm[9]	$0.55 / Ontario Energy Board	Natural gas rates & prices in Ontario (oeb.ca – 2023-07-30) • Enbridge Gas – Union South Rate Zone: 122.7759 c/m^3 • Enbridge Gas Distribution: 15.7735 c/m^3 • EPCOR Natural Gas Ltd: 23.3044 c/m^3, 15.7983 c/m^3 o Average cost = 19.55135 c/m^3 • Convert to a cents per cubic foot by dividing by 35.3147: o Average: 0.5536 c/ft^3 • Multiply the above by 100 to obtain a therm (100 cubic feet) o Average: 55.36 c/therm
Carbon in Can $/metric ton	$1,042.10/ tC	The estimated social cost of carbon in 2022 (in 2021 dollars) is $256/t$CO_2$ (Government of Canada, 2023[10]). The adjusted value of this amount (in 2023 dollars) is approximately $283.95/t$CO_2$ using the Bank of Canada

[9] One therm is a non-SI unit of heat energy. It is the amount of energy in 100 cubic feet of gas.

[10] See Environment and Climate Change Canada. (2023). *Social cost of greenhouse gas emissions.* Government of Canada. https://www.canada.ca/en/environment-climate-change/services/climate-change/science-research-data/social-cost-ghg.html

Variable/Parameter/ Dataset	Value/Source	Comments
		inflation rate[11]. To convert cost per tonne of carbon dioxide to tonne of carbon, it is necessary to multiply by 3.67.
Avoided Runoff in Can$ (CAD)/m^3	$2.324 / Default i-Tree Eco value	Default value from i-Tree Eco. It uses the U.S. national average dollar value to estimate value of avoided runoff. This value is based on 16 research studies on costs of stormwater control and treatment (Nowak, 2020)

3.3. Additional Health Assessment

3.3.1 Background

King opted to include an additional tree health assessment. The purpose of this assessment was to gain a holistic understanding of tree health including trunk and root issues that can take a long time to affect crown health. Health indicators related to trunk integrity, canopy structure, and canopy vigour were assessed in the field and combined to obtain an overall health score for each tree. The development of the tree health protocol was informed by the Council of Tree and Landscape Appraisers (CTLA) Trunk Formula method, TRCA's Protocol for Conducting a Hazard Tree Assessment, Neighbourwoods Protocol (developed by Kenney and Puric-Mladenovic at the University of Toronto), and Appendix I of the ISA Tree Risk Assessment Manual by the International Society of Arboriculture.

3.3.2 Field Data Collection

While crews were in the field collecting data for i-Tree Eco, they also collected data on tree health. Several indicators of trunk integrity, canopy structure, and canopy vigour were assessed. Crews assigned a score ranging from very poor (1) to very good (4) to each indicator and also recorded the presence or absence of negative symptoms/signs, e.g., marginal scoring. These scores were aggregated and averaged to obtain an overall health score per tree. The collection procedure and ratings for each indicator within each category are outlined in Appendix G. Field crew were instructed to apply species-specific knowledge in rating each indicator as some species naturally show signs that could be interpreted as poor health by an untrained eye, for example, self-pruning in spruce and silver maples.

3.3.3 Data Analysis Methods

For each tree, an average health/condition score was calculated by summing the indicator scores for each category – trunk integrity, canopy structure, and canopy vigor – dividing by 3. The condition score ranges from 1 to 4, where a higher score indicates a better health rating, and a lower score is a worse health rating. Dead trees were assigned a score of 1.

[11] The inflation update was calculated based on data available prior to November 15, 2023 using the Bank of Canada Inflation Calculator: https://www.bankofcanada.ca/rates/related/inflation-calculator/.

Next, an average health score was calculated for each plot, I, in stratum *r.*

$$\bar{y}_{r_i} = \sum_{j=1}^{n_{r_i}} \frac{y_{r_{ij}}}{n_{r_i}}$$

Where $\bar{y}_{r_i}$ is the average health score for plot in stratum r, n_{ri} is the number of trees in plot *I, and* $y_{r_{ij}}$ is the value of the variable y in subsample/tree, *j*, of sample/plot I in stratum r. In this case, $y_{r_{ij}}$ would be condition score for tree *j*.

The overall average health score was then calculated for each land use stratum.

$$\bar{y}_r = \sum_{i=1}^{n_r} \frac{\bar{y}_{r_i}}{n_r}$$

where $\bar{y}_r$ is the average health score for stratum *r*, n_r is the number of plots in stratum *r*, *I* is the ith plot in stratum r and $\bar{y}_{r_i}$ is the average health score for the ith plot in stratum r[12].

A health score is calculated for the municipality as a whole.
Calculate the mean of the stratum means, weighted by the stratum area.

$$\bar{y}. = \frac{\sum_{r=1}^{s} A_r \bar{y}_r}{A}$$

Where $\bar{y}.$ Is the average health score for the municipality, *s* is the total number of stratum, A_r is the area of stratum *r*, $\bar{y}_r$ is the mean health score for stratum *r* and *A* is the total area in study area (sum of all area stratum)

We then tested for significant differences in health between land use strata using the Kruskal-Wallis test for ranked data.

Lastly, we calculated the average health by species for the whole municipality.

3.4 i-Tree Forecast

i-Tree Forecast is a separate model incorporated into the i-Tree Eco application. It was utilized in this study to estimate future canopy cover based on the current state of the forest and King's tree planting plans, which were provided by King. The objective of the i-Tree Eco Forecast analysis was to determine if, given the current planting plans, canopy cover would continue to stay within the current recommended canopy cover range by 2052 (26 to 41 percent), or if it would increase or decline. If the canopy cover target range were not to be maintained, simulations would be run to determine how many more trees would need to be planted to ensure that the canopy cover range was maintained. The planting assumptions used for simulation are identified in Appendix B.

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[12] Formula from i-Tree Eco sample_variance.pdf (itreetools.org)

i-Tree Forecast simulates future forest structure using current forest structure data from i-Tree Eco as the input. Forecast simulates each year within the simulation period using three components:

1) Tree growth: the projected growth of tree diameter, crown size, and leaf area for each tree recorded. Tree growth or annual increase in DBH is based on the number of frost-free days, crown light exposure, dieback, growth rate classification and median height at maturity.
2) Tree mortality: the projected annual mortality based on default or user-defined annual mortality rates for trees of various condition scores. Tree mortality rates are adjusted for tree size/maturity by i-Tree Eco.
3) Tree establishment: the projected number of trees added each year based on user inputs. Users must enter the stem diameter of newly established trees and annual planting rates. Note, it does not include natural regeneration of trees, e.g., via the production, dispersal, and germination of seeds without human intervention, which is how new trees are established in natural areas. This makes i-Tree Forecast more suitable for highly urban landscapes, parks, and street trees.

i-Tree Forecast also allows the user to choose to simulate extreme events such as insect or disease outbreaks and storm events.

3.4.1 Simulation Scenarios

Simulations were run for a 30-year forecast period from 2022 to 2052. This corresponds to the time frame for meeting the canopy cover goals in the York Region Forest Management Plan. Simulations included diseases and pests that are currently impacting the forest. Storm events were excluded due to uncertainty in mortality rates following different types of storms, the geographical extent of damage, and the frequency of storms. The effects of climate change were incorporated by increasing the growing season length which would impact the annual growth rate of trees.

Currently, the length of the frost-free season is 163 days (climateatlas.ca). According to Historical and Future Climate Trends in York Region (Fausto et al. 2015), the length of the growing season is expected to increase by approximately 30 days by the 2050s. Since only one value can be entered into i-Tree Eco, an average value of 178 was used (the average of 163 and 193 days).

At this time, the most commonly observed pests and diseases impacting King are emerald ash borer (EAB; *Agrilus planipennis*), spongy moth (*Lymantria dispar dispar*), Dutch elm disease, and beech bark disease (*Neonectria faginata*). EAB is nearing the end of its worst impacts and the spongy moth population is collapsing under this current spread event. i-Tree Forecast only applies mortality rates to tree species impacted by the pest. Only pests that are known to occur in King were considered in the i-Tree Eco model. Oak wilt (*Ceratocystis fagacearum*) has yet to cross into Canada. Asian long-horned beetle (*Anoplophora glabripennis*) was last found in Ontario in 2013 and eradicated. Hemlock woolly adelgid (*Adelges tsugae*), according to the Canadian Food Inspection Agency, was found in the Niagara Peninsula but eradicated. However, it was recently observed in Northumberland County and is actively being managed. There is greater uncertainty as to when the other pests may arrive and establish themselves, for how long and what impact they will have, hence, they were excluded. These pests and diseases should be considered in future iterations of the Forest Study.

Appendix B summarizes the parameters used to set up i-Tree Forecast.

3.5 Soil

3.5.1 Background

Soil quality has been widely recognized in the literature and in strategic (urban) forest management guides and plans as a vital component and indicator of forest health. However, while regional urban forest management plans and assessments reference the need for high quality soil and sufficient soil quantity, they seldom provide guidelines beyond soil volume and the use of soil cells for street trees. To begin to address this gap, a baseline assessment of the physical and chemical soil properties across King was conducted as part of the King Township Forest Study. The results can be used to inform future management decisions targeting forest enhancement and planting and provide an additional facet that can contribute to our understanding of the overall health of the forest.

Three soil properties indicative of soil health were measured for this study: compaction, salinity, and pH.

Compaction

Research by the United States Department of Agriculture (USDA) has shown that almost no roots can penetrate soil with a penetration resistance (psi) of 300 psi or more (Duiker, 2002).

Psi values can be interpreted as follows:

- 0 – 200 psi: uncompacted / good growing conditions,
- 201 – 300 PSI: moderately compacted / fair growing conditions, and
- >300 PSI: highly compacted / poor growing conditions.

Salinity

Salts are chemical compounds which are made up of positively charged cations and negatively charged anions. Salts in moderation are good for plants as they provide key nutrients, and most fertilizers are salts. Salt concentrations in soil can vary greatly and are affected by several environmental factors including climate, local biota (plants and animals), bedrock and surficial geology, as well as human impacts on the land (USDA,2014).

pH

Like salinity, soil pH is affected by several environmental factors including, climate, local biota (plants and animals), bedrock and surficial geology, as well as human impacts on the land. In general, pH readings between 1 and 6 are considered acidic, 7, neutral, and 8 to 14, basic. Soil pH directly impacts the growing abilities of plants (Landscape Ontario, 2019).

3.5.2 Field Data Collection

The collection of soil data was auxiliary assessment outside of the i-Tree Eco data collection. A protocol specific to soil collection was developed and an overview of the methodology is included as follows. Measurements for compaction and salinity were taken *in situ* using a penetrometer and a probe, and pH measurements were attained by taking soil samples, which were submitted to ALS Environmental laboratory for analysis. Four *in situ* measurements were taken one metre around the centre of plots that had natural cover, were in parks, or undeveloped, and/or far away from human utilities, or around a tree or shrubs within plots near development to reduce the risk of striking utility lines. Four soil samples for pH were obtained within the circle delineated by the *in situ* measurements. Due to the necessity of taking actual samples from the ground for pH, it was not possible to obtain pH samples for most of the sites.

Compaction

Soil compaction was measured at four locations as described above using an analogue penetrometer. It was inserted into the soil until a depth of about 6 to 10 inches. The field crew would record uncompacted, moderately compacted, or highly compacted according to the range of psi values observed as follows:

- 0 – 200 PSI: uncompacted
- 201 – 300 PSI: moderately compacted, or
- >300 PSI: highly compacted.

Salinity

Salinity was assessed indirectly by measuring electrical conductivity (EC). Salt increases the ability of soil to conduct an electrical current, and therefore, electroconductivity can be used to infer salinity levels (Simons & Bennett, 2020; USDA, 2017). EC is proportional to the total amount of salts present in a solution (it has been correlated to concentrations of nitrates, potassium, sodium, chloride, sulfate, and ammonia), however, it does not provide a direct measurement of specific ions or salt compounds. It is possible to generalize and say that an EC of 1.0 mS/cm contains up to 1.0 gram of measured salts per 1 liter of water (Klaassen, n.d.)

FieldScout EC meters and probes were used to measure electroconductivity *in situ*, and results were recorded on mobile devices using Survey123. Conductivity measurements are directly affected by temperature, however, the EC meter compensated for temperature directly. Conductivity is also impacted by moisture levels. To produce a consistent moisture level, distilled water was poured into the measurement location to reach a saturation point before inserting the EC probe approximately six inches into the ground. Trial experiments had found it was not possible to consistently obtain deeper depths than six inches in compacted soils.

pH

Originally, a FieldScout pH meter and probe was obtained to also measure pH *in situ.* However, after one week of use, the probe broke. After discussion with the supplier, it was decided to discontinue the use of the probe *in situ* which could not cope with the harsh real-world soil conditions, and an alternative approach was developed. Four samples were taken by auger within the first 6 inches of the surface. They were mixed together and sent for analysis at ALS Environmental. Due to the original methodology not requiring soil samples, this request was not made in the landowner letters. As such, pH soil samples were predominately limited to public lands, unless express permission was obtained from private property owners.

3.5.3 Data Analysis Methods

Compaction, salinity, and pH were each analyzed separately and then compared with percentage dieback.

Compaction

Compaction levels were transformed to ranked values, 1, 2, and 3 corresponding with uncompacted, moderately compacted and highly compacted. These values were used to calculate an average compaction level per plot. Average compaction scores can be interpreted as follows:

- 1 – 1.75: Uncompacted
- 1.75 – 2.5: Moderately compacted
- >2.5: Highly compacted

The proportion of plots within each compaction category were calculated for the whole municipality, on public and private lands, and across land use stratum. Public lands included municipal, provincial, and conservation authority owned/managed lands. Land use stratum were grouped into more general categories to ensure a sufficient sample size to lower uncertainty and perform statistical testing. Pearson's Chi-squared test was used to test if there were differences in the proportion of plots in each compaction category between groups, and the pairwise Wilcox test was used to identify which groups were different when there were more than two groups.

Salinity

Electroconductivity measurements per plot were screened for outliers. Outliers were removed before calculating an average electroconductivity score per plot. Plot-level electroconductivity measures were used to calculate the mean, median, minimum, and maximum electroconductivity scores for the municipality, for public (defined as described previously) and private lands, and per stratum. Land use stratum were grouped together to increase sample size when necessary.

The Wilcoxon rank sum test for non-normal data were used to test for statistically significant differences in electroconductivity between private and public lands, while the Kruskal-Wallis rank sum test for non-normal data were used to test for differences among land use stratum.

pH

A single pH value was obtained for each plot from ALS Environmental. Fifty pH samples were obtained across King and were used to calculate the average, median, minimum, and maximum pH for King. A Wilcox rank sum test for non-normal data was used to test for a statistically significant difference in pH between public and privately owned plots and land use stratum. Land use stratum were grouped together to obtain a sufficient sample size to reduce uncertainty and allow for statistical testing.

Relationships between Soil Compaction, Salinity, pH, and Tree Condition

The relationship between soil compaction, electroconductivity, and pH and tree condition measured as percentage crown dieback were explored using correlation testing, scatter plots and linear regression. Where data were not bivariate normal Spearman's rho and Kendall's tau testing was used.

3.6. Invasive Species

3.6.1 Background

The objective of the invasive species analysis was to evaluate the degree and intensity of spread of invasive plants, pests, and diseases of concern across the municipality and different land use strata. Data about the presence or absence and extent of invasive species were collected by the field crew while at the i-Tree Eco plots.

Invasive species, pests, and diseases were identified based on the 2018 Toronto Canopy Study, the 2016 York Region Forest Management Plan, and consultation with invasive species specialists at York Region and TRCA (see *Table 7*). Diseases and insects such as oak wilt (*Ceratocystis fagacearum*) and spotted lanternfly[13] (*Lycorma delicatula*) that could become invasive in the future were not included in the list of species as they had not yet been seen in Ontario in 2022.

Table 7: List of invasive plants, pests, and diseases

Trees	Shrubs	Other Plants	Pests and Diseases
Norway maple *(Acer platanoides)*	European buckthorn (*Rhamnus cathartica*)	Goutweed (*Aegopodium podagaria*)	Asian long-horned beetle (*Anoplophora glabripennis*)
Manitoba maple *(Acer negundo)*	Morrow's honeysuckle (*Lonicera morrowii*)	Oriental bittersweet (*Celastrus orbiculatus*)	Spongy moth (*Lymantria dispar dispari*)
Callery pear (*Pyrus calleryana)*	Tartarian honeysuckle *(Lonicera tatarica)*	Wintercreeper euonymus (*Euonymus 23etiola*)	Hemlock woolly adelgid (*Adelges tsugae*)
Ivory silk lilac (*Syringa reticulata*)	Shrub honeysuckle (*Lonicera x bella*)	Dog-strangling vine (*Cynanchum rossicum*)	Emerald Ash Borer (*Agrilus planipennis*)
Tree of heaven (*Ailanthus altissima*)	European fly honeysuckle (*Lonicera xylosteum*)	Lily of the valley (*Convallaria* majalis)	Beech bark disease (*Neonectria faginata*)
Black Locust (*Robinia pseudoacacia*)	Non-native honeysuckle spp.	Periwinkle (*Vinca minor*)	Beech leaf disease (caused by parasitic nematode *Litylenchus crenatae ssp. Mccannii*.)
Black Alder (*Alnus glutinosa*)	European spindle-tree (*Euonymus europaeus*)	Himalayan Balsam (*Impatiens glandulifera*)	Dutch elm disease (*Ophiostoma ulmi*)
	Winged spindle-tree (*Euonymus alatus*)	Garlic mustard (*Alliaria petiolate*)	
	Japanese knotweed (*Reynoutoria japonica*)	Phragmites (*Phragmites australis*)	
		Wild parsnip (*Pastinaca sativa*)	

3.6.2 Field Data Collection

At each plot, crews were instructed to look out for the invasive species listed in *Table 7*. If a species was present, a score was assigned based on the degree of spread across and outside of the plot.

[13] Spotted lanternfly is not of major concern in York Region because it prefers the invasive species, tree of heaven (*Ailanthus altissima*), and is a threat to wineries and fruit orchards, which are not present or as prevalent in the Region.

Scoring level of spread for plant species

Field crews recorded the degree of invasion for each plant system using an ordinal or ranked system where 1 was the least amount of spread and 4 was the most. A definition for each is provided in *Table 8*. The scoring system was based on the 2018 Toronto Canopy Study.

Table 8: Degree of spread scoring system for invasive plants

Score	Definition	Detailed Description
1	1 to 2 patches of the invasive plant	Trees: 1 or more trees that are adjacent to each other, or 1 or 2 patches of adjacent seedlings/saplings Shrubs: 1 or more shrubs that are adjacent to each other, or 1 or 2 patches of seedlings/saplings Ground cover/Vine: 1 to 2 patches of adjacent plants 1 to 2 patches have maximum size: 0 – 25% of plot (or a circle with a max diameter of 11.35 m)
2	3 or more scattered pockets	There are 3 or more than patches and together they cover 0 – 49% of plot
3	A blanket effect	Pervasive spread: 50 – 100% cover
4	An extensive blanket effect within the plot and the surrounding area	50% - 100% within plot and continues into surrounding area.

Note: The area of invasive cover pertains only to the pervious area; For example, a plot could be 60% impervious while 100% of the pervious area is filled with an invasive plant. In that case it would be assigned to a level 3.

Scoring pest and disease spread

The field crew recorded the distribution of symptoms/damage caused by each of the listed pests/diseases, using a numbered ranking system:

- 1: presence of a pest symptom/damage on 1-3 trees
- 2: presence of a pest symptom/damage on 4-6 trees
- 3: presence of a pest symptom/damage on 7 or more trees

The field crew recorded the distribution of each of the pests (insects), using a numbered ranking system:

- 1: presence of a pest/larvae/egg/caterpillar on 1-3 trees
- 2: presence of a pest/larvae/egg/caterpillar on 4-6 trees
- 3: the presence of a pest/larvae/egg/caterpillar on 7 or more trees

3.6.3 Data Analysis Methods

Invasive plants, pests, and diseases were each analyzed separately.

Presence/Distribution

- Plants, insects, and diseases: Invasive species presence/distribution was estimated for the municipality and each land use type by calculating the percentage of plots (which were visited in the field) that had the presence of at least one invasive plant.
- Plants, insects, and diseases: For each invasive species, the percentage of plots visited by the field crew that had the presence of species, x. Using this information, it was possible to identify which species were most commonly distributed across the municipality and each land use stratum.
- Plants only: A third measure was calculated to assess co-invasion of plants. Using data only from those plots that had the presence of at least one invasive species, the average number of invasive plant species was also calculated.

Degree of spread

Plants, insects, and diseases: Using the spread score for each species and plot, the average spread was calculated across the municipality and per land use stratum. The average was calculated by only including data from plots which an invasive species present.

Combined invasion score for plants

A combined invasive score which indicated the overall level of invasion was calculated by multiplying the average number of species by the average degree of spread for the municipality as a whole and each land use stratum.

3.7. Climate Vulnerability

The climate vulnerability of the top twenty most frequently occurring tree species was assessed. The approach for the climate vulnerability assessment follows the methods used to prepare the Peel Region Urban Forest Best Practice Guides, Guide 4: Potential Street and Park Tree Species for Peel in a Climate Change Context and is consistent with climate change adaptation frameworks developed by Gleeson et al. (2011), Glick et al. (2011), and Ordóñez & Duinker's (2015).

3.7.1. Background

One of the priority action's put forward to foster community resiliency as part of York Region's Draft Climate Change Action Plan, 2020, is to conduct a vulnerability assessment on natural systems. Therefore, conducting a vulnerability assessment of York Region's forest can contribute to this action and help better understand the expected impacts of climate change on the forest and inform adaptation.

3.7.2. Emissions Scenario and Timing Window

The emissions scenario used for the King climate vulnerability assessment was RCP 8.5 (AR5) – the "worst case" scenario based on "business as usual" – from the Intergovernmental Panel on Climate Change's fifth assessment report (IPCC, 2013). York Region's Historical and Future Climate Trends (Fausto et al. 2015) and Peel Region Urban Forest Best Practice Guides, Guide 4: Potential Street and Park Tree Species for Peel in a Climate Change Context (Peel Guide 4) also use RCP 8.5 (AR5). Under this climate scenario, both York Region and Peel Region are projected to have similar climatic changes (Section 3.8.3).

The time window for the assessment Is 2041-2070, also known as the near future or 2050s. This time period is most suitable for forest planning in the next 30 years. It also aligns with the time frames used in York Region's Draft Climate Change Action Plan (2020) and Historical and Future Climate Trends (Fausto et al. 2015) and the Peel Region Urban Forest Best Practice Guide 4.

3.7.3. Near Future Climate and General Impacts on King's Forest

According to Historical and Future Climate Trends in York Region (Fausto et al. 2015), under RCP 8.5 conditions (business as usual scenario), the following climatic changes are anticipated in the years 2041 to 2070, all of which will impact the development of the King forest:

- Minimum temperatures are expected to increase significantly across all seasons and annually. This will increase the range of tree species northwards. Species that are already at their southerly extent are likely to shift northwards and become rare or extirpated. Species typically present further south are likely to establish themselves. Additionally, warmer temperatures will impact the population, survival rate, and distribution of invasive pests and diseases.
- Precipitation is likely to increase annually and in every season except summer when it is expected to remain the same or possibly decrease. Similar or decreasing rainfall in combination with hotter temperatures is expected to result in drier conditions in the growing season. This will cause stress on many species which are less drought tolerant.
- More frequent and intense extreme weather events are likely. In particular, it is anticipated that extreme precipitation events will become more frequent and severe, particularly in summer. Storm events will increase tree damage and mortality. For example, the windstorm event of May 21st, 2022 caused widespread, intense damage to trees and property across much of Southern Ontario.
- The number of days of extreme heat will increase significantly, and the number of extreme cold temperatures will decrease. The increase in extreme hot days will increase stress on many species, particularly those on the southern end of their range.
- The length of the growing season will increase by over 30 days by the 2050s. The start date will arrive earlier, while the end date will be later. The growth of trees will accelerate, although this will be countered by less water availability.

3.7.4. Assigning a Vulnerability Score

A vulnerability score was assigned to the top twenty most abundant tree species in King based on their exposure and sensitivity to climate change using the method and values developed in the Peel Urban Forest Best Practice

Guide 4 (henceforth noted as the Guide)[14]. Exposure refers to how much a species will be exposed to the impacts of climate change (such as high temperatures, extreme weather events, droughts), and sensitivity refers to the inherent characteristics or traits of species that make them more susceptible to climate change.

In the Guide, a combined vulnerability score was calculated for 88 tree species based on the likelihood of the species' exposure to climatic stress and the species' sensitivity to drought as follows:

Exposure to Climate Change

- Trees were considered to be exposed to climate change impacts if climate change would result in them occurring outside of their ideal range as determined by their climate envelope. Species which occur in areas with low climate suitability in the near future will experience climatic stress.
- The Guide classified tree species as likely to have high, moderate, or low exposure to climatic stress as follows:
  - High: species for which climatic suitability declines within Peel; area of suitable habitat in Peel is less than 20%.
  - Moderate: species with some loss in climatic suitability within Peel; area of suitable habitat in Peel does not fall below 20%
  - Low: species with no future loss or with a gain in climatic suitability within Peel Region; area of suitable habitat is more than 20%

Sensitivity to Drought

- The Guide classified species as having low, moderate, or high sensitivity to drought based on existing resources documenting drought tolerance.
- Niinemets and Valladares' (2006) five-level scale for assessing drought tolerance based on the geographical areas where species occur was used in the Guide to assign a drought sensitivity score. The Niiniments and Valladares numeric scale was converted to categorical values as follows:
  - High: 1 to 2.19

[14] Note that there are other assessments for tree species vulnerability availability in Ontario. These may use different future climate scenarios and criteria or methods to assess exposure and sensitivity. For example, the NatureServe Climate Change Vulnerability Index is another tool used in the Greater Toronto Area and beyond. This tool assess sensitivity based on genetic variability, dependence on other species, sensitivity to pathogens/pests, and other factors. The choice of climate scenario and criteria can change how the vulnerability score assigned to different species. For this study, we opted to use the Guide because it aligned with the climate scenario used in York Region's Draft Climate Change Action Plan (2020) and *Historical and Future Climate Trends* (Fausto et al. 2015), its application to a wide range of species, and the use of a climate dependent sensitivity criteria. For more information, CVC's (2023), Climate change vulnerability of treed habitats in the Credit River Watershed, Appendix E, contrasts vulnerability scores of common climate vulnerability assessments.

   - Moderate: 2.20 to 3.39
   - Low: values greater than 3.4.

Combined Vulnerability Score

- The Guide calculated a combined vulnerability score based on exposure and vulnerability as follows:
   - Extreme: high in climate exposure *and* drought sensitivity
   - High: high ranking of either climate exposure *or* drought sensitivity
   - Moderate vulnerability: two moderate rankings *or* one moderate and one low ranking of either climate exposure or drought sensitivity
   - Low vulnerability***:*** low sensitivity to drought *and* low climatic exposure

The list of the top twenty most abundant species in King was cross-referenced with the calculated vulnerability scores for the species list from the Guide. Vulnerability ratings from the Guide were used to assign vulnerability scores to each of the top species across King (*Table 26*) in Section 4.8. Any tolerances, sensitivities, and risks identified for each species in the Guide were noted in *Table 26*.

3.7.5. Development of Impact Statements

Impact statements identifying how climate stressors are expected to affect the entire forest and the top five most abundant species growing across King were developed using the "If-Then-So" method – a qualitative approach used in traditional risk-based assessments. The method requires the following questions to be answered:

- **If** expected changes in the future climate were to occur, including acute shocks (e.g. more extreme weather events) and chronic stresses (e.g. hotter and drier summers),
- **Then** what outcomes/impacts on the forest as a whole and individual species would be expected?
- **So,** what are the consequences of those outcomes/impacts (including strategic, financial, operational, environmental, public perception, and safety)?

4.0 RESULTS

4.1 Canopy Distribution

The 2020 canopy cover analysis found that approximately 11,383 ha or 34 percent of King's land area is covered by trees and tall shrubs[15] (termed existing canopy). The previous canopy cover assessment used i-Tree Canopy and estimated canopy cover to be 33 percent (LSRCA, 2016). However, a qualitative visual assessment of change between the two time periods found it was not possible to determine whether this was a real change or due to random error[16]. The 2020 analysis also found that impervious surfaces, which include roads, buildings, and other paved surfaces, represent approximately 4 percent of the land area. The remaining 62 percent includes grass, low shrubs, and bare ground (*Figure 2* and Figure 3). At 34 percent, King has a high canopy cover, but it still falls narrowly below the 36 to 41 percent range recommended in the York Region Forest Management Plan.

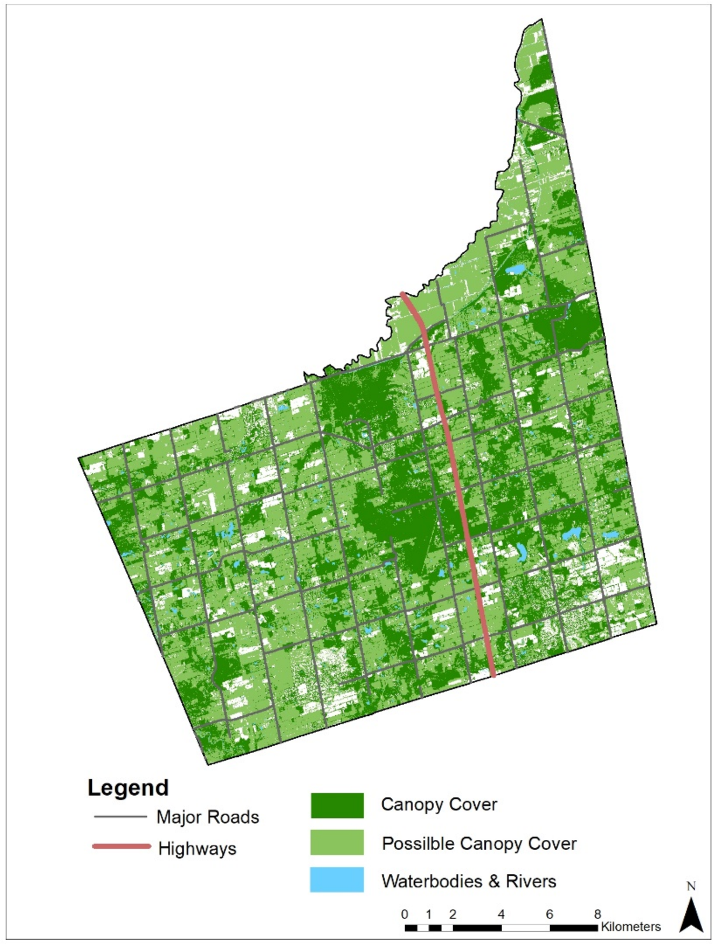

Figure 2: Distribution of existing and possible vegetated canopy cover across King

A total of 63 percent (20,928 ha) of the Township's land area could theoretically support future canopy. Within the possible canopy category, 61 percent (20,266 ha) of the municipality is potential vegetated canopy and another 2 percent is potential impervious canopy (662 ha). Much of the potential vegetated canopy cover occurs on agriculture and would not be possible to reforest. It is also worth nothing that these quantities do not consider that some asphalt, concrete, or bare soil surfaces may already be approved for development.

[15] Tall shrubs were not distinguishable from trees due to their height. They were approximately 2 meters or taller.

[16] Due to differences in the methods used for the two canopy cover assessments it is difficult to compare results directly.

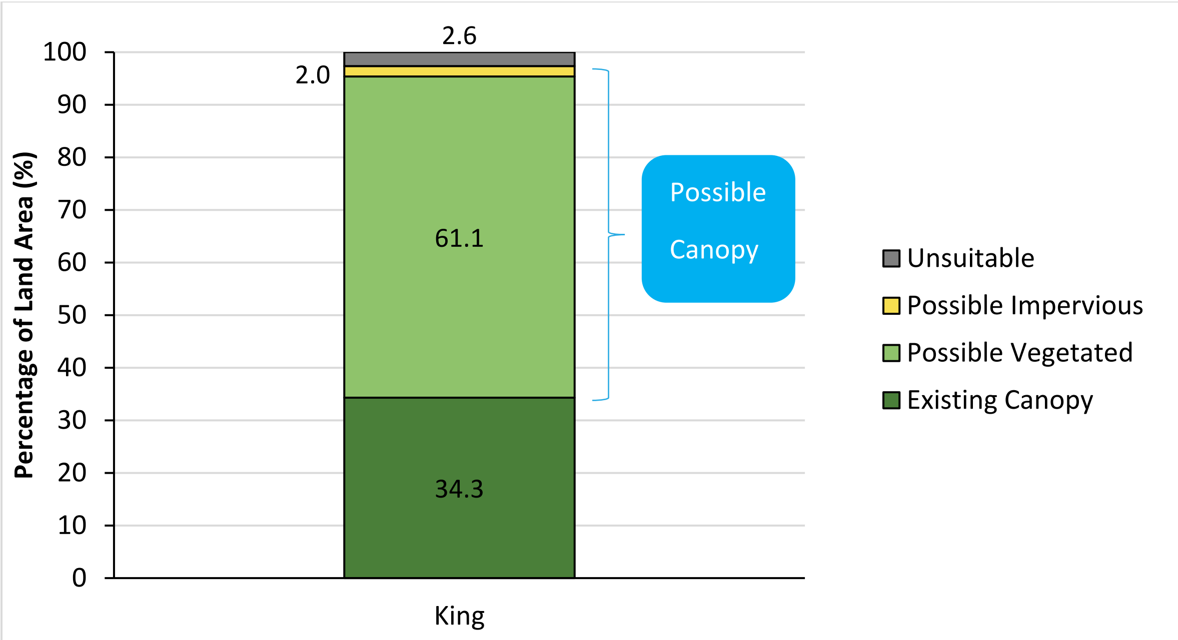

Figure 3: Canopy cover metrics for King

4.1.1 Canopy Cover and Plantable Space by MPAC Land Use Type

Canopy cover metrics were also calculated for each MPAC land use type. As noted in Section 3.1, land use changes have occurred since 2016 (the date of land use designation by MPAC) and unknown polygons were filled with existing datasets without ground verification, thus results summarized by land use should be viewed as approximate totals. Figure 4 summarizes the proportion of each land use type within King. *Agriculture* occupies the greatest proportion of area in at 62 percent, followed by *Residential Low* at 17 percent. Appendix C provides a summary of land cover and canopy cover metrics for King and per MPAC land use type.

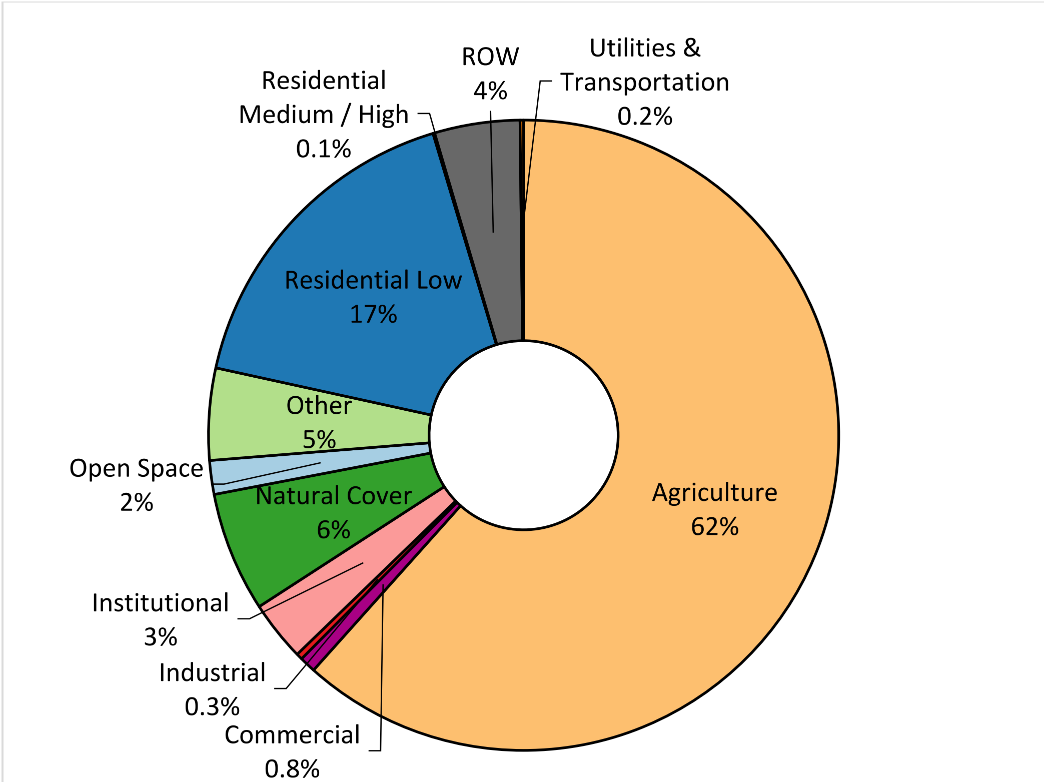

Figure 4: Current approximate MPAC land use distribution in King

The distribution of canopy cover varies across the MPAC land uses in King. Table 9 provides a break down of how much each land use category contributes to overall canopy cover and the canopy cover percent within each land use type. These values are illustrated in Figure 5 and Figure 6. The greatest proportion of the existing canopy cover is found in *Agriculture* which contains 4,783 hectares of tree canopy or 42 percent of King's total canopy area. *Residential Low* is the second biggest contributor of canopy cover at 27 percent, followed by *Natural Cover* (12%). The smallest portions of the total canopy cover are found in *Commercial*, *Industrial, Open Space, Residential Medium/High* and *Utilities & Transportation* (< 2 % each). The low proportion of total canopy found in these land use types can be attributed to them occupying a smaller proportion of the total land area in the municipality.

Table 9: Canopy cover metrics by MPAC land use categories in King

MPAC Land Use	Contribution to Total Canopy Cover (%)	Canopy Cover (hectares)	Canopy Cover within Land Use (% of Land Area)
Agriculture	42.0	4,783.19	23.3
Residential Low	27.1	3,085.41	54.9
Natural Cover	12.0	1,365.70	68.0
Other	8.2	937.00	59.9
Institutional	4.7	539.05	54.5

ROW	2.5	286.04	19.6
Open Space	1.8	201.02	36.3
Commercial	1.2	139.28	50.0
Industrial	0.2	23.76	23.9
Residential Medium / High	0.1	11.39	40.8
Utilities & Transportation	0.1	8.37	13.7
King	100	11,380.23[17]	34

Understanding the distribution of canopy cover is important, but another key component is understanding the distribution within land uses to guide management decisions. Twenty-seven percent of the *Residential Low* category land area is made up of canopy cover, whereas the *Natural Cover* category has a canopy cover of 67 percent. However, due to the relative size of this land use (11% of municipal area), canopy within the *Natural Cover* category represents only 23 percent of the municipality's total canopy cover area, contributing 694 hectares. Existing canopy cover percent is lowest in the *Commercial* and *Industrial* land use categories (less than 10% each).

Potential Canopy Cover

The greatest possibility to increase total municipal canopy is theoretically found in the *Agricultural* land use category. Approximately 15,413 ha (75% of land use land area) of the *Agriculture* category is classified as potential vegetated canopy cover, and an additional 188 ha is classified as potential impervious canopy. This is unsurprising, because *Agriculture* occupies 62 percent of the municipal area; however, possible canopy considers only the physical requirements of tree planting and not the social or economic expectations for each land use. In reality, it is unlikely that most of this area can be planted with trees, although there are opportunities to plant windbreaks around fields.

The second and more realistic opportunity to Increase canopy cover Is within *Residential Low,* with a total potential canopy cover space available of 2,282 hectares (41% of land area in this category), of which 2,127 hectares occurs on herbaceous and/or low shrub.

The *ROW*[18] land use category also maintains a large proportion of land available for tree establishment with 603 hectares possible vegetated cover and an additional 144 hectares of possible impervious cover; 636 hectares in *Natural Cover* are classified as potential canopy. There are also some opportunities on properties classified as

[17] Note that the total area of canopy cover by land use type does not exactly match that of the municipality (11,383 ha) due to some small differences (< 3 m) between the MPAC land use spatial boundary and the municipal boundary along the northern edge.

[18] *Utilities and Transportation* excludes ordinary right-of-ways and is comprised of large infrastructure projects such as power stations, airports, public transportation-easements and railways.

Other, Institutional, and *Open Space.* King has a relatively high tree cover percentage, however, as development increases, it will be important to ensure that development guidelines allow for tree planting and maintaining of pervious surfaces.

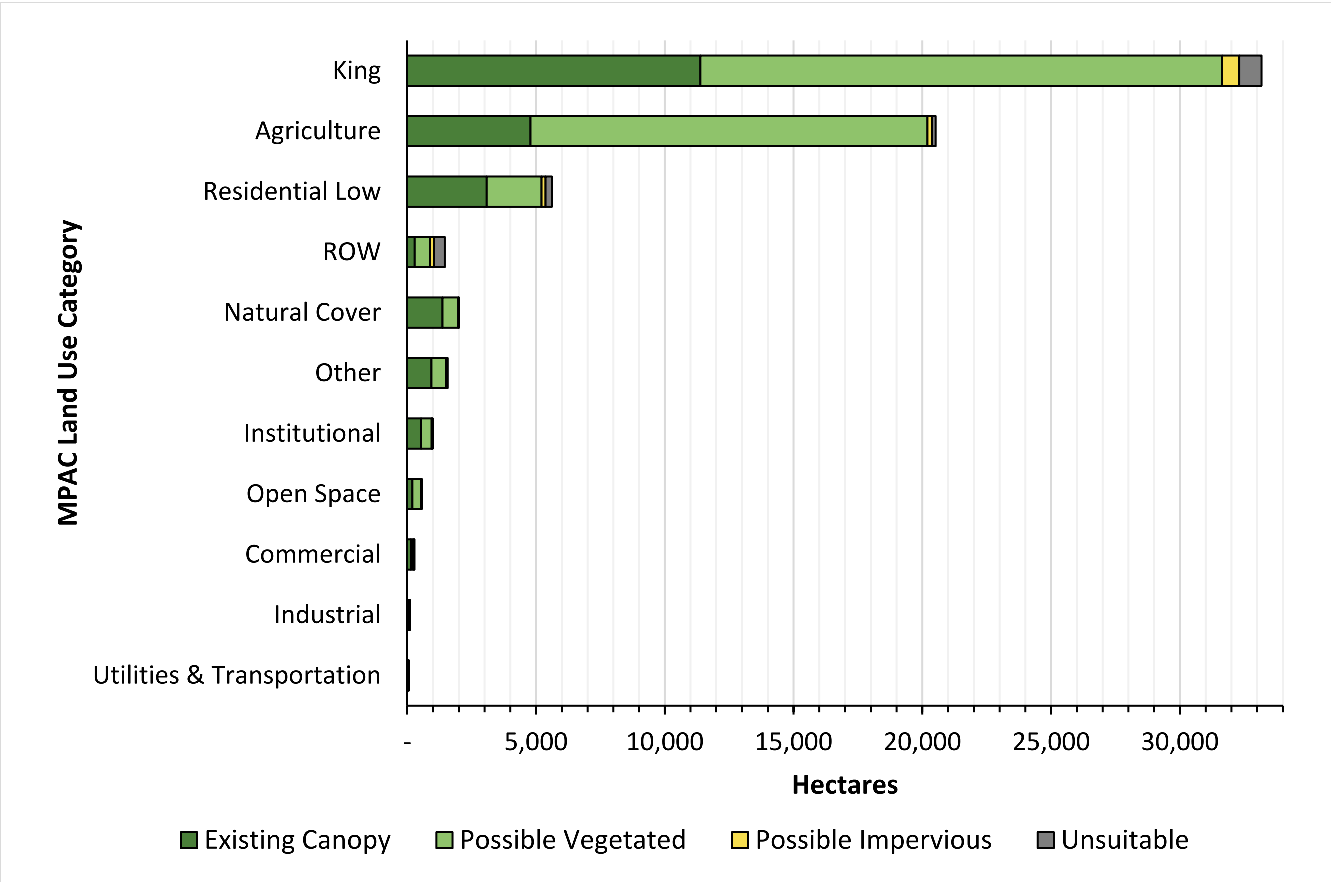

Figure 5: The distribution of existing canopy cover, possible vegetated cover, and possible impervious canopy cover measured in hectares within MPAC land use type

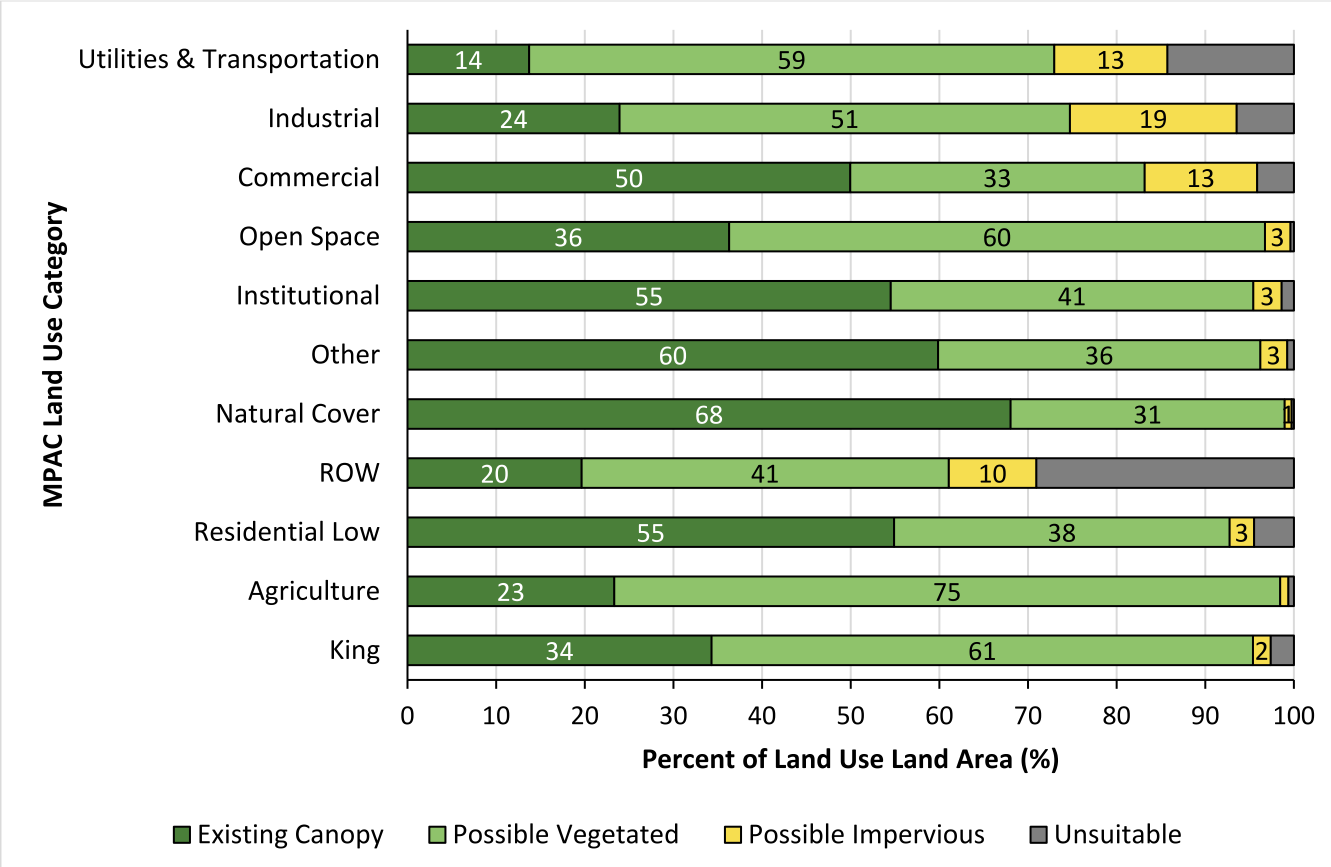

Figure 6: The distribution of existing canopy cover, possible vegetated cover, and possible impervious canopy cover as a percent of land use land area within MPAC land use type

4.2 Forest Structure

4.2.1 Structure

The i-Tree Eco model determined that there are approximately 9,588,224 (±1,179,056) trees in King. The results suggest a large tree canopy across the municipality suggestive of a more natural forest composition. The average tree density in King is 285 trees/ha, which is above the average for the Greater Toronto Area[19] of 202 trees/ha, considering municipalities with available data. The Whitchurch-Stouffville Forest Study (Lake Simcoe

[19] Tree densities (/ha) from recent i-Tree Eco studies in the Greater Toronto Area: Ajax (2023): 134; Aurora (2023:): 169; Bolton (2011): 185; Brampton (2011): 134; Caledon East (2011): 633; East Gwillimbury (2017): 136; Georgina (2017): 181; Markham (2022): 155; Richmond Hill (2022): 291; Mississauga (2011): 71; King (2023): 285; Newmarket (2016): 77; Pickering (2012): 354; Whitchurch-Stouffville (2017): 119; Toronto (2018): 162; Vaughan (2023): 144.

Conservation Authority, 2024) found a similar tree density of 289 trees/ha. The *Other*[20] *– Institutional* land use stratum has the highest tree density at 533 trees/ha, followed by *Open Space – Natural Cover* (466 trees/ha) and *Residential* (441 trees/ha) (*Figure 7*). The high tree densities observed in *Other – Institutional* and *Residential* are owing to the fact that many parcels of land zoned as these land use types are still largely undeveloped or are very low-density residential estates and covered in forest.

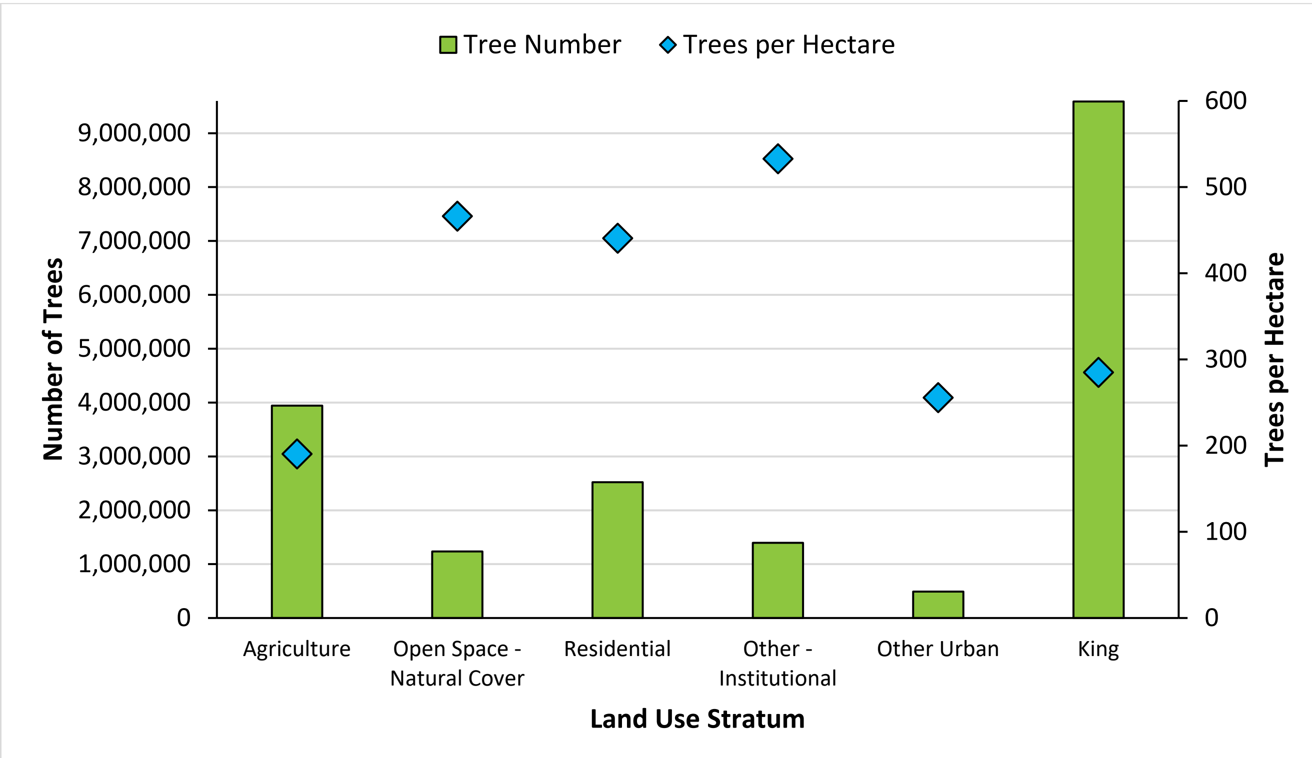

Figure 7: Total number of trees and tree density (trees per hectare) summarized by land use stratum in King (2023)

Leaf area in King is approximately 91,956 hectares (±11,985 ha) across a municipal area of 33,656.3 ha. Therefore, the mean leaf area density (of trees) in King is approximately 27,334 m^2/ha (±3,563 m^2/ha). This can also be expressed as 2.73 m^2 of leaf area for every 1.0 m^2 of land area (±0.4 m^2/ha). Leaf area density varies widely between land uses and is concentrated in the *Residential* land use, followed by both *Open Space – Natural Cover* and *Other – Institutional* stratums (*Figure 8*); these land uses represents 34 percent of the total area in King. Overall leaf area is greatest in the *Agricultural* land use stratum, however leaf area density is the lowest due to the large presence of active agricultural lands. Despite having the lowest density, this stratum contains the largest respective tree population (*Figure 7*).

[20] *Other* land use is a mixed category comprised largely of lands zoned as vacant residential land, recreational/non-commercial sports complexes, and common land (as of 2016 and therefore may be out of date).

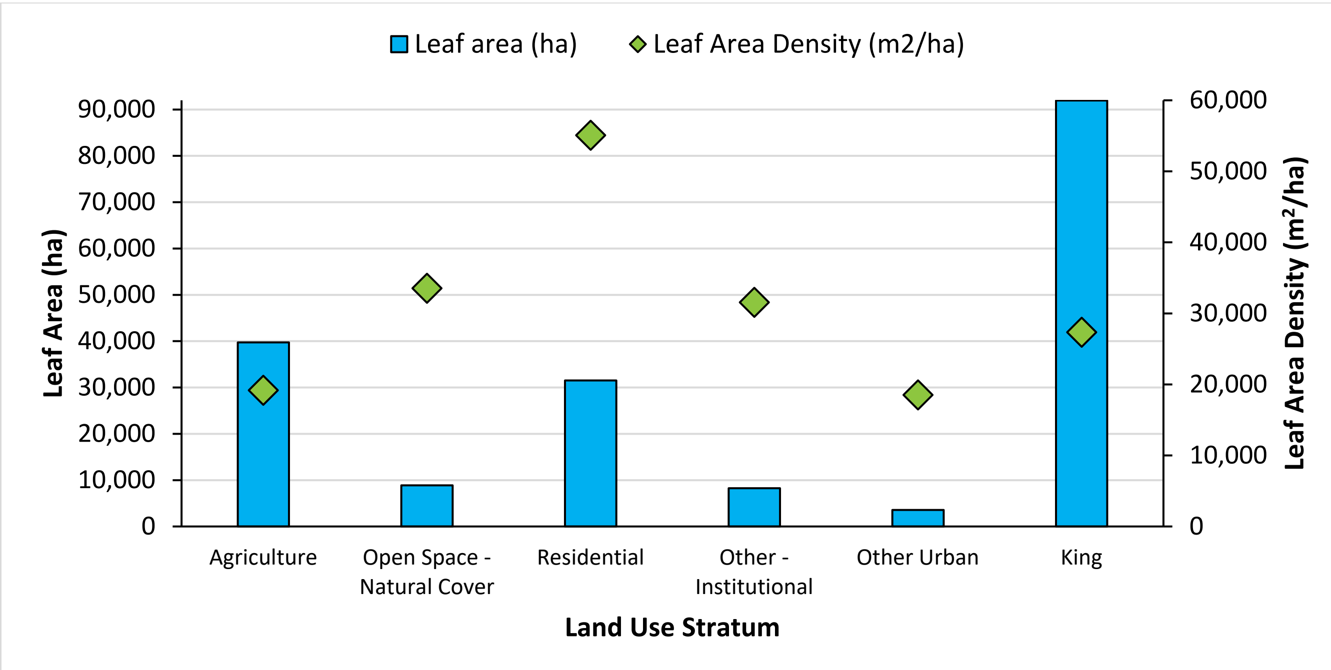

Figure 8: Leaf area (ha) and leaf area density (m2/ha) by land use stratum in King

Table 10: Summary of structural metrics per stratum

Land Use Stratum	Number of Trees	Trees per Hectare	Leaf Area (ha)	Leaf Area Density (ha/m2)
Agriculture	3,944,429	190.3	39,726.2	19,165.3
Open Space – Natural cover	1,234,907	466.3	8,879.6	33,526.5
Other – Institutional	1,396,810	532.8	8,274.2	31,561.5
Residential	2,521,014	440.6	31,518.3	55,079.2
Other Urban	491,064	255.7	3,557.8	18,522.1
King	9,588,224	285.0	91,955.9	27,334.1

It is interesting to note that *Residential* parcels have the second highest tree population, the second highest tree density and the greatest leaf density. As mentioned, most *Residential* parcels are often large low density estates and/or undeveloped, representing a good opportunity to protect what is there or risk losing much of the existing forest in King.

Public and Private Trees

Seventeen percent (±5%) of the tree population occur on public lands, such as municipal parks, rights-of-way (ROWs), protected areas, and conservation authority lands and 83 percent (±12%) of trees are privately owned. The *Open Space – Natural Cover* land use stratum has the greatest proportion of public trees at 57 percent of trees in that stratum, and 9 percent of all public trees. However, the majority of the tree population in King occurs on private lands. Due to the dichotomy in tree ownership, communication with private landowners may be quite valuable in educating residents on the importance of their lands in the context of the Township's forest.

4.2.2 Composition

Species composition can be expressed either as a percent of total leaf area[21] or as a percent of the total number of trees. When the latter measure is used, species that maintain a smaller growth form and that grow in high densities, such as Eastern white cedar (*Thuja occidentalis*), tend to dominate total species composition. In contrast, composition expressed as a percent of total leaf area captures the relative contribution made by each species to the canopy layer as well as to the provision of ecosystem services (as ecosystem services are generally a function of leaf area).

Whether species composition is expressed as percent of the total number of trees or percent of leaf area alters which species appear the most abundant. As shown in *Figure 9*, the top three most abundant species by number of trees is sugar maple (*Acer saccharum*, 13.3%), eastern white cedar (9.7%), and white ash (*Fraxinus americana*, 8.2%), while the most abundant species in terms of leaf area, shown in *Figure 10* are sugar maple (*Acer saccharum*, 29.5%), American basswood (*Tilia americana,* 7.6%), and white spruce (*Picea glauca*, 5.9%). The top ten most abundant species have a relatively uniform distribution each contributing approximately 3 to 13 percent of the tree population, whereas sugar maple completely dominates the proportion of leaf area at 29.5 percent.

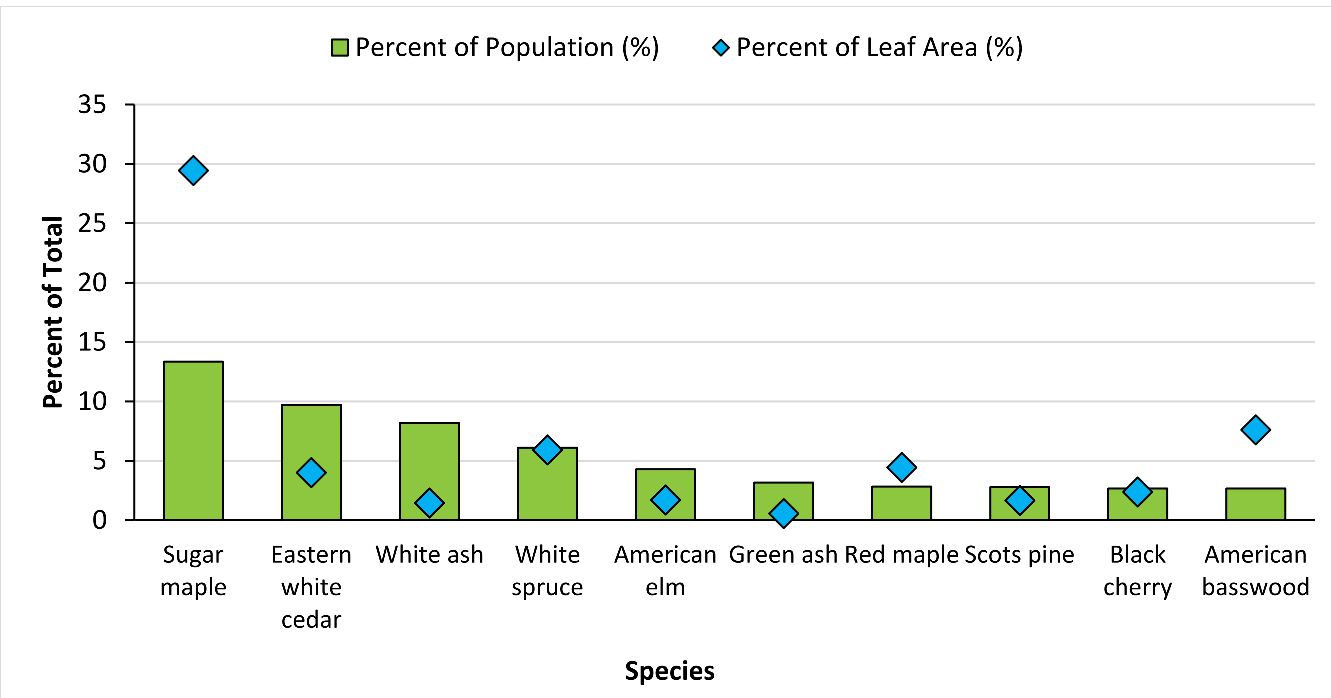

Figure 9: Top ten most abundant tree species by percent of trees

[21] Leaf area is defined as the total surface area (one-sided) of tree leaves. It is not equivalent to canopy cover which is the area of ground covered by canopy as viewed from directly above. Leaf area is much larger than canopy cover.

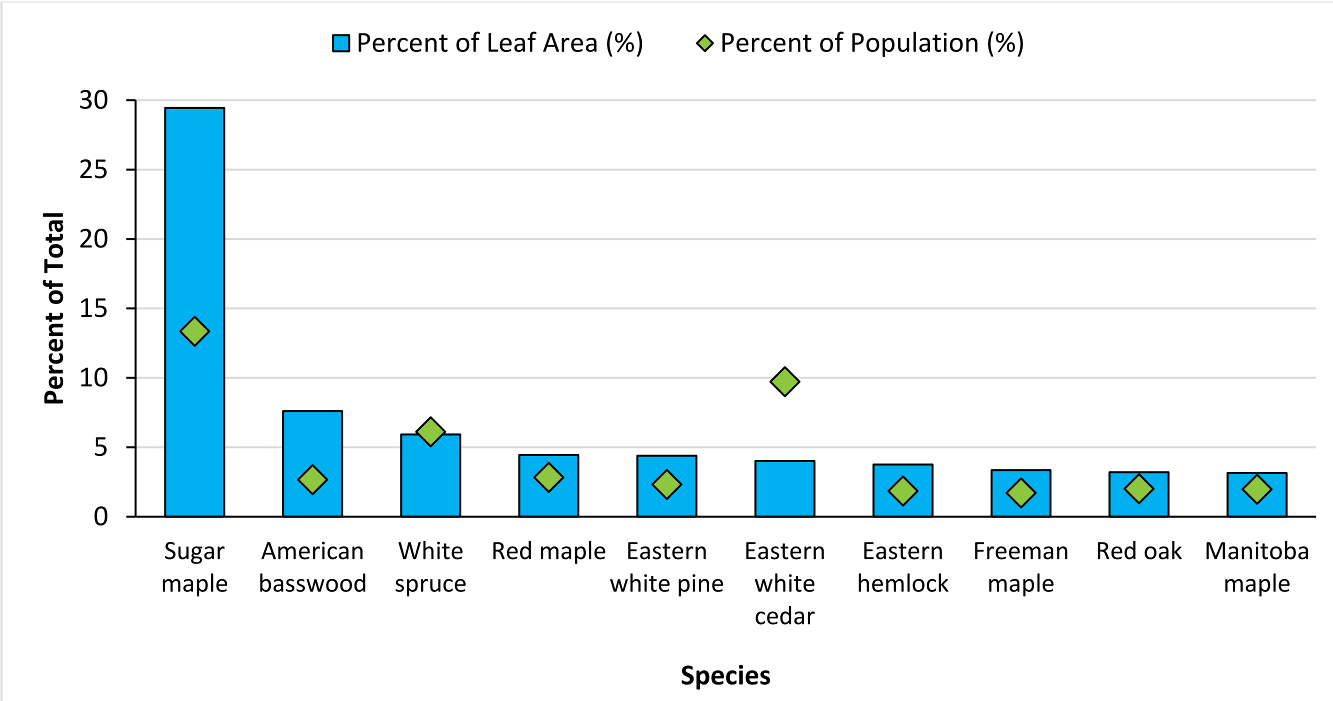

Figure 10: Top ten most abundant tree species by leaf area

In addition to species dominance, several genera and sub-families dominate King's forest (*Figure 11*). Maple (*Acer spp.,* 18.7%), ash (*Fraxinus spp.,* 14.8%), cedars and junipers (*Cupressoideae* sub-family, 9.7%, predominantly eastern white cedar), pine (*Pinus spp.*, 8.7%), spruce (*Picea spp*., 8.5%), elm (*Ulmus* spp.*,* 4.3% comprised only of American elm), and cherry (Prunus spp., 3.3%) were the most common subfamily and genera in the municipality in terms of tree population. Interestingly, likely in part to having a large forest population, genera and subfamily dominance is reflective of native populations and in contrast to more urban municipalities has minimal invasive dominance. Species dominance also varies by land use as summarized in *Table 11*. It should be noted that land use strata were grouped slightly differently from other concurrent Forest Studies due to the small number of plots falling into the following MPAC land use types: *Commercial, Industrial, ROW's, Utilities* and *Transportation*. To account for these underrepresented urban land use types, they were grouped into the *Other Urban* stratum.

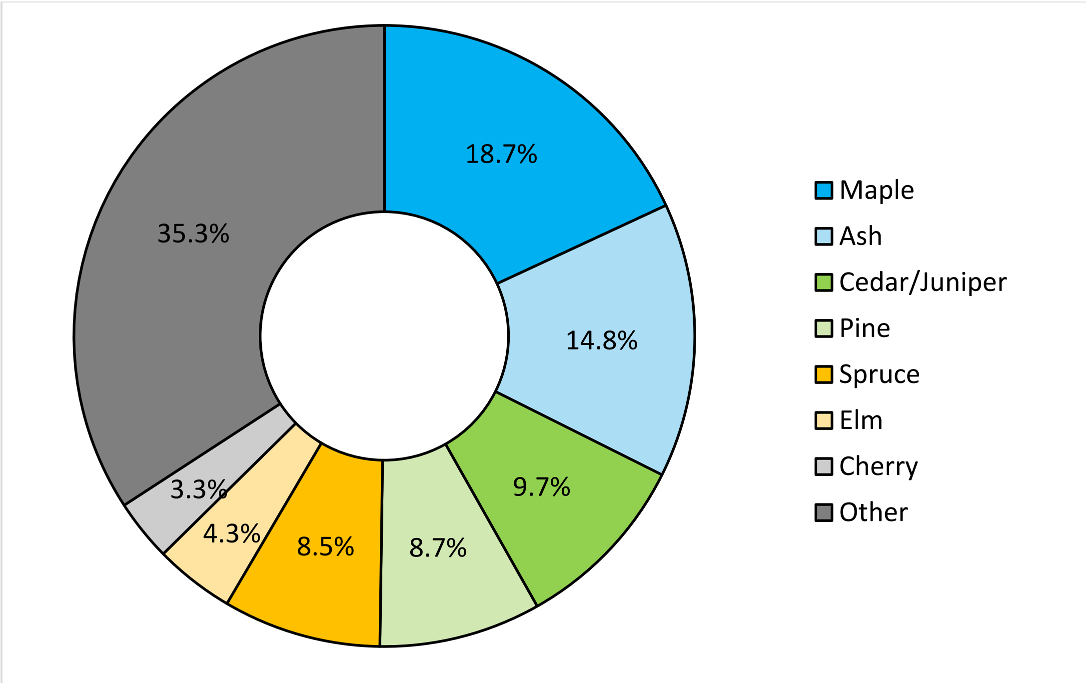

Figure 11: Most dominant tree genera and sub-families in terms of percent (%) of tree population

Table 11: Dominant tree species by percent of total leaf area and percent of total stems within land use stratum in King.

	Percent of Total Leaf Area		Percent of Total Trees	
Land use	**Common Name**	**Percent**	**Common Name**	**Percent**
Agriculture	Sugar maple	38	Sugar maple	20
	American basswood	11	Eastern white cedar	10
	Red maple	5	White ash	9
Open space – Natural cover	Sugar maple	17	White ash	14
	Large tooth aspen	14	Green ash	12
	Eastern hemlock	11	Sugar maple	9
Other – Institutional	Eastern white pine	20	Eastern white cedar	19
	Eastern white cedar	11	White ash	13
	Black walnut	11	Ash spp**	8
Residential	Sugar maple	29	Trembling aspen	21
	White spruce	17	Sugar maple	10
	Freeman maple	8	Eastern white cedar	7
Other Urban*			European buckthorn	14
	Sugar maple	18	Freeman maple	10
	Norway spruce	18	American elm	8
	Freeman maple	12	Eastern white cedar	8
			White spruce	8

* Estimates for Other Urban are associated with a very high standard error relative to population size due to the small number of trees sampled in these categories.

** Ash spp. Refers to dead, unidentifiable ash species

A total of 77 tree species were identified across all plots in King. Species richness is highest in the *Residential* land use stratum (56 species); this comparatively large number of species found can likely be attributed to the number of exotic horticultural species commonly found in residential gardens. It follows that in the context of forest studies that include urban areas, high species richness should not necessarily be viewed as an indication of ecosystem health. Rather, it may simply indicate an abundance of exotic species. Thus, urban forests often have a species richness that is higher than surrounding rural landscapes.

The township is characterized by a much higher proportion of native species in comparison to more urban municipalities in York Region. Eight-eight percent of the tree species identified were native to Ontario. This can be attributed to the large, intact, interconnected and remnant forest patches across the municipality that do not experience the same level of disturbance as urbanized areas.

4.2.3 Size Distribution

All trees measured were grouped into size classes based on diameter at breast height (DBH) and diameter class increased in 7.6 cm increments. Approximately 61 percent of all trees are less than 15.2 cm DBH (*Figure 12*). The proportion of large trees is quite high; just over thirteen percent of the tree population has a DBH of 30.6 cm or greater. Similarly, the average tree diameter across the forest in 2022 is 16.4 cm, which is greater than the neighbouring municipalities.

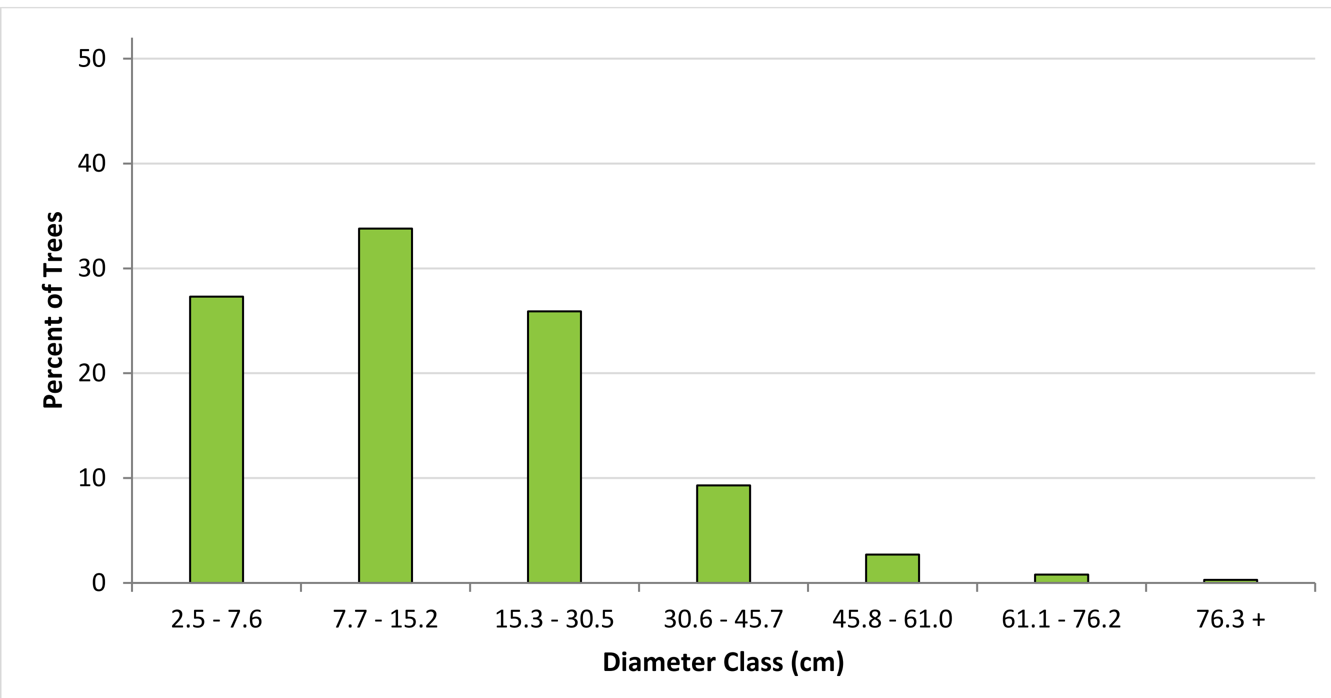

Figure 12: Diameter class distribution of trees in King in 2023

Figure 13 presents the diameter class distribution by land use for 2023. Across all land use strata, the trend is similar, with the two smallest diameter classes containing the majority of the trees, while fewer trees are found in the larger (>45.7 cm) diameter classes (<4%) (*Figure 13*). The uniform trend is especially interesting given the prominence of natural forest cover across all land use strata which convey a DBH composition representative of natural woodlots. The largest proportion of large trees are growing on *Agriculture* and *Residential* lands, with 15.0 and 14.9 percent, respectively, above 30.6 cm in DBH.

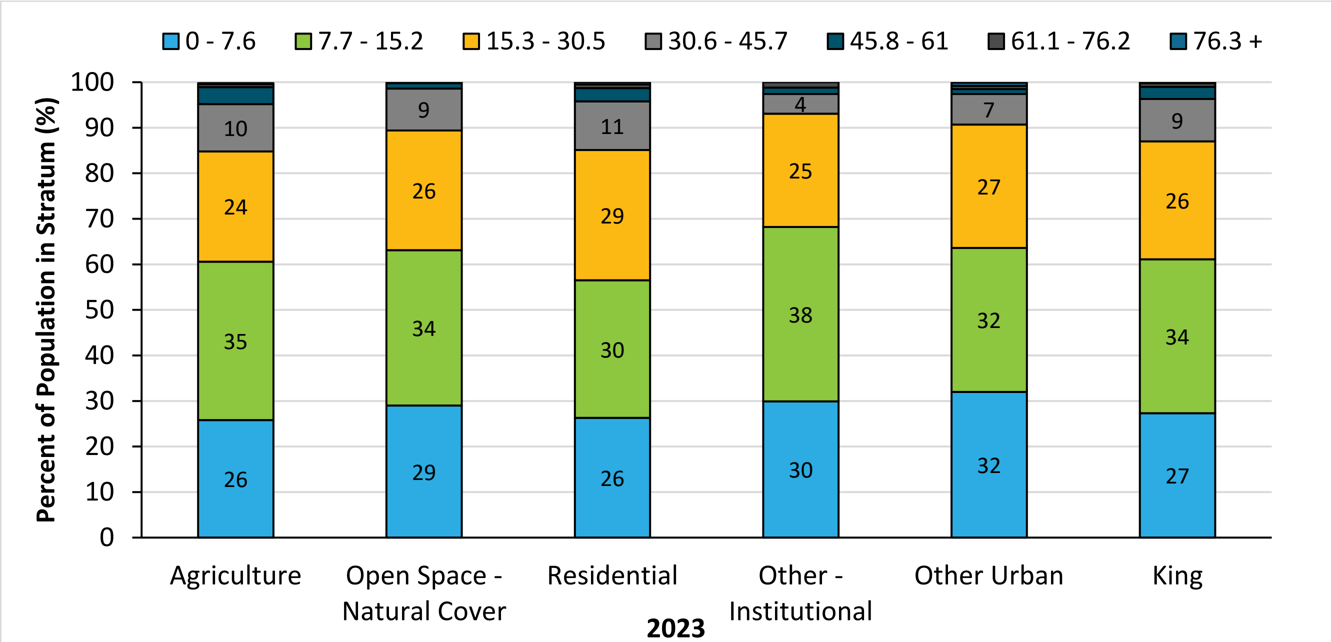

Figure 13: Diameter class distribution of trees by land use stratum in King 2023

4.2.4 Condition

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

- Excellent: <1% dieback
- Good: 1-10% dieback
- Fair: 11-25% dieback
- Poor: 26-50% dieback
- Critical: 51-75% dieback
- Dying: 76-99% dieback
- Dead: 100% dieback – no leaves/all branches dead

Basic condition ratings do not incorporate stem defects and root damage. Approximately 60 percent of trees in King are estimated to be in either excellent or good condition (*Figure 14*), with an average condition score of 69%. It should be noted that condition ratings are subject to observer bias given the nature of judgement ratings. If trees in fair condition are considered, the percent of trees in excellent to fair condition is 68 percent which may account for some of the potential biases.

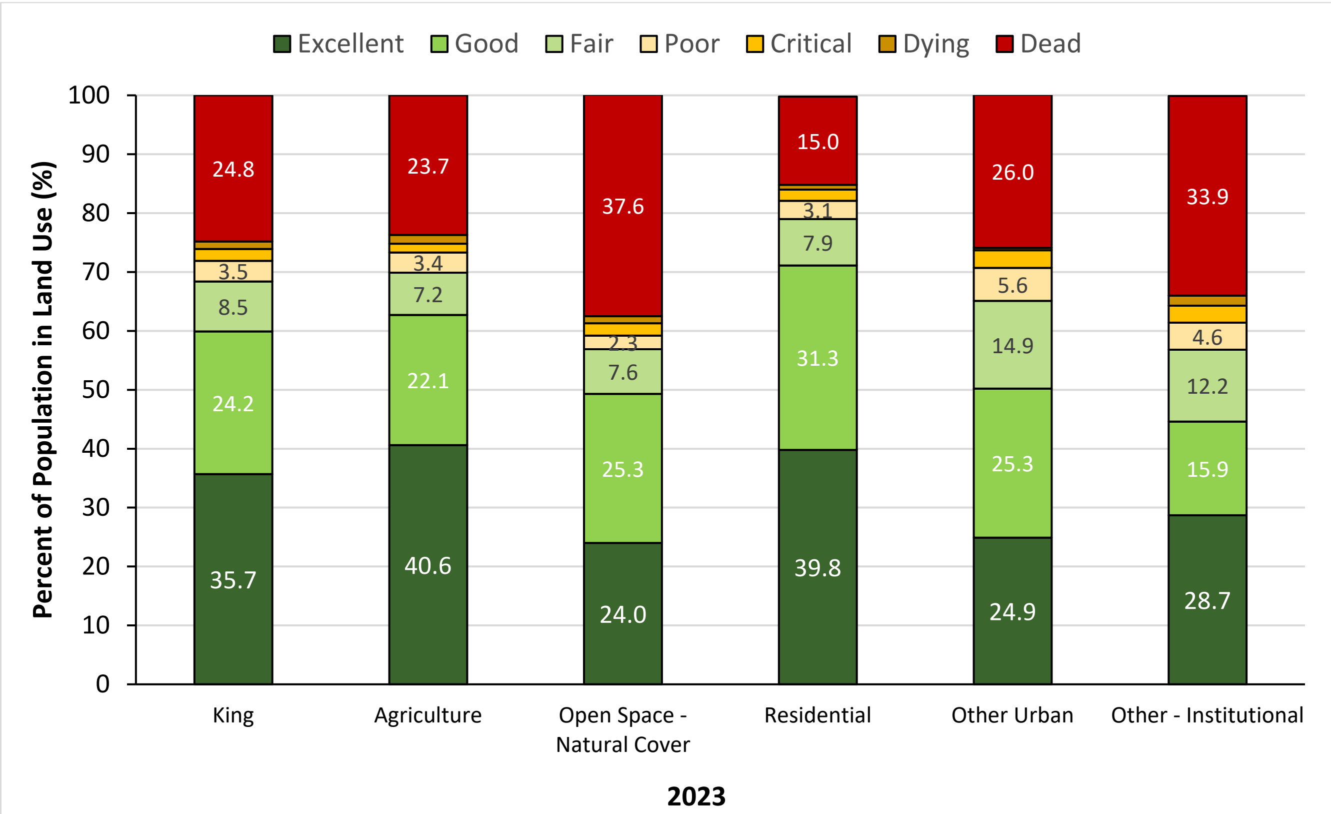

Figure 14: Condition of trees by land use stratum in King in 2023

The assessment of dead trees is straightforward and much more objective than the condition of living trees. Therefore, the proportion of dead trees can be considered the most reliable estimate. The presence of dead trees across all strata are much higher than urban municipalities. One potential cause for this is the dominance of natural areas which tend to be unmaintained and thus include more trees in poor or dead condition as these are not generally a risk to the public or homeowners and may be left to stand. In fact, dead trees provide important habitat and resources to wildlife and other organisms.

Another factor is the dominance of *ash spp*., which is the second most dominant genus in the Township. A large proportion of specimens of white, green, and black ash across the Township were found to be dead, at 58, 53 and 73 percent, respectively; together these species comprise 21 percent of the tree population in King. Additionally, *ash spp.*, which were dead and unidentifiable ash represented 2.4 percent of the total tree population. Given the prominence of ash across the Township's natural areas and in light of impacts from emerald ash borer (EAB, *Agrilus planipennis*), the high proportion of dead trees is within expectations. *Open Space – Natural Cover*, *Other – Institutional*, *Agriculture* and *Residential* land uses each have large ash populations *Table 12*.

Table 12: Ash number and condition across land use strata

Land Use Class	Species	Tree Number	Description of ash condition: Percent of stems recorded as dead (%)
Agriculture	White ash	365,007	63
	Green ash	17,662	33
	Black ash	23,549	75
	Dead ash*	76,534	100
Open Space – Natural Cover	White ash	176,415	55
	Green ash	145,116	73
	Dead ash*	45,527	100
Residential	White ash	51,731	60
	Green ash	110,359	44
	Black ash	37,936	91
Other Urban	White ash	9,128	20
	Green ash	18,255	10
Other – Institutional	White ash	182,193	53
	Green ash	12,146	0
	Black ash	32,390	50
	Dead ash*	109,316	100%

*Represent dead unidentifiable ash spp.

Other species contributing to the dead tree condition in the *Agriculture* stratum include eastern white cedar (*Thuja occidentalis*; 64% dead), trembling aspen (*Populus tremuloides*; 54% dead), jack pine (*Pinus banksiana*; 75% dead) and unidentifiable dead pine (*pine spp.*; 100% dead). In *Open space – Natural Cover*, all recorded eastern service berry (*Amelanchier canadensis*), hawthorn spp. (*Crataegus spp.*), chokecherry (*Prunus virginiana*), and staghorn sumac (*Rhus typhina*) exclusively contribute to the dead tree population in the stratum. In *Residential*, witch hazel (*Hamamelis virginiana;* 50% dead), American elm (*Ulmus americana*; 43% dead) and black cherry (*Prunus serotina*; 38% dead) are generally doing poorly. Lastly, in *Other – Institutional,* yellow birch (*Betula alleghaniensis;* 50% dead), American elm (*Ulmus americana*; 70% dead) and choke cherry (100% dead) are the common species contributing to the dead population in this stratum.

To reiterate, it should be noted that much of the Township's tree cover is contributed by natural forested lands where dying and dead trees are not actively removed if they do not pose a risk to infrastructure or public safety.

4.2.5 Additional Health Assessment

Additional data was collected for trunk and root integrity, canopy structure, and canopy vigour to obtain a more holistic understanding of health beyond percentage canopy dieback. A health score ranging from very poor (1) to good (4) was assigned to each element and used to calculate an average health score per tree. Average health scores were then computed per plot and per stratum, and for King as a whole. A score of 3.25 or higher is considered good, scores between 2.5 and 3.25 are fair, scores between 1.75 and 2.5, poor, and less than 1.75, very poor. The results of the per stratum analysis are summarized in Figure 15. To increase sample size, *Open Space – Natural Cover* and *Other – Institutional,* as well as *Residential* and *Other Urban.* As shown in Figure 15, all land use strata, except '*Other*', have an average tree health score that exceeds 3, which is considered fair. '*Other'* falls into the fair health category. Trees in King have an average health score of 3.3 (good).

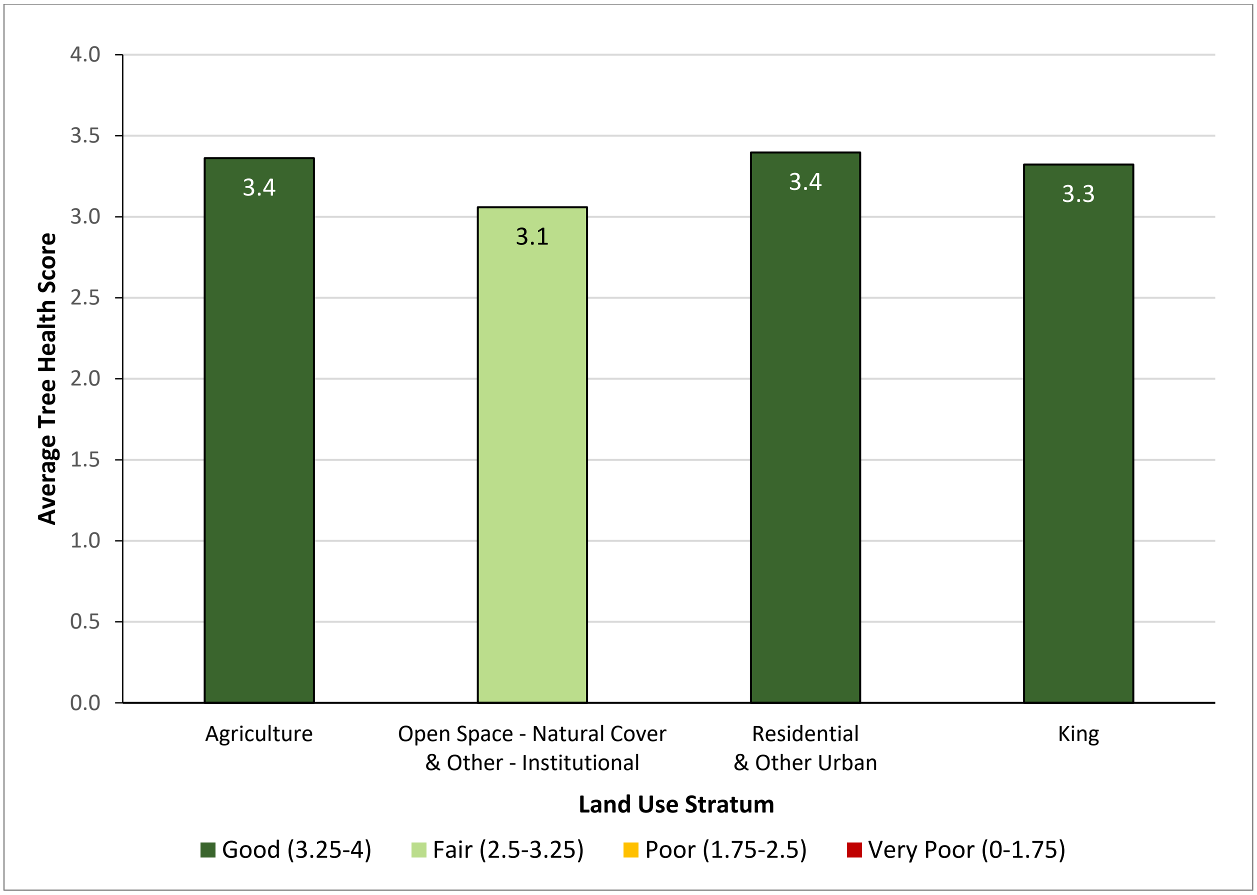

Figure 15: Additional tree health assessment results per stratum

A Kruskal-Wallis test revealed that there is a significant difference in health scores among at least some of the land use stratum (χ^2 = 6.07, df = 3, $p < 0.05$) and pairwise Wilcox testing identified that there was an almost significant difference between *Residential & Other Urban* stratum and *Open Space – Natural Cover & Other – Institutional* (p = 0.052)*. Residential* & *Other Urban* has the same average health score as *Agriculture.*

4.2.6 Structural Value

The estimated structural value of all trees in King in 2023 is approximately $2.3 billion. This value does not include the ecological or societal value of the forest, but rather represents an estimate of tree replacement cost if the trees were destroyed. I-Tree Eco assesses structural value using a version of the Council of Tree and Landscape Appraisers (CTLA) Trunk Formula Method (Nowak, 2020). This value is based on species, DBH, condition, and location. A base value of a tree is determined by its replacement cost, which in turn is informed by the maximum DBH trees available for replacement and average cost per square cm of trunk area. The base value is adjusted by a species factor (species specific factors are available for Canada as a whole), condition (the inverse of percent dieback), and land use (as an indicator of location). For non-U.S. countries, the average replacement cost assumes a maximum replacement size of 10 cm and cost per unit area based on the average value of all species within hardwood (dicotyledon) and softwood (conifer) categories. There is a positive relationship between the structural value of a forest and the number and size of healthy trees. Trees in locations that provide more amenities to humans, such as golf courses, are also provided a higher score.

4.3 Forest Function

4.3.1 Carbon Storage and Sequestration

Gross sequestration by trees in King is approximately 28,490 tonnes of carbon per year (104,472 tonnes of carbon dioxide per year) with an associated annual value of $29.7 million. Net carbon sequestration[22] in King is approximately 12,790 tonnes per year (46,899 tonnes CO_2 per year) with a value of $13.3 million. Trees in King are estimated to store 1,017,851 tonnes of carbon (3,732,121 tonnes of CO_2-equivalents); the value of this service is $1.06 billion. Carbon services in King are quite high due to the large tree population size.

The top five species for carbon storage and sequestration are shown in *Table* 13. Sugar maple (*Acer saccharum*) – which accounts for 13.4 percent of the tree population and 29.5 percent of the leaf area in King (27,077 ha ±7,600) – both stores and sequesters the greatest volume of carbon (approximately 21% of total carbon stored and 34% of total net sequestered carbon). The presence of white ash in the top five for total carbon stored is concerning given the impacts of EAB. Much of this carbon will be released back into the atmosphere as dead trees decompose. Classic native forest species such as red maple (*Acer rubrum*), black cherry (*Prunus serotina*), and American basswood (*Tilia americana*) make up the remainder of the top five for annual sequestration.

Table 13: Top five species for carbon storage and net sequestration

Carbon Stored			Net Carbon Sequestration		
Species	**Tonnes C**	**Percent**	**Species**	**Tonnes C/year**	**Percent**
Sugar maple (*Acer saccharum*)	212,198.30	20.8%	Sugar maple (*Acer saccharum*)	4,333.9	33.9%
Eastern white cedar (*Thuja occidentalis*)	111,885.40	11.0%	Red maple (*Acer rubrum*)	1,615.8	12.6%
American basswood (*Tilia americana*)	52,964.20	5.2%	Black cherry (*Prunus serotina*)	1,474.0	11.6%
White ash (*Tilia americana*)	48,798.10	4.8%	American basswood (*Tilia americana*)	1,364.6	10.7%
White spruce (*Picea glauca*)	39,219.50	3.9%	Freeman maple (*Acer x 45freemanii*)	1,356.5	10.6%

[22] Net sequestration is a measure of the carbon sequestered by trees calculated as the gross carbon sequestered minus the carbon emissions due to decomposition after tree death.

4.3.2 Annual Air Pollution Removal

The i-Tree Eco model quantified pollution removal by trees and shrubs in King based on air pollution data from stations in Newmarket and north Toronto in 2019. Pollution removal is greatest for ozone (O_3), followed distantly by nitrogen dioxide (NO_2) and particulate matter less than 2.5 microns ($PM_{2.5}$) (Figure 16). Trees and shrubs remove a total of 468 tonnes of air pollution (CO, NO_2, O_3, $PM_{2.5}$, SO_2) per year with an associated removal value of $359,486[23]. The removal of $PM_{2.5}$ has the greatest value in terms of health benefits, followed by ozone.

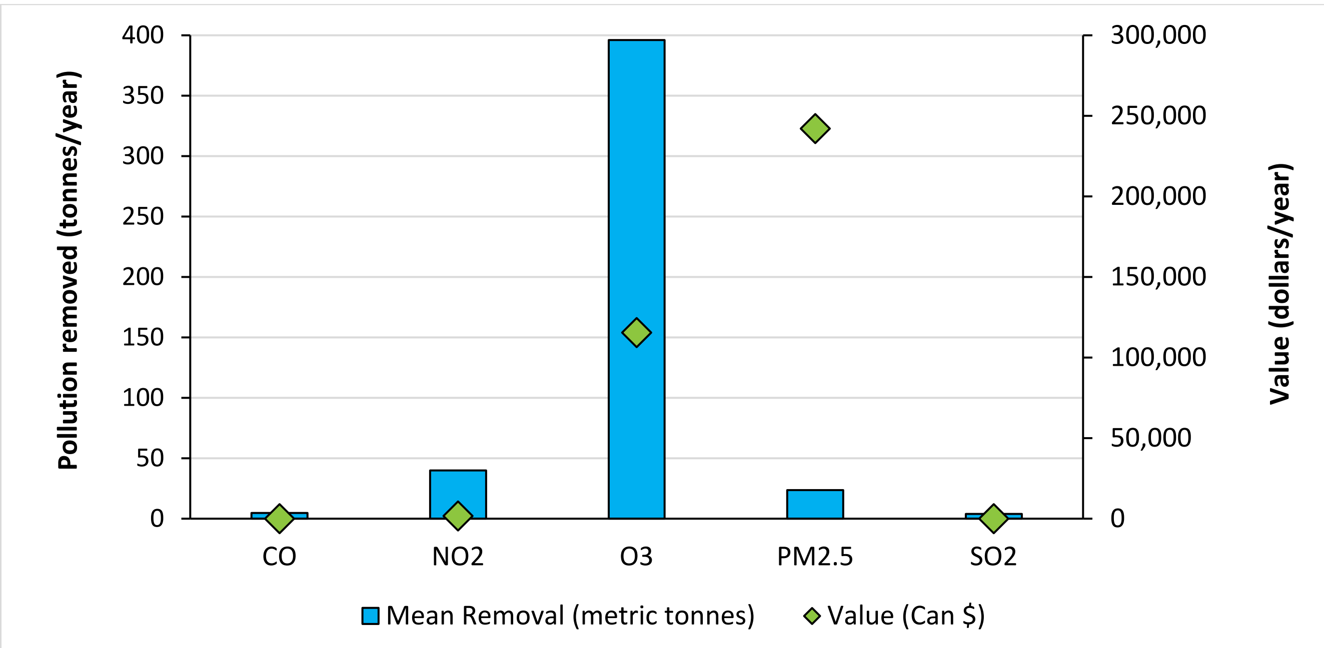

Figure 16: Annual pollution removal by trees and shrubs and associated removal value

4.3.3 Residential Energy Effects

The i-Tree Eco model estimated the effects of trees (≥ 6.1m in height and within 18.3m of a residential building, excluding high rises) on building energy use due to shading, windbreak effects, and local micro-climate amelioration. Estimates are based on field measurements of tree distance and direction to space-conditioned residential buildings[24]. Annually, trees adjacent to residential buildings in King are estimated to reduce energy

[23] The per tonne value of air pollution removal depends on the size of the human population that experiences the health benefits. Given King's relatively small population size, this benefit value is therefore lower than in urban settings. More details can be found in Section 3.2.6 of this report.

[24] While this estimation is based on a U.S. model, given the similarities between heating and cooling infrastructure and the similar climatic region between both countries the model should be fairly accurate for southern Ontario. Local costs of natural gas and electricity were used to estimate the value of energy savings. For more details see Section 3.2.6.

consumption by15,403.1 megawatt-hours for natural gas use and 1,365 megawatt-hours (MWH) for electricity use (*Table 14*).

Based on average energy costs in 2023, trees in King are estimated to reduce energy costs for residential buildings by $439,311 annually (*Table 15*)[25].

Table 14: Energy savings due to trees near residential buildings in King in 2023

Energy Units	Heating	Cooling	Total
Natural Gas (Megawatt-hour)	15,403.1	N/A	15,403.1
Electricity (Megawatt-hour)	447.4	917.8	1,365.2
Total			16,768.3

Table 15: Financial savings (Canadian $) in residential energy expenditures during heating and cooling seasons in 2023

Energy Units	Heating	Cooling	Total
Natural Gas	$ 289,135	N/A	$ 289,135
Electricity	$ 49,218	$ 100,958	$ 150,176
Total	$ 338,353	$ 100,958	$ 439,311

4.3.4 Hydrological Effects

i-Tree Eco was used to calculate the hydrological benefits provided by trees in King based on 2019 rainfall data from Pearson International Airport[26]. The i-Tree Eco model estimates the amount of rainfall intercepted, stored, evaporated, and transpired by trees as well as the volume of runoff avoided because of the urban tree canopy (Nowak 2020). Results are shown in *Figure 17* and summarized in *Table* 16. Trees in the *Agriculture* and *Residential* land use strata provide the greatest hydrological services to the municipality. Rainfall that is prevented from entering the stormwater system reduces the costs of building stormwater infrastructure and the risk of flooding. The overall value of the stormwater benefit (measured as avoided runoff) is $5.5 million per year based on 2019 precipitation levels[27].

[25] See Section 3.2.6 for the source of electricity and gas costs. Energy saving value is based on the price of $110.00 per MWH for electricity and $5.50 per MBTU for natural gas. The latter is equivalent to $18.77 per MWH.

[26] A total of 94 centimeters of annual precipitation (excluding snow) was recorded in 2019.

[27] The overall value is based on a rate of $2.324 / m^3 – the default value from i-Tree Eco converted into CAD. This rate is based on sixteen research studies on costs of stormwater control and treatment (Nowak, 2020).

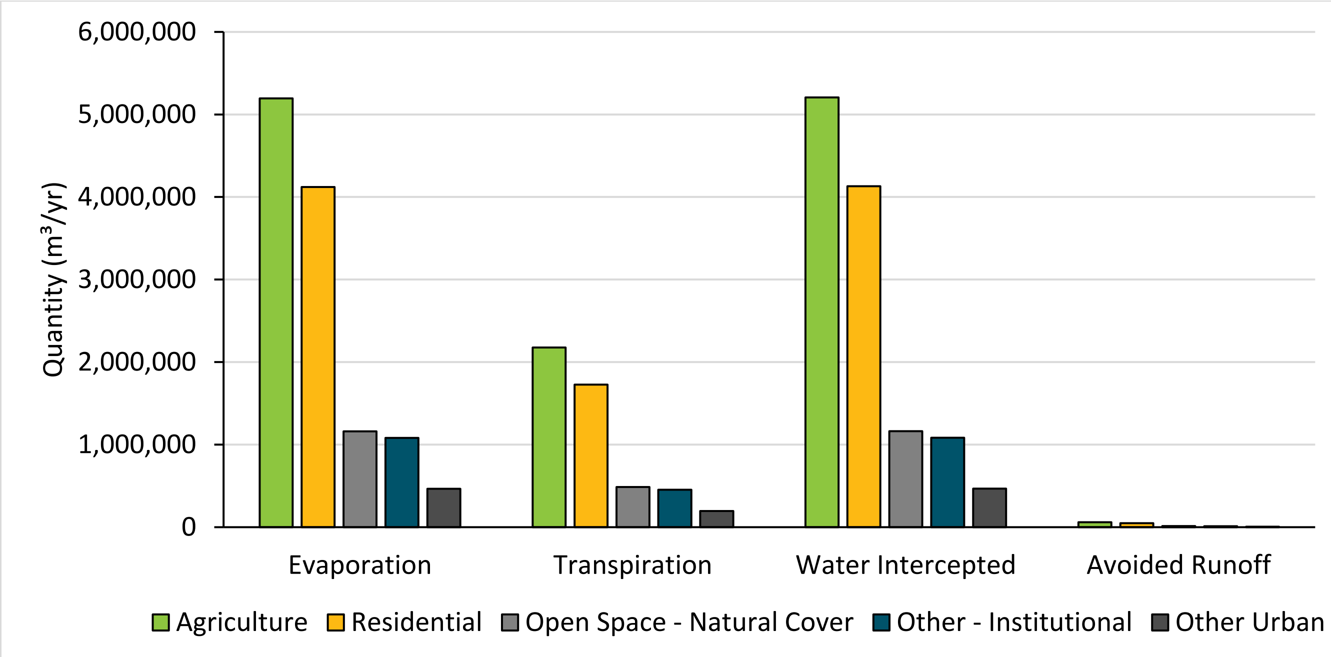

Figure 17: Hydrological services provided by trees in King in 2019

Table 16: Avoided stormwater runoff and value in King, 2019

Land Use Stratum	Avoided Runoff (m^3/yr)	Value ($/yr)
Agriculture	60477.74	$ 140550.27
Residential	47982.17	$ 111510.57
Open Space – Natural Cover	13517.98	$ 31415.79
Other – Institutional	12596.41	$ 29274.06
Other Urban	5416.24	$ 12587.34
King	**139,990.55**	**$ 325,338.04**

4.3.5 Other Benefits and Disservices

King's forest provides numerous other services, many of which are hard to quantify. It produces 34,023 tonnes of oxygen per year and under the shade in residential areas reduces the UV index by 52 percent and by 36 percent overall in residential areas, thereby reducing exposure to harmful UV rays and the risk of developing skin cancer.

Unfortunately, trees also have some disservices. In addition to being a source of allergens, trees emit volatile organic compounds (VOCs) such as monoterpene and isoprene. A total of 336,751 kg/year is emitted per year, with the greatest mass being emitted from *Residential* and *Agricultural* areas which have the most trees. White spruce (*Picea glauca*) emits the most VOCs at 53,249 kg/year followed by sugar maple (*Acer saccharum* – 35,748 kg/year) and Northern red oak (*Quercus rubra* – 34,400 kg/year)

4.4 i-Tree Forecast

Based on the current municipal planting programs and expected canopy growth, and despite the anticipated impacts of spongy moth (*Lymantria dispar dispar*), emerald ash borer (*Agrilus planipennis*), Dutch elm disease, and beech bark disease (*Neonectria faginata*), King will exceed the recommended canopy cover range, (i.e. 36 to 41 percent) over the next thirty years. At the current rate of planting of 5,962[28] trees per year assumed over 30 years and assuming natural tree growth, the i-Tree Forecast model estimates that canopy cover will increase by 12.79 percent to reach 46.79 percent by 2052. Under a doubled planting scenario, i.e., 11,924 trees per year, the model estimates that canopy cover will increase by 12.89 percent to reach 46.89 percent by 2052. Lastly, assuming no planting programs are undertaken, the forecast projects canopy cover will increase by 12.69 percent to reach 46.69 percent by 2052 (Figure 18).

It should be noted that i-Tree Eco does not include natural regeneration or ingrowth of trees. In other words, it assumes that the only new trees established in the simulation period are those that would be deliberately planted.

It is also important to note that the average annual number of frost-free days in King was increased during the thirty-year simulation period to account for expected climactic changes (see Section 3.4.1). The longer growing season is more likely to benefit tree growth in the latter half of the simulation period than the earlier half. Thus, canopy growth over the next six years is likely to be less than 2 percent.

[28] This annual rate is based on the naturalized plantings occurring in King. For the purposes of i-Tree Forecast, plantings were assumed to occur in the *Open Space – Natural Cover* land use type. Trees were assumed to have a DBH of 2 cm at the time of planting. See Appendix B for more information on i-Tree Forecast parameters.

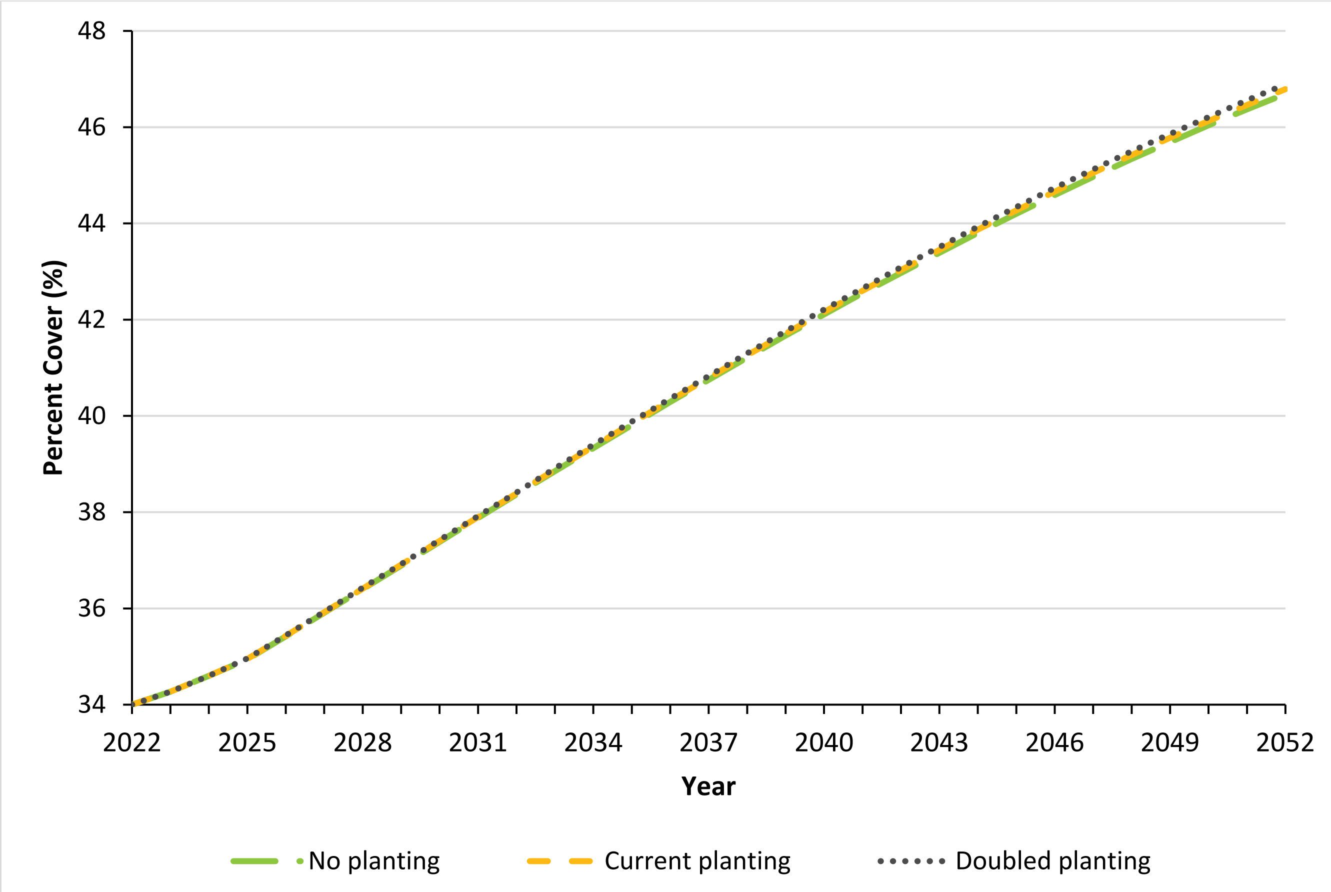

Figure 18: i-Tree forecast projections on canopy cover across planting scenarios

4.5 Soil Health

4.5.1 Compaction

Eighty plots were measured for compaction in King. Across the study area, 37.5 percent of the sampled plots were uncompacted, 23.7 percent were moderately compacted, and 38.8 percent were highly compacted[29]. The proportion of uncompacted plots was equivalent on public (municipal, provincial and conservation authority ownership) and private lands, and mean compaction was slightly higher on public lands, but this difference was not statistically significant (*Table 17*).

[29] These proportions should not be taken as representative of the municipality as a whole, but rather of the plots where we were able to take soil measurements.

Table 17: Compaction across private and public lands in King. Public lands include municipal, provincial, and conservation authority properties.

Ownership type	Number of plots sampled	Mean compaction score	Percent uncompacted (of measured plots)	Percent moderately or highly compacted[30] (of measured plots)
Private	64	2.04 (±0.81)	37.5%	62.5%
Public	16	2.17 (±0.92)	37.5%	62.5%

Across land use strata, the mean compaction and proportion of compacted plots were higher in *Residential & Other Urban* (compaction mean = 2.26 ± 0.78) as compared to *Agriculture* (compaction mean = 1.86 ± 0.76) and *Open Space – Natural Cover & Other – Institutional* (compaction mean = 1.86 ± 0.93) land use strata. The proportion of compacted, moderately compacted, and uncompacted plots per stratum is shown in *Figure 19*. These differences were not found to be statistically significant across land use strata.

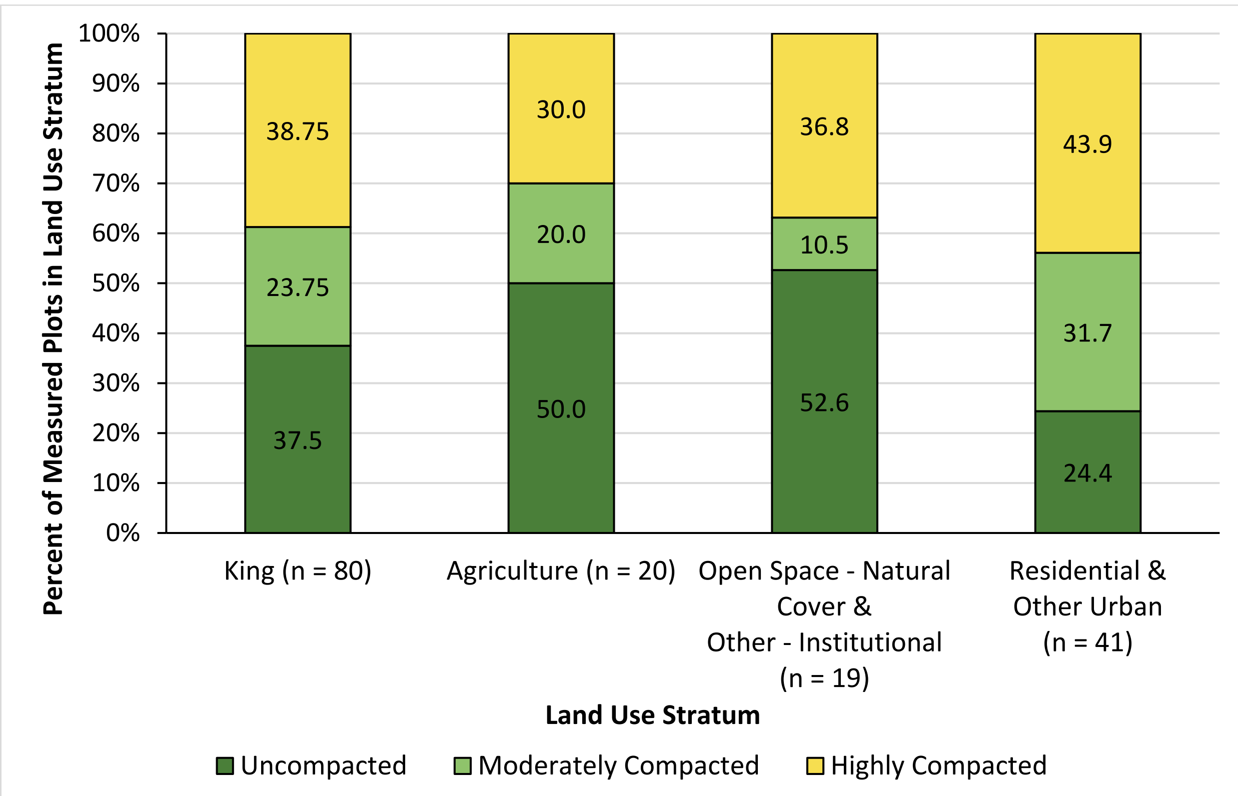

Figure 19: Compaction across land use strata. Land use strata were aggregated to increase the sample size.

[30] Owing to there being only two moderately compacted plots on public land, moderately and highly compacted plots were amalgamated for analysis.

4.5.2 Salinity

Salinity across King was inferred from *in situ* electroconductivity (EC) measures. In total, 75 plots were assessed and found to have a mean of 171.4 µS/cm (±204.6), median of 116.2 µS/cm, and a minimum and maximum value of 11.1 µS/cm and 1,237.0 µS/cm, respectively. The majority of values were below 400 µS/cm.

Public lands were found to have a higher average EC value than private lands in King, however, owing to a small sample size on public lands it was not possible to detect a statistically significant difference between ownership types (*Table 18*). A higher salinity on public lands is unsurprising as they tend to be more developed (including ROWs) than private lands.

Table 18: Electroconductivity across private and public lands in King.

	Number of Plots	Mean (µS/cm)	Median (µS/cm)
Private	60	150.7 (± 155.3)	113.0
Public*	15	254.5 (± 332.2)	129.2

Note: * Public lands include municipal, provincial, and conservation authority properties.

Differences in salinity across land use strata were also explored and results are shown in *Table 19* and *Figure 20*. *Open Space – Natural Cover* and *Other – Institutional* were grouped together to increase sample size and because they were deemed similar enough. Most plots on *Other – Institutional* fell on open space or forested areas. Similarly, *Residential* and *Other Urban* were also grouped together. No statistically significant difference was detected among land use strata using the Kruskal-Wallis rank sum test for non-normal data. The median value was highest for *Residential – Other Urban*, while *Agriculture* and *Open Space – Natural Cover & Other – Institutional* were very similar to each other. *Open Space – Natural Cover & Other – Institutional* and *Residential & Other Urban* have much higher mean values than *Agriculture* due to the presence of outliers in the upper range that pull the mean upwards. These outliers are explored below. Excluding the outliers from *Open Space – Natural Cover & Other Institutional,* the maximum value is only 242.2 µS/cm. Overall, given the largely rural nature of King, it is not that surprising that there are not large differences in salinity among land use strata.

Table 19: Electroconductivity across land use strata. Strata were grouped together to increase the sample size.

	Number of Plots	Mean (µS/cm)	Median (µS/cm)
Agriculture	19	127.2 (± 93.3)	100.8
Open Space – Natural Cover & Other – Institutional	19	213.3 (± 303.0)	106.5
Residential – Other Urban	37	172.6 (± 184.0)	129.3

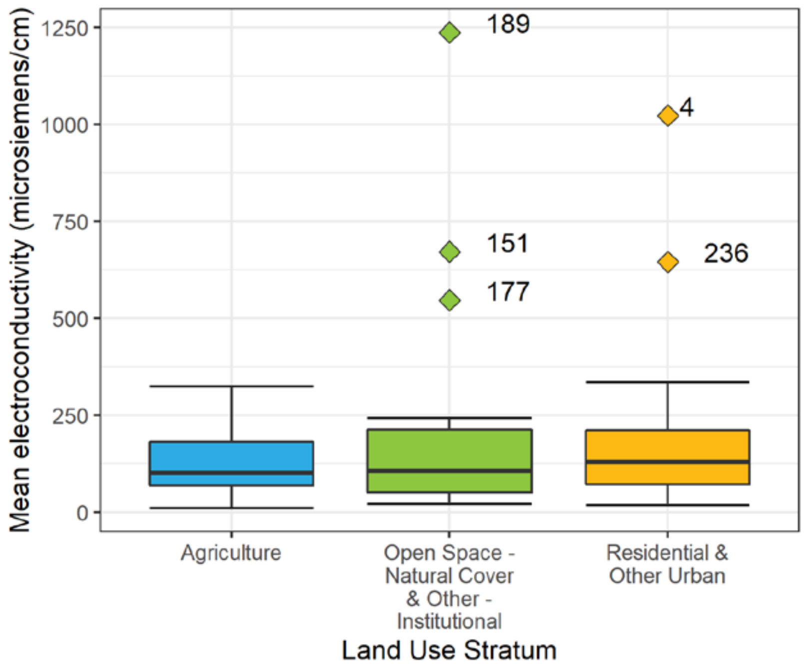

Figure 20: Boxplots of electroconductivity across land use stratum in King.

Figure note: The solid middle line in the figure shows the median value (50th percentile), while the lower and upper limits of coloured box indicates the 25th and 75th percentiles, respectively. The whiskers (upper and lower black horizontal bars) are the minimum and maximum measurements that are within a normally expected range[31]. The diamonds indicate outlier values, and the labels indicate their plot ID.

As shown in *Figure 20*, plot 189 is an outlier for the *Open Space – Natural Cover & Other – Institutional* land use stratum and is the largest outlier for the combined dataset (EC = 1,215 µS/cm). The geographic location of the plot is depicted in *Figure 19.* This site falls into a woodlot along King Vaughan Rd and Keele Street and is surrounded by some residential properties. The topography of the site acts as a natural drainage feature with slopes leading down into the woodlot. This may explain the organic and moist soils recorded at the plot and the high salinity reading which may be caused by run off deposits from surrounding residential lands uses. The plot is heavily dominated by eastern white cedar (*Thuja occidentalis*) which is somewhat more salt tolerant than its coniferous counterparts and does best in moist soils. Other

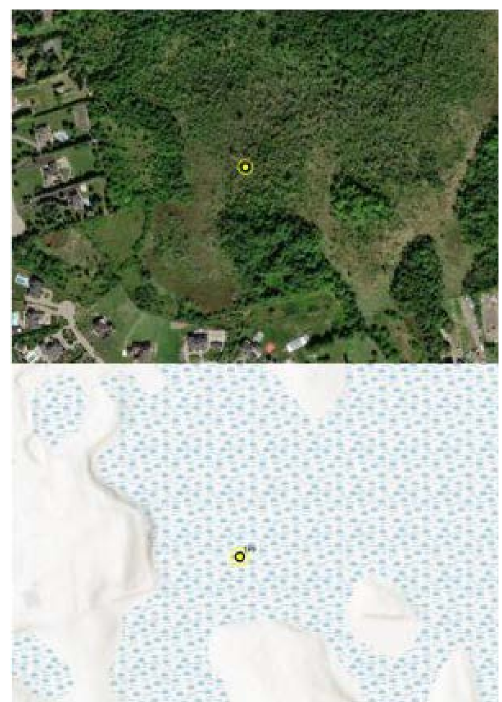

Figure 21: A depiction of the geographic location of plot 189

[31] The upper value of this range is defined as the 3rd quartile (75th percentile) + 1.5 x interquartile range and the lower value is the 1st quartile (25th percentile) – 1.5 x interquartile range. The interquartile range is the difference between the 3rd quartile and the 1st quartile.

prevalent species include yellow birch (*Betula alleghaniensis*) which also prefer moist soils, and a number of black ash (*Fraxinus nigra*) which are characteristic species of moist to wet organic soils. There were also several dead hardwood trees recorded which could be due to increased soil saturation and/or salinity by lying on a downslope hill.

4.5.3 pH

Seventy-four pH samples were obtained across King. The average pH was 6.52 (± 0.87), a median of 6.81, minimum of 3.34 and a maximum of 7.57. The optimal pH range for most plants in southern Ontario is 5.5-7.5 as this is when nutrients are most available, however, optimal ranges vary by species (OMNR, 2000).

The relationship between pH and ownership type – private and public was investigated (*Table 20*). A Wilcox rank sum test for non-normal data found that the difference in pH between public and privately owned plots was *not* statistically significant.

Table 20: pH across private and public lands in King

	Number of Plots	Mean (pH) (± standard error)	Median (pH)
Private	58	6.48 (± 0.92)	6.81
Public	16	6.68 (± 0.69)	6.78

pH was also examined by aggregated land use strata. Using *Kruskal-Wallis* test a significant difference was found between strata ($\chi^2 = 9.2804$, $p < 0.01$). A pairwise Wilcox test identified that *Residential & Other Urban* were significantly different from *Agriculture* and *Open Space – Natural Cover & Other – Institutional* ($p < 0.02$), with the former having a higher pH (see *Table 21* and *Figure 20*).

Table 21: pH across land use types in King

Stratum	Number of plots with pH measurement	Mean (± standard error)	Median
Agriculture	19	6.18 (± 0.97)	6.28
Open Space – Natural Cover & Other – Institutional	19	6.32 (± 0.74)	6.22
Residential & Other Urban	36	6.82 (± 0.80)	7.15

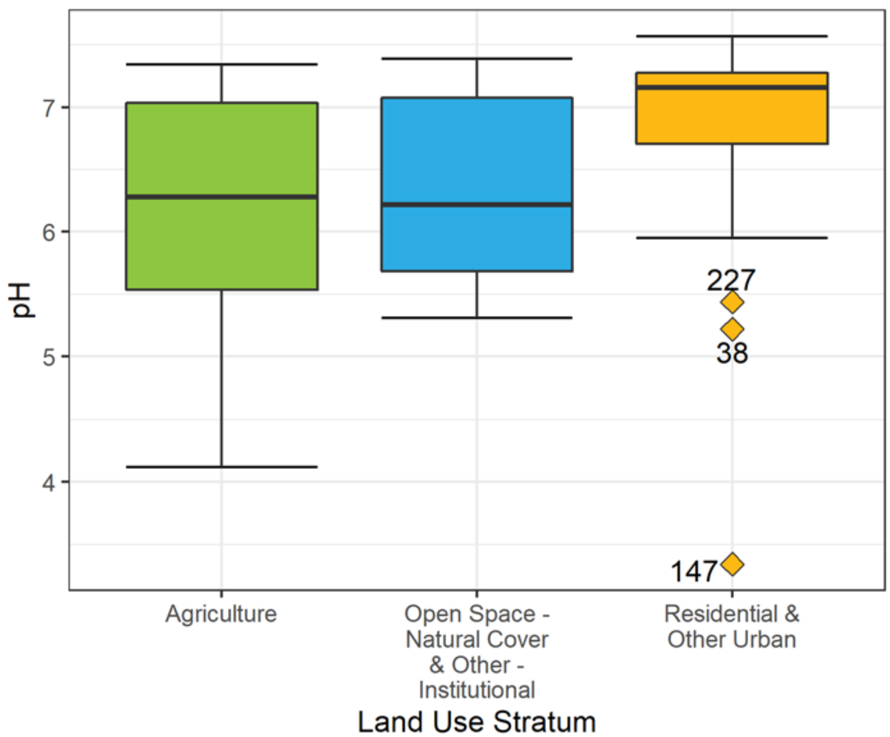

Figure 22: pH by aggregated land use stratum in King

Figure 23: Plot 147 = an outlier plot for pH

Plot 147 with a pH of 3.3 is an outlier in the *Residential & Other Urban* class as well as an overall outlier for the dataset. Its geographic location is shown in *Figure 21.* This site acts as an interesting representation of how agricultural lands can impact sliver woodlots, through fertilizer inputs and manure (other applicable nitrogen/urea rich sources), which may runoff into the lot. However, further in field analyses would need to be conducted to accurately discern input impacts on soil composition. Plot 147, having fallen into the narrow portion of this woodlot, may experience larger deposit effects than the internal portion of this woodlot. This site has very acidic soil and was recorded as the most water saturated across all surveyed plots. The species composition reflects these acidic and water-logged conditions. Eastern white cedar (Thuja occidentalis), tamarack (*Larix laricina*), yellow birch (*Betula alleghaniensis*), black ash (*Fraxinus nigra*), bebb willow (*Salix bebbiana*) and speckled alder (*Alnus incana*) were observed at this location. Of the representative species, tamarack, black ash, willows, and alders prefer moist to saturated soils and are typically tolerant of acidic conditions.

4.5.4 Relationships between Soil Compaction, Salinity, pH, and Tree Condition

The relationships between tree condition, measured as average percentage crown dieback per plot, and the three soil condition measures, namely, soil compaction, salinity (indicated by electroconductivity) and pH, were explored via correlation testing. Negative relationships were found between percent dieback and soil compaction and pH. Results are summarized in *Table 22*.

Table 22: Correlation between crown dieback and compaction, salinity, and pH

Dieback vs.	Summary	Degrees of Freedom	Pearson's Correlation Test	Spearman's Correlation Test	Kendall's Correlation Test
Compaction	A highly significant negative correlation with dieback	72	*cor = -0.35* *p < 0.005**	*rho* = -0.43 *p* < 0.0005**	*tau* = -0.32 *p* < 0.0005**
Salinity (electro-conductivity)	A non-significant relationship with dieback	69	*cor* = +0.19 *p* > 0.1	*rho* = -0.09 *p > 0.1*	*tau* = -0.06 *p* > 0.4
pH	A significant negative correlation with dieback	67	*cor* = -0.30 *p* < 0.05*	*rho* = -0.42 *p* < 0.0005**	*tau* = -0.27 *p* < 0.0001**

While we expected higher compaction, salinity, and pH to be associated with increased average crown dieback, these inverse relationships may be due to the fact that natural areas, which tend to have lower soil compaction, salinity and pH, also have higher proportions of dead or dying trees since they are not removed for safety. Similar effects were observed in other municipalities within York. This hypothesis was tested by comparing the mean percent dieback on forested versus non-forested plots using a Mann-Whitney Wilcoxon test. It was revealed that there was a significant difference in tree dieback with forested plots having a higher mean percent dieback than non-forested plots (W = 1108, $p < 0.0001$).

Figure 24 visualizes tree condition and soil condition data as a scatter plot and the linear relationship between the two is demonstrated by the addition of a regression line, where forested and non-forested plots are indicated by green and blue, respectively. Correlation tests were run again with data points split between forested and non-forested plots. Once forested and non-forested data points were pulled apart, the observed correlations between crown dieback and soil condition all become non-significant. Crown condition is impacted by many interacting variables and cannot be easily reduced to a single soil variable.

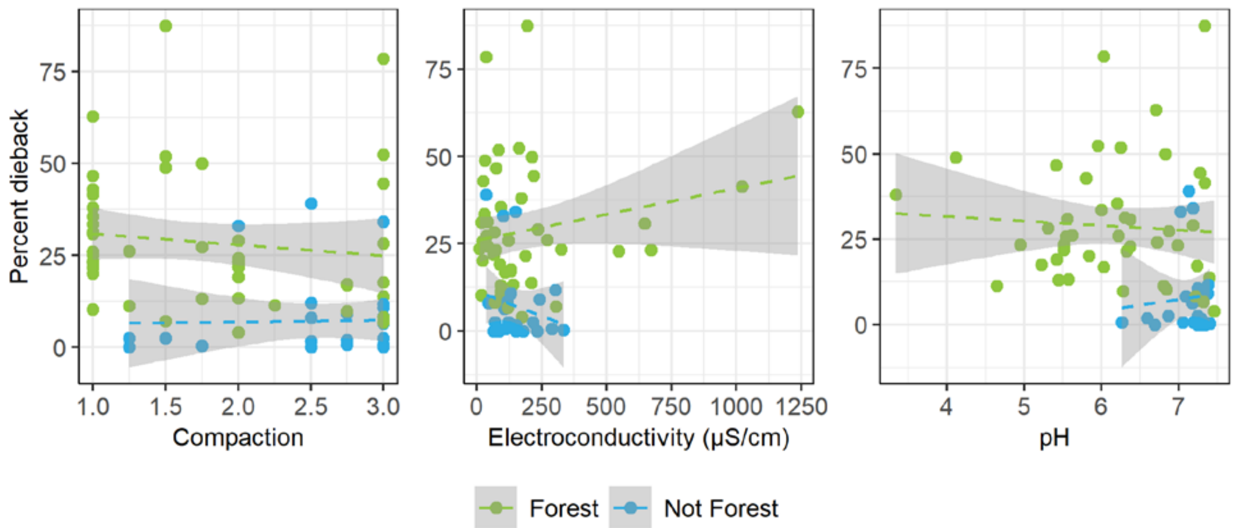

Figure 24: Scatterplots of crown dieback versus soil compaction, electroconductivity an indicator of salinity, and pH.

Note: Line indicates a linear regression between percent dieback and the soil condition variable. A separate regression line was added for forested and non-forested plots. The grey area indicates the standard error.

4.6 Invasive Plants

Out of the 193 plots surveyed, 48 percent of plots (92 plots in total) had at least one invasive plant species present (*Table 23*). *Residential* and *Other – Institutional* had the greatest proportion of plots that were invaded at 78 percent and 63 percent, respectively. This was followed by *Open Space – Natural Cover* (52%) and *Other – Urban* (50%). Despite having a number of remnant woodlots, it might seem surprising that *Agriculture* has a lower percent of plots with invasive plants (29%). However, a large proportion of plots surveyed in this category occurred in active agricultural fields with no tree cover.

Table 23: Invasive plant species statistics for King and by land use stratum

Land Use Stratum	Number of Plots	A) Percent Plots with at Least One Invasive Plant Species	B) Avg. Number of Invasive Plant Species on Invaded Plots	C) Avg. Spread[32] of Invasive Plants on Invaded Plots	D) Avg. Num. Species x Avg. Spread
Residential	41	78.1	3.4	1.4	4.8
Other – Institutional	16	62.5	4.0	1.6	6.4
Open Space – Natural Cover	23	52.2	3.5	1.7	6.0
Other – Urban	26	50	2.4	1.1	2.6
Agriculture	87	28.7	3.2	1.5	4.8
King	**193**	**47.7**	**3.3**	**1.4**	**4.6**

It was found that when plots are invaded, they typically have more than one invasive plant species present (see *Table 23,* column B), although the intensity of spread (the degree to which it has taken over a site) was quite low (column C). *Other – Institutional* areas had the highest number of invasive plants (average of 4), while *Open Space – Natural Cover* has the greatest average level of spread[33] (1.7). An overall invasion score (*Table 23*, column D) was calculated by multiplying the average number of invasive plants with the average spread. *Other – Institutional* was shown to have the worst invasion levels, followed by *Open Space – Natural Cover.*

The most common invasive species in terms of the proportion of plots affected were European buckthorn (*Rhamnus cathartica*); 26% of plots), Manitoba maple (*Acer negundo*; 14.5%), non-native honeysuckle (*Lonicera japonica, L. maackii, L. morrow,* and *L. tartarica*.; 14%), garlic mustard (*Alliaria 58etiolate*; 10%), dog-strangling vine (*Cynanchum rossicum;* 6%), and Norway maple (*Acer platanoides*; 6%). These species also tended to have a higher spread per invaded plot. An exception is goutweed (*Aegopodium podagraria*) which had a high degree of spread (2) on those plots in which it did occur. *Figure 25* shows the proportion of plots impacted and the average spread of invaded plots for all those species detected in this study. Tree of heaven (*Ailanthus altissima*), black alder (*Alnus glutinosa*), callery pear (*Pyrus calleryana*), Japanese knotweed (*Reynoutria japonica*), Himalayan Balsam (*Impatiens glandulifera*), and wild parsnip (*Pastinaca sativa*) were not found in any plots.

[32] Spread is the degree to which the plant was found to have colonized the plot ranging from 1 (one or two small patches) to 4 (across the entire plot and outside).

[33] Field crews recorded the degree of invasion for each priority invasive plant using an ordinal or ranked system where 1 was the least amount of spread and 4 was the most. The rankings were defined as follows: 1 (one to two patches of the invasive plant), to 2 (three or more scattered pockets), 2 (a blanket effect), up to 4 (an extensive blanket effect within the plot and the surrounding area).

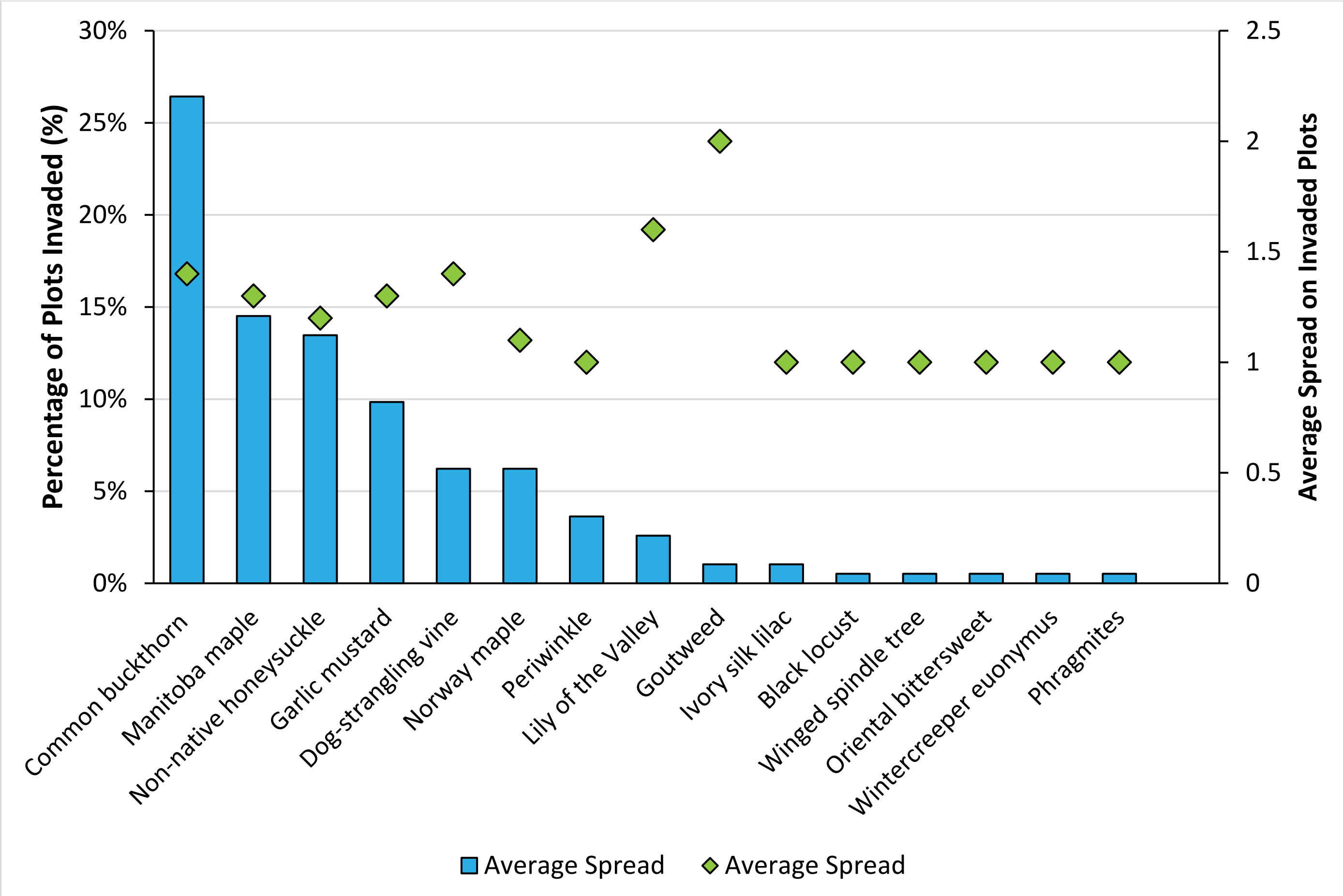

Figure 25: Percent and spread of invasive plant species in King

European buckthorn, Manitoba maple, non-native honeysuckles and garlic mustard were most prevalent across most land uses as shown in *Table* 24. *Table 25* lists the land uses on which the most common invasive species were most frequently found.

Table 24: Top three most prevalent invasive species by land use

Land Use Stratum	Three most prevalent Invasive Plant Species (% of Plots)	Percent Plots with at Least One Invasive Plant Species	Avg. Spread of Invasive Plant on Invaded Plots
Residential	European buckthorn	43.9	1.3
	Garlic mustard	26.8	1.3
	Non-native honeysuckle	21.9	1.1
Other – Institutional	European buckthorn	50.0	1.1
	Non-native honeysuckle	18.8	1.3
	Manitoba maple	18.8	1.3
Open Space – Natural Cover	European buckthorn	30.4	1.4
	Non-native honeysuckle	21.7	1.0
	Manitoba maple	17.4	1.3
Other – Urban	European buckthorn	32.0	1.5
	Manitoba maple	20.0	1.2
	Norway maple	16.0	1.0
	Non-native honeysuckle	16.0	1.0
Agriculture	European buckthorn	11.4	1.5
	Manitoba maple	9.1	1.3
	Garlic mustard	6.8	1.2
King	European buckthorn	26.4	1.4
	Manitoba maple	14.5	1.3
	Non-native honeysuckle	13.5	1.2

Table 25: Land uses on which most common invasive plant species were most frequently found

Species	Top Three Land Use Stratum on which Species was Most Frequently Found	Percent Plots with Species Present (%)	Avg. Spread of Species on Invaded Plots
European buckthorn	Other – Institutional	50.0	1.1
	Residential	43.9	1.3
	Other Urban	32.0	1.5
Manitoba maple	Other Urban	20.0	1.2
	Residential	19.5	1.4
	Other – Institutional	18.8	1.3
Non-native honeysuckle	Residential	21.9	1.1
	Open Space – Natural Cover	21.7	1.0
	Other – Institutional	18.8	1.3
Garlic mustard	Residential	26.8	1.3
	Open Space – Natural Cover	13.0	1.7
	Other – Institutional	12.5	1.0
Dog-strangling vine	Residential	12.2	1.2
	Other – Institutional	6.3	2.0
	Agriculture	4.5	1.8
Norway maple	Other Urban	16.0	1.0
	Other – Institutional	12.5	1.5
	Residential	9.8	1.0

Due to the presence of natural woodlands in King, the presence of invasive plants, pests and diseases was expected. However, invasives do not dominate the species composition like the more urban municipalities in York Region which have higher levels of disturbance and natural vegetation loss. Despite this fact, management and monitoring should be considered to maintain and reduce the impacts of invasive species on the forest.

4.7 Invasive Pests and Diseases

4.7.1 Invasive Pests

While visiting plots to collect i-Tree Eco and other data, field crews also recorded the presence and degree of spread of emerald ash borer beetle (*Agrilus planipennis*), spongy moth (*Lymantria dispar dispar*), hemlock woolly adelgid (*Adelges tsugae*), and Asian long-horned beetle (*Anoplophora glabripennis*). Signs of hemlock woolly adelgid, Asian long-horned beetle, and live EAB were not observed at any sites. However, signs of spongy moth and EAB were present at 30 percent of plots and 18 percent of plots, respectively. *Figure 26* shows the percentage of plots where the insect itself (in some stage of lifecycle development) or insect damage was observed per land use type, while the average spread, ranging from the least (1) to the most (3), is shown on the second axis. A mean spread value of one indicates that the insect/damage was observed on 1 to 3 trees, two, 4 to 6 trees, and 3, more than 6 trees.

Spongy moth was most frequently observed across *Residential* lands—51 percent of plots were invaded with an average spread of 1.9 indicating among 4 – 6 trees affected. *Other – Institutional* (50%) was close behind with 50% of plots invaded, followed by *Open Space – Natural Cover* with average spread of 1.9 and 2.2, respectively. EAB was highly invaded on *Other – Institutional* (38% of plots with a mean spread of 2.0) and *Open Space – Natural Cover* (26% with a higher average spread of 2.5).

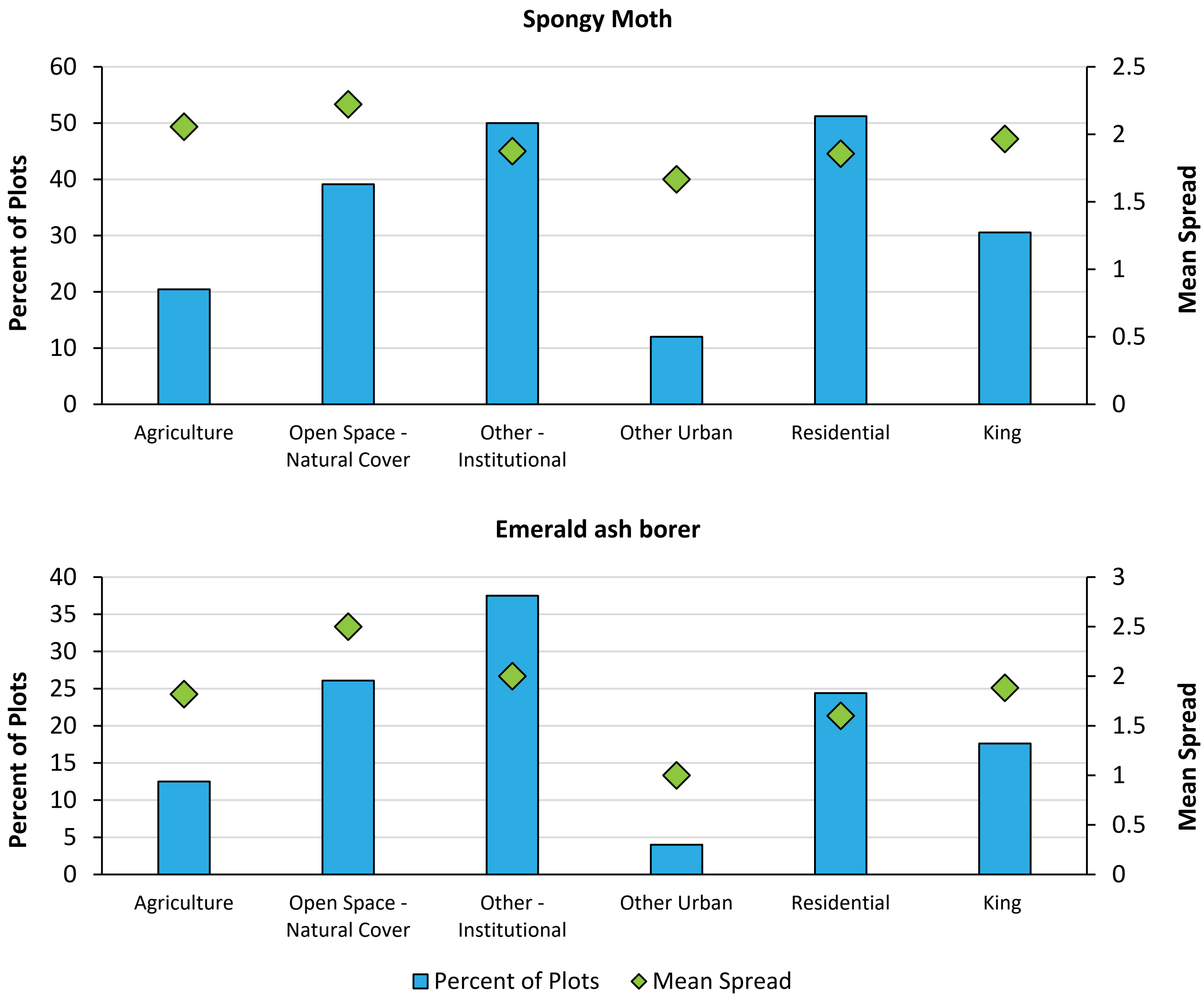

Figure 26: Percent of plots and average spread of spongy moth and emerald ash borer

4.7.2 Invasive Diseases

While collecting field data at plots, crews also checked trees for the presence of beech bark disease (*Neonectria faginata*), beech leaf disease (caused by *Litylenchus crenatae ssp. Mccannii*.), and Dutch elm disease (*Ophiostoma ulmi*). Dutch elm disease was found in all land use stratum except *Other Urban* and was prominent in *Other – Institutional* (12.5% of plots) and *Residential* (7% of plots) with a spread of 2 and 1.7, respectively. Dutch elm presence is likely attributed to high presence of elm (5th most abundant species) across forests in Township. Beech bark disease was observed in *Other – Institutional* lands (12.5% of plots with a spread of 1), *Agriculture* (3.4% of plots with a spread of 2), and *Open Space – Natural Cover* (4.3% of plots with a spread of 1) and. Beech leaf disease was observed in 1 plot in the *Other – Institutional* stratum.

4.8 Climate Vulnerability

4.8.1 Vulnerability Scores for the Top Twenty Most Abundant Species

The top twenty most abundant tree species in King were given a climate vulnerability score based on their exposure (occurrence outside of their ideal temperature range) and sensitivity to drought. The results are shown in *Table 26*.

Some notable results to highlight about the top twenty abundant tree species are that:

- The five most common species in King's forest make up 42 percent of the population of trees across the municipality (see Section 4.2.2).
  - The most abundant species found in King is the sugar maple (*Acer saccharum*), making up 13 percent of the tree population across the Township and 29.5 percent of leaf area. The second most abundant species is the eastern white cedar *(Thuja occidentalis*).
- 13 or 65% of the top 20 species were evaluated as highly or extremely vulnerable to future climate conditions in King.
- Average condition:
  - While the average condition score of the King Forest is 69 percent (equivalent to a percent dieback of > 30% and narrowly falling into the poor condition class and), there are several species that contribute to this lower average condition. Of the top twenty species, white (*Fraxinus americana*) and green ash (*Fraxinus pennsylvanica*) (third and sixth most abundant, respectively) had some of the worst average condition ratings (58.2% and 53.1% respectively) due to the impacts of emerald ash borer. Due to the ash population in King being quite prominent, the average condition of ash has a sizeable impact on the Township forest statistics as a whole.

Table 26: Climate vulnerability scores the top twenty most abundant species in King

Vulnerability Score	Vulnerability classifications based on climate projections between 2040 to 2070 assuming the RCP8.5 scenario (PCCP 2021) [34]
Low	Species having low sensitivity to drought and low climatic exposure
Moderate	Species with two moderate rankings or with one moderate and one low ranking of either climate exposure or drought sensitivity
High	Species that had a "high" ranking of either climate exposure or drought sensitivity
Extremely High	Species that were both "high" in climate exposure and drought sensitivity rankings

Common Name	Percent of Population (%)	Population with DBH <15.2 cm (%)	Vulnerability Score	Tolerances	Sensitivities	Risks
Sugar maple	13.4	65.0	Moderate		• Sensitive to drought	
Eastern white cedar	9.7	63.6	High	• High resistance to ice damage	• At the southern end of their current range	

[34] This assessment is based on the *Peel Urban Forest Best Practice Guide 4* and therefore uses RCP 8.5 (Representative Concentration Pathway) which represents the worst-case scenario for carbon emissions. Alternative vulnerability assessments may consider RCP 4.5, a moderate emission scenario, in which species' climate vulnerability may be shifted towards more modest values than under RCP 8.5. In addition, the selection of sensitivity and exposure criteria may also differ, resulting in further differences in vulnerability score. For more information, CVC's (2023), *Climate change vulnerability of treed habitats in the Credit River Watershed*, Appendix E, contrasts vulnerability scores of common climate vulnerability assessments. Source: https://cvc.ca/document/climate-change-vulnerability-of-treed-habitats-in-the-credit-river-watershed/

Common Name	Percent of Population (%)	Population with DBH <15.2 cm (%)	Vulnerability Score	Tolerances	Sensitivities	Risks
White ash	8.2	85.3	High		• Flood intolerant • Vulnerable to pest/disease	Not recommended to be planted
White spruce	6.1	48.9	High	• High resistance to ice damage	• Flood intolerant • At the southern end of their current range	
American elm	4.3	75.7	Low		• Low resistance to ice damage • Vulnerable to pest/disease	
Green ash[35]	3.2	83.8	High		• Flood intolerant • Vulnerable to pest/disease	Not recommended to be planted
Red maple	2.8	59.3	Moderate	• Flood tolerant	• Drought intolerant	
Scots pine	2.8	20.9	High		• Flood intolerant	Potential invasive quality
Black cherry	2.7	60.9	Moderate	• At the northern end of their current range	• Low resistance to ice damage • Flood intolerant	

[35] Green ash was not assessed as part of the Peel Region Urban Forest Best Practice Guides, Guide 4: *Potential Street and Park Tree Species for Peel in a Climate Change Context* (Peel Guide 4). Due to similarities with white ash, it was given the same score.

Common Name	Percent of Population (%)	Population with DBH <15.2 cm (%)	Vulnerability Score	Tolerances	Sensitivities	Risks
American basswood	2.7	41.7	Moderate		• Low resistance to ice damage	
American beech	2.4	65.3	High	• Flood tolerant	• Drought intolerant • Vulnerable to pest/disease	
Eastern white pine	2.3	35.2	High	• Drought tolerant	• Flood intolerant	
Red pine	2.2	30.0	High		• Flood intolerant •	
European buckthorn	2.1	92.2	High			Not recommended – invasive
Trembling aspen	2.0	26.1	High		• Low resistance to ice damage	
Red oak	2.0	72.4	High			At risk of Oak Wilt
Manitoba maple	2.0	39.4	Low		• Low resistance to ice damage •	Not recommended – potentially invasive
Yellow birch	2.0	72.1	Extreme	Flood tolerant	Drought intolerant	
Eastern hemlock	1.8	42.7	Extreme	High resistance to ice damage	• Vulnerable to pest/disease	
Freeman maple	1.7	29.1	Moderate			

4.8.2. Impact of Climate Change on the King Forest and Top Five Most Abundant Species

Trees, particularly those in urban areas, are exposed to a variety of environmental stressors that are expected to be exacerbated by climate change. Based on the projected climatic conditions under the RCP 8.5 scenario, it is anticipated that King's forest will be vulnerable to increased average temperatures, heat events, drought, and changes in precipitation patterns. Additionally, pests and diseases are likely to become more pervasive because of increased average temperatures and shorter, warmer winters. These impacts will directly affect the ability of urban trees to become established and survive. *Table 27* and *Table 28* present summary impact statements identifying how stressors brought on by climate change are expected to affect the entire forest and the top five most abundant species growing across King.

Table 27: Impacts of climate change on King's Forest

Climate Stressor	Outcome	Consequence
Increase in the frequency, intensity, and severity of extreme heat and other extreme weather events (e.g. wind storms)	• Greater damage to urban and street trees (and reduced urban tree canopy cover) • Higher tree mortality	• Loss of ecosystem goods and services provided by trees • Decreased shade from loss of canopy cover • Increased heat island effect in urban areas • Increased maintenance and tree replacement costs
Increase in average temperature, including warmer winters and drier summers	• Increased stress responses, such as loss of leaves and reduced tree growth • Shifting ecoregions for plants and animals • Change in species composition and the establishment of certain species (some species fare well with higher temperatures and drier conditions, while others do not) • Increased risk of pests and diseases • Disruptions in seed production	• Loss of ecosystem goods and services provided by trees • Loss of biodiversity among tree species • Increased maintenance and tree replacement costs • Increased survival and spread of invasive pest species such as emerald ash borer and diseases
Increase in extreme precipitation	• Greater damage to urban trees • Higher tree mortality • Increased risk of pests and diseases • Increased soil erosion • Increased stress and decline in tree growth	• Loss of ecosystem goods and services provided by trees • Increased maintenance and tree replacement costs • Increased survival and spread of invasive pest species such as emerald ash borer and diseases

Table 28: Impact statements for top five most abundant species

Species	Vulnerability	Outcome	Consequence
Sugar maple	Moderate	Decrease in health and increased mortality due to dry conditions and drought	Risk of population decline in King and loss of associated ecosystem services; Increased maintenance and monitoring required
Eastern white cedar	High	Shifting ecoregion for species	Risk of species extirpation from King due to the species being currently at southern end of current range
White Ash	High	Decrease in health and increased mortality due to EAB, remaining population in poor condition therefore vulnerable to stresses including precipitation and flood events	Population already in decline in King due to EAB; Increased maintenance and monitoring required for remaining population
White spruce	High	Decline in condition and/or increased mortality due to higher precipitation and flood events	Risk of population decline in King; Increased maintenance and monitoring required
American elm	Low	Decline in condition and/or increased mortality due to higher frequency of ice events and the in the presence of Dutch elm disease	Risk of moderate population decline in King; Increased maintenance required for individuals affected by Dutch elm disease

5.0 DISCUSSION AND RECOMMENDATIONS

The following section discusses results as well as provides recommendations that follow from the discussion topic. Some recommendations may pertain to more than one discussion topic although they only appear once.

5.1 State of the Forest

The discussion and recommendations presented in this section pertain to three aspects of forest structure: distribution (sub-section 5.1.1), species composition (sub-section 5.1.2), and age (or size) (sub-section 5.1.3). Many benefits attributed to the forest are largely influenced by these structural elements.

5.1.1 Existing and Possible Forest Distribution

King's forest covers approximately 34 percent (11,383 ha) of the total land area and the total leaf area in the study area spans 919.56 km^2, with a leaf area density of 2.73 m^2 for every 1.0 m^2 of land area. These impressive canopy cover and leaf area statistics are largely contributed by the prominent private woodlands which make up the majority of the forest cover in King. It is estimated that eighty-three percent of King's trees fall on private property.

In King's 2023-2026 Corporate Strategic Plan, a canopy cover target of 36 percent was set, based on the York Region Forest Management Plan (2016) which recommended a canopy cover range of 36 to 41 percent and a woodland cover range of 26 to 28 percent. It is recommended that a time commitment be included in the Corporate Strategic Plan in alignment with the York Region Forest Management Plan (e.g. 41% by 2051). Although i-Tree Forecast projects that this target will be met before 2051 through natural canopy growth, the model does not take into account potential losses from unanticipated pests and diseases, changing climate, or development. It will be important to monitor forest canopy to determine if it will actually increase and plant trees to offset losses from tree mortality or clearing. By setting a time frame, it will be possible to estimate how many trees or hectares of trees need to be planted annually to reach this this target. A timeline to reach the canopy target makes it more tractable and easier to incorporate into the Township's Corporate Strategic Plan, asset management plan, and budgeting process.

Approximately 63 percent of the municipality (20,928 ha) has been identified as possible tree canopy (area theoretically available for additional tree establishment); the majority of this is identified as possible vegetated land cover (20,266 ha), i.e., land currently covered in low vegetation that could be planted with trees. However, it is not practical to plant in all pervious vegetated areas due to site considerations. The largest portion, by far, of this pervious area is comprised of agricultural lands that are unlikely to be available for planting, although opportunities exist for planting hedgerows and shade trees. Additionally, some types of wetlands and those deemed provincially significant are unlikely available for planting given the characteristics of these landscapes and the ecological value they provide to the Township. Potential impervious land (i.e., asphalt, concrete, or bare soil surfaces) may already be approved for development and thus removed from planting consideration.

King has opportunities for planting on both public and private properties across the municipality, with the greatest potential to increase total leaf area and canopy cover on King's private lands, largely found within the *Agriculture* and *Residential Low* land uses. Seventy-five percent of the land area in *Agriculture* is possible vegetated cover potentially available for tree planting, and 38 percent of *Residential Low*. *Natural Cover* (33%), *Other* (40%), *Institutional* (24%), and *Open Space* (60%) land uses also present some good opportunities to increase canopy cover. In total, these land use opportunities represent 55 percent of the entire land area across King. However, after removing *Agriculture* which makes up the vast majority of the possible vegetated cover, the remaining cover from the main contributors represents only *nine percent* of the land area across King.

From a municipal perspective, there is significant opportunity to increase canopy cover within the *ROWs*. It is important to note that the opportunities for canopy enhancement identified in *ROWs* may be a function of tree size. All available planting locations (based on tree spacing standards) could be occupied, but canopy cover could still be low, given many of the trees are young. In this case, funding would be better spent on maintenance of existing trees to ensure tree health and survival. Additionally, although establishing tree canopy on impervious surfaces is more challenging than on pervious cover, it would reduce the heat transfer from such surfaces and the volume of stormwater runoff.

King also has opportunities for planting on private lands. It is necessary to use a variety of tools to engage private property owners including education, incentives, and mechanisms to make it easier to plant and maintain trees. The development and enforcement of by-laws is also essential for protecting the existing trees on private lands and ensuring that developers protect and plant trees. Development guidelines should ensure that developers include tree planting that follows industry best practices.

It can be useful to set canopy targets for specific land use types and use a prioritization method or tool to identify priority planting areas within particular land uses and neighbourhoods. York Region has developed a tree planting prioritization tool that could be adapted and customized for the Township of King. The tool allows the user to adjust the weighting of nine criteria (canopy cover, potential canopy, air quality, urban heat island, water quality, stormwater reduction, critical places, vulnerable population, and economic vitality) and identify priority areas for planting at the dissemination block scale.

Planting and establishment activities need not be focused only on areas lacking tree cover. Rather, a successful strategy for increasing the ecosystem services provided by the forest is the establishment of an under-planting program, which will not only increase leaf area density in the short-term but will also ensure that aging trees are gradually replaced by a younger generation. Many areas have been impacted by emerald ash borer (EAB, *Agrilus planipennis*) causing a decline in ash tree (*Fraxinus* spp.) populations. These areas can be targeted for the planting of diverse tree and shrub species to ensure succession. Additionally, many areas have been recently impacted by spongy moth (*Lymantria dispar dispar*), particularly natural areas. While spongy moth has been problematic for a few years, it does not often cause widespread mortality, however impacted areas should be monitored and restored as needed.

Increasing native shrub cover under canopied areas also represents an opportunity to increase total leaf area. Shrub cover that is established around mature trees can discourage human traffic and compaction of root zones. Many of the benefits provided by the forest, such as microclimate amelioration and sequestration of gaseous pollutants, are directly related to leaf atmospheric processes (e.g. interception, transpiration) (McPherson, 2003). It follows that an increase in the provision of these benefits can be best achieved by increasing total leaf area density.

Beyond planting strategies, existing valley systems, woodlots, and wetlands, as well as restoration areas, need to be prioritized. The *Other* and *Institutional* land use types are of particular interest given that they represent a number of vacant lands, woodlots, and valleylands. Although these are often fragmented systems, they should be considered for protection. Protection of fragmented networks can improve species migration efforts while limiting edge effects from future development and provide corridors for species range shifts as climate change impacts continue to increase.

The distribution of the forest is also an important social justice consideration. Ultimately, the protection of trees equates to the protection of ecosystem services that are essential to the health of both humans and wildlife (e.g., clean air, cooler summer temperatures). The services provided by the forest are an asset that belong to the entire community and must be managed in a manner that ensures equitable access by all residents.

Recommendation 1 - MT: Finalize the Township's Tree Management Plan in 2025 which will address: local canopy targets, species diversity, and forest health, maintenance, and monitoring.

The Plan will act as an operational guided document to inform staff on best management practices relating to tree planting within the Township.

Recommendation 2 - MT: The Township should strongly consider alignment with targets for canopy cover outlined in the York Region Forest Management Plan.

Recommendation 3 - MT: Develop canopy cover targets for land use types within the Official Plan.

Developing canopy cover targets for each land use type will allow more targeted planting plans to be developed. Targets should consider the availability of space, the suitability of planting, and how much canopy would be desirable within each land use type. The land cover map produced as part of the 2021 York Region Canopy Cover Assessment could be used in this analysis. An updated land cover map will be produced by York Region in 2026.

Recommendation 4 - ST: Work with York Region to customize and utilize the Region's tree planting prioritization tool for King to improve equitable canopy cover distribution, the maximization of ecological benefits and ecosystem services, and target areas impacted by invasive pests.

Recommendation 5 - MT: Develop mechanisms and education programs to encourage and support private landowners (particularly of commercial, industrial, and agricultural spaces, and property developers) to plant, protect and enhance trees and employ best practices for tree maintenance.

Mechanisms, campaigns, and courses could be facilitated through the Forestry and Trees program that the Township has already implemented or via newly developed program.

Recommended tree planting practices on agricultural lands could include tree farms, intercropping, riparian buffers, wind breaks, and biomass production.

Consider an education and incentivization program centered on promoting intercropping across the Township's robust agriculture sector as a functional means to alleviate agricultural runoff impacts.

Recommendation 6 - LT: Continue assessing forest structure, function, and distribution every ten years through the Forest Studies and canopy cover every five years through the York Region Canopy Cover Assessment.

Recommendation 7 - LT: Consider developing an understory planting program targeting natural forest woodlands and historically managed woodlots or plantations.

Underplanting should consider species specific shade tolerances and select species based on the forest subcanopy composition. Additionally, soil type, plant spacing and root protection for both existing and planted trees are considerations that should be evaluated prior to engaging in underplanting.

5.1.2 Tree Species Effects

Leaf morphology is influenced by species characteristics and varies across the forest, influencing growth patterns, canopy cover, and benefits provision. For example, the dominant tree species in the study area, sugar maple (*Acer saccharum*), is a broad-leaved species and despite only representing 13 percent of the tree population, is by in the far the largest contributor to leaf area (30%). Alternatively, the second most common species, eastern white cedar (*Thuja occidentalis*), a narrow-leaved species, comprises 10 percent of all trees across the municipality but only contributes 4 percent of the leaf area across the forest.

Species composition in King is largely influenced by the remnant forest and woodland composition of the *Agriculture* and *Residential* land uses. As such, species common in the forests of this region strongly influence municipal-scale species composition. For example, nine of the top ten species across the municipality are made up of species characteristic of the Lake Simcoe – Rideau ecoregion with the exclusion of Scots pine (Figure 9). It should be noted that Scots pine plantations likely contribute to majority of the population count for this species. In terms of percent of population, sugar maple (13%), eastern white cedar (10%), white ash (8%), white spruce (6%), and American elm (4%) are the five most abundant comprising 41 percent of the total trees. The tree composition cross the Township is quite balanced, likely driven by natural woodlands comprising the bulk of species composition.

The five most dominant species in King in terms of tree leaf area are sugar maple (30%), American basswood (*Tilia americana*, 8%), white spruce (*Picea glauca*, 6%), red maple (*Acer rubra*, 4.5%), and eastern white pine (*Pinus strobus*, 4%). Together, these five species represent 52.5 percent of the total tree leaf area across King. It should be noted that while white and green ash (*Fraxinus americana, Fraxinus pennsylvanica*) were the third and sixth most prominent species with respect to tree population, these species contribute a negligible percentage of the total leaf area due to the impacts of EAB.

Some of these genera are distributed across land use categories as they thrive in natural areas as well as high traffic urban zones (ex. Eastern white cedar and white spruce). A high relative abundance of maple is typical in the forests of this ecoregion; however, a lack of diversity among genera is a threat to the sustainability of the forest. This is of less concern in King since 41 percent of the tree population and 52 percent of the leaf area are represented by 5 species. However, sugar maple is the dominant leaf area contributor and represents 30% of the total leaf area. Despite dominating the leaf area, it is the characteristics species of mixed and deciduous forests of the region and is expected to thrive in terms of leaf area.

In general, it is important to establish native species and establish and maintain a diverse tree population. Monitoring species composition provides information on the diversity of the forest and how vulnerable it might be to threats such as climate change and introduced pests. Changes over time indicate which species might be struggling with environmental shifts and which might be thriving or perhaps becoming invasive and therefore requiring management intervention or changing planting strategies.

The Sustainable Urban Forest Guide (Leff, 2016) recommends that no single species (native or not) represent more than five percent of a municipality's total tree population, no genus more than ten percent and no family more than fifteen percent. By these standards, King is unfortunately overly dominated at the species, genera, and family levels. However, it is important to note that these rules apply well to intensively managed urban trees but can be relaxed for natural areas. Climatic and soil conditions and natural disturbance patterns generally establish the diversity of species in natural forests. In urban areas, a greater diversity of tree species supports increased biodiversity and a wider range and quantity of ecosystem services (Gamfeldt et al., 2013). While native *and* introduced tree species have a place in urban areas, some introduced species can pose a risk to native plants if they spread easily and out-compete or displace native species. Invasive species are therefore to be avoided in plantings.

Recommendation K4 from 2017 Forest Study:

- no species represents more than 5% of total population
- no genus represents more than 10% of total population
- no family represents more than 20% of the intensively managed tree population both municipal-wide and at the neighbourhood level

The impact of the EAB infestation highlights the risk associated with a lack of species diversity. Ash species were distributed across all land uses in King, reflecting the ability of these species to thrive in both natural areas and high traffic urban environments where soil quality is low. Unfortunately, while King still has a significant green and white ash population, their overall condition is very poor (35% and 42%, respectively). Additionally, the forest has recently experienced a widespread spongy moth outbreak which feeds on a greater variety of species (discussed further in section 5.3.3). The frequency and severity of pest outbreaks is increasing in southern Ontario, creating an even greater need for diversity and resilience.

King is located in an ecoregion capable of supporting a high level of diversity relative to other regions in Canada (ecodistrict 6E-6, which corresponds to the Lake Simcoe – Rideau Ecoregion and lies just north of the Carolinian forest region). Therefore, more aggressive diversity targets, especially in urban areas, may be feasible. In addition, by utilizing a diverse mix of species from the Carolinian zone and Lake Simcoe – Rideau ecoregion, King's urban areas will be more adaptable to both the predicted and unknown impacts of climate change. King is advised to establish a species composition for intensively managed urban trees which no species represents more than five percent of the tree population, no genus represents more than ten percent of the tree population, and no family represents more than twenty percent of the total tree population.

Diversity targets must also include a spatial scale in order to ensure that a sufficient amount of diversity is observed at the neighbourhood and land use level. Such diversity is not likely feasible within the street tree population as a smaller range of species can survive the harsh growing conditions found along high traffic boulevards and streetscapes. Efforts must be made to encourage and support nurseries, private landowners, and developers to sell or plant a greater diversity of native and suitable non-native non-invasive species. There is a need to decrease the planting of eastern white cedars on private properties, encourage diversity in afforestation and reforestation programs, and control invasive species such as European buckthorn to decrease species population. King should consider adding an educational campaign focused on species diversity for private landowners that ties in with any existing programming.

The use of high-quality native planting stock grown from locally adapted or suitable seed sources is strongly encouraged in all municipal planting projects, particularly in locations adjacent to natural areas. Planting stock availability will be directly dependent on the supply levels of local nurseries. Genetic variability within a species facilitates the survival of that species by increasing the likelihood that some individuals will be adapted to withstand a major stress or disturbance event (discussed further in section 5.4.4). A reliance on clones in the forest will have the opposite effect and will increase the risk of catastrophic loss of leaf area and tree cover in the event of a pest or disease outbreak. Species ranges should be considered when planting in the future as well to accommodate for a shifting climate (i.e., planting species at the northern half of their range as opposed to southern).

Recommendation 1 continued - MT: As part of the Tree Management Plan update, reassess tree care and maintenance practices for trees in highly urbanized areas. Consider indicators associated with street tree mortality, including plant hardiness and tolerances to harsher urban conditions, tree pit enhancements, direct tree care/stewardship, and assessing local traffic, and building conditions. Develop a post-tree planting management and monitoring procedure to complement King's tree maintenance program to ensure tree survivorship and mitigate common stressors in the urban environment.

Consider the inclusion of a naturalization and restoration procedure section within King's Tree Management Plan to bolster planting inputs in the natural heritage system and other naturalized areas.

It is recommended that management, monitoring, and maintenance begin directly after tree planting. Monitoring of municipal plantings should be undertaken for at least five years following planting (year 1, 3 and 5). Some stressors to mitigate include soil compaction, salt pollution, mechanical injuries, and drought related stress.

Recommendation 8 - LT: In line with current practices, continue to establish a diverse tree population in *intensively managed urban areas*, in which no species represents more than five percent of the tree population, no genus represents more than ten percent of the tree population, and no family represents more than twenty percent of the intensively managed tree population.

Recommendation 9 - MT: Consider the development of a campaign focused on educating private landowners and the public about the ecosystem benefits across the Township's forest and the importance of species diversity for a resilient forest, particularly in the context of climate change. Incentivize private landowners to plant a greater diversity of native species to increase the functional diversity of species planted in King and encourage private landowners to plant alternatives to eastern white cedar given its high vulnerability to climate change.

This could be implemented through multiple channels. An educational package for new homeowners within greenfield developments could be provided as part of the Draft Plan Condition for new subdivisions and as part of building or site alteration permits for new residential constructions.

Recommendation 10 - MT: Utilize native and appropriate non-native, non-invasive planting stock in both intensively and extensively managed areas. Increase genetic diversity of tree populations by using the guidance provided by the Ontario Tree Seed Transfer Policy. This policy is intended to help managers source seed based on the projected changes in climate to increase the likelihood of producing trees well-adapted to current and future conditions.

5.1.3 Tree Size Effects

The proportion of large trees in King is quite good for a municipality in the Greater than Toronto Area; approximately 13.1 percent of the tree population has a DBH of 30.6 cm or greater in contrast to the average of 9.7 percent for urban municipalities[36]. The results of the i-Tree Eco analysis revealed the diameter class distribution in King as: 61.1 percent of municipal trees were less than 15.2 cm DBH, 25.9 percent were between 15.3 and 30.5 cm, 12.0 percent were between 30.6 and 61 cm, and only 1.1 percent were greater than 61 cm.

Diameter class distribution of the tree population is influenced by a variety of factors. In addition to the age distribution of the forest, the land use land cover history and form strongly influence average tree size, as well as the natural growth patterns and characteristic forms of the dominant species. Much of the urban development in King has occurred quite recently. Consequently, the trees planted at these new development sites have not yet reached maturity. In these more open spaces, the have the potential to become large in the future if they are well maintained and protected. However, most of King's tree population occurs within natural forest remnants where tree structure is driven by light availability and space constraints. Despite competition with other trees, large old growth trees tend to be found in mature woodland stands where they have had the opportunity to reach a mature age. However, large trees are still underrepresented across King. Therefore, it is vital that trees are maintained and protected to ensure these services are delivered into the future. With respect to species form, sugar maple is the most commonly occurring species and can become very large, while the second most common species, eastern white cedar, typically maintains a comparatively small, shrubby form even at maturity.

Due to the largely unmodified and unmanaged nature of the forest, there is an appropriate historic/pre-settlement age-class distribution for which to strive. In other words, the forest has necessarily maintained a diameter or age-class distribution that is observed in conventionally managed woodlands. Typically, woodlands maintain an inverse j-shaped curve that reflects the abundance of small trees in the understory as a result of natural regeneration (Oliver & Larson 1996). Natural regeneration is the primary means for forest succession reflected in the size distribution across the Township. However, in areas of the municipality where mature trees are dominant, managers should plan for future succession by planting replacement trees well in advance of mature tree decline and removal.

As trees increase in size, their environmental, social, and economic benefits increase as well. Young urban trees show an exponential increase in ecosystem service contribution within their early growth windows. Given the increase in light availability and lack of competition in most urban environments, young urban trees have been shown to have accelerated carbon cycling by up to four times compared to their natural counterparts (Smith et al., 2019). As trees continue to age, their resources shift from focusing on primary growth to secondary growth and the once rapid increases in carbon cycling and associated ecosystem services slows down, albeit increasing over time. Large trees provide larger energy savings, air and water quality improvements, runoff reductions, and visual impacts than smaller trees. They also contribute more to increases in property values, sequester and store

[36] Average percentage of tree population with DBH of 30.6 cm or greater across urban municipalities (Vaughan, Markham, and Richmond Hill) as part of the Forest Studies

more carbon dioxide, and provide greater infrastructure repair savings. For example, in Modesto, California, the shade from large-stature trees over city streets was projected to reduce costs for repaving by 58 percent (financial savings of \$7.13/m^2) over a 30-year period when compared to unshaded streets (McPherson & Muchnick 2005). In comparison, shade from small-stature trees was projected to save only 17 percent in repaving costs (financial savings of \$2.04/m^2). However, it is important to note that in the winter climate of York, shaded streets require more salt to address snow and ice.

Recommendation 11 - LT: Evaluate and develop the strategic steps required to maintain the number and proportion of medium and large trees across King's forest including in the natural heritage system, street and park trees, and trees on private lands, where feasible.

This can be achieved using a range of tools including Official Plan planning policy, by-law enforcement, and public education. Maintenance and monitoring of new plantings is critical to ensure that juvenile trees are healthy and able to grow to maturity. Where tree preservation cannot be achieved, an Official Plan policy could be considered that would require compensation for the loss of mature trees and associated ecosystem services.

Recommendation 12 - MT: Review and enhance tree preservation requirements in municipal guidelines and regulations for sustainable streetscape and subdivision design standards to support tree establishment and eliminate conflict between natural and grey infrastructure. Continue to apply ThinKING Green to ensure sustainability of new developments.

ThinKING Green has been developed to expand upon and replace the Township's current Sustainable King: Green Development Standards Program. ThinKING Green builds upon the Sustainable King: Green Development Standards Program by introducing a new Principle Area to the Program, and a number of new sustainability metrics. The Program also provides a new method for evaluating the sustainable performance of new development through the assignment of a Sustainability Score.

ThinKING Green implements the sustainability policies outlined in the Township's *Our King Official Plan* and aligns with the goals of the Township's *Corporate Strategic Plan*. The Program is also proposed to apply to all Site Plan Development and Draft Plan of Subdivision Applications to ensure that all new development aligns with the Township's vision of a sustainable, healthy, and resilient community. ThinKING Green encourages all new development to protect and enhance the natural environment while utilizing efficient, innovative, and sustainable measures. The sustainability metrics propose to reduce the environmental and carbon footprint of developments by incorporating alternative energy sources, innovative landscaping, and green technologies. The metrics also promote the identification, protection, enhancement, and restoration of the natural environment.

Recommendation 13 - ST: Continue to apply Section 2.3, Natural Environment: Tree Canopy of the Sustainable King: Green Development Standards Program – Single Family Dwellings to maintain the mature tree population in new residential developments and incorporate enhancement plantings where appropriate. Track canopy cover losses associated with corporate plantings projects, development applications and residential site alterations. Consider incorporating site alteration applications for residential dwellings (e.g. pool permit applications).

Recommendation 14 - ST: Host an annual knowledge sharing meeting between the Region and Township to educate staff on by-laws, particularly the Forest Conservation Bylaw, to improve awareness about the applicability of York bylaws for the Township.

York Region's Forest Conservation Bylaw applies to trees of any size in privately owned woodlands and protects many of the trees outside of York Region. According to York Region, a woodland or woodlot is a piece of treed land with an area of at least 0.2 hectares that has at least:

- 1000 trees of any size, per hectare; or,
- 750 trees measuring over 5 centimetres diameter at breast height, per hectare; or
- 500 trees measuring over 12 centimetres diameter at breast height, per hectare; or,
- 250 trees measuring over 20 centimetres diameter at breast height, per hectare.

5.2 Forest Function

The following is a discussion of the services (benefits) that have been quantified by the i-Tree Eco model for effects on air quality, stormwater runoff, residential energy effects, and climate change mitigation and adaptation. All forest benefits should increase in King as a result of the implementation of the recommendations shared in this report. In addition, recommendations are provided here to address additional needs and opportunities.

5.2.1 Effect on Air Quality

Trees and shrubs in King removed a total of 468 tonnes of air pollution (CO, NO_2, O_3, $PM_{2.5}$, SO_2) annually with an associated removal value of $359,486 annually. Pollution removal is greatest for ozone (O_3), followed distantly by nitrogen dioxide (NO_2) and particulate matter less than 2.5 microns ($PM_{2.5}$). Ozone has been identified as the primary component of photochemical smog and is known to irritate and damage the respiratory system, reduce lung function, and increase susceptibility to respiratory infections (EPA, 2003). Ozone is linked with an increased number of daily deaths, respiratory deaths, and cardiovascular deaths (Manisalidis et al., 2020). Exposure to ambient nitrogen dioxide is shown to have an interaction with the immune system which could increase the risk of respiratory tract infections (Chen et al., 2007). $PM_{2.5}$ is shown to cause similar effects with acute exposure leading to irritation of the eyes, nose, throat, and lungs with potential for effects related to toxicity and inflammatory responses (Feng et al., 2016). Fine particulate matter has also been linked to cardiovascular diseases and raised infant mortality (Manisalidis et al., 2020). These pollutants are emitted primarily from the burning of fossil fuels, vehicular engines, and industry.

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

The i-Tree Eco results show that larger diameter trees remove more pollution on average, per tree, than smaller trees. Similarly, trees were found to remove greater volumes of pollution than shrubs. In both cases, pollution removal capacity was a direct function of leaf area. Selecting species that are well adapted to local conditions and require little to no maintenance is recommended as they will typically have longer life spans providing long term filtration of air pollutants. Additionally, studies have shown that areas with high levels of ground emissions, such as vehicular traffic along a highway, should be targeted for plantings. As pollutants are released upwards from areas of high emission, the adjacent planted areas can increase immediate removal while limiting trapping pollutants beneath the canopy (Nowak et al., 2002).

However, it is important to note that trees and shrubs emit volatile organic compounds (VOCs) such as monoterpene and isoprene. These compounds are natural chemicals that make up essential oils, resins, and other plant products, and are the precursor chemicals to ozone and carbon monoxide formation (Kramer and Kozlowski, 1979). An estimated total of 336,751 kg/yr of VOCs (271,164 kg/yr of monoterpenes and 65,587 kg/yr of isoprene, respectively) were emitted annually from King's forest with the largest portion of the emissions coming from the *Residential* and *Agriculture* areas which have the most trees. However, this process is temperature dependent and given that trees typically contribute to lowering air temperature, the net results are still usually positive in terms of the impact of trees on air quality.

Recommendation 15 - LT: Where appropriate, select and plant long lived, low maintenance, and low volatile organic compound (VOC) emitting tree species.[37]

- Volatile Organic Compounds (VOC), such as isoprenes and monoterpenes, are organic chemicals produced as a byproduct from tree foliage to attract pollinators, repel potentially harmful fauna, and as a response to stress. It has been shown to contribute to the formation of ozone based on field and meteorological data. It should be noted that conifers are known to emit VOC's year-round due to foliage retention and as a means to combat heat stress.
- Common low VOC emitting genera' include birch, linden, and tulips**.** For a comprehensive species list by VOC emission scores see Yang et al. (2015), *Ranking the suitability of common urban tree species for controlling PM2.5 pollution.*
- Since larger, long-lived individuals provide the greatest per-tree effects they should be selected to provide long-term benefits. Similarly, having low maintenance trees will reduce the associated air pollutants from arborist maintenance by use of gas-powered equipment.

Recommendation 16 - LT: Bolster the evergreen tree population across the municipality to improve year-round pollution removal services.

By planting evergreen species with foliage all year round, air pollution removal benefits can also be provided during the leaf-off seasons (late fall to early spring). Unfortunately, there are no best management practices for the ratio of evergreen to deciduous trees. Most literature suggests incorporating the right tree for the right place, however, given that coniferous species tend to be more limited than deciduous species on municipal planting lists, and in order to avoid trending towards homogenous coniferous populations, it is suggested to consider a ratio of 30 percent coniferous to 70 percent deciduous trees in public areas such as right-of-ways.

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[37] Some evergreen species emit high levels of VOCs, however this should not preclude them from planting programs. When possible and appropriate, consider planting low VOC emitting species.

Recommendation 17 - MT: Engage in strategic tree planting in high emissions zones.

Areas with high pollution emissions should be targeted as high priority planting sites for tolerant species. For example, planting adjacent to highways or high emission industrial sites would be beneficial to offsetting immediate emissions. The York Region Priority Planting Tool considers air quality as one of the criteria for determining priority planting locations and should be leveraged to identify areas for strategic planting to contribute to pollution removal. The indicator in the tool identifies areas with higher traffic volume and greater proportions of trucks on regional roads that typically have higher concentrations of particulate matter.

5.2.2 Effect on Stormwater Runoff

Stormwater runoff is a concern in urbanized landscapes as cities continue to develop and extreme weather events increase in frequency due to climate change. As built infrastructure is implemented, the associated increase in impervious surfaces can function to increase runoff (Hirabayashi, 2012). The increase in impervious land cover allows contaminants such as oils and fertilizers to be transported by runoff into adjacent channels, streams, and ground water. As polluted stormwater feeds into the hydrological system, it can have cascading effects on sensitive species and nutrient imbalances (Kollin, 2006). Green infrastructure, in developed spaces, can help mitigate these negative impacts by retaining stormwater. The trees of King provide a huge hydrological benefit with a stormwater offset estimated at 139,991 m^3 across the municipality, valued at $325,338 annually. The *Agriculture* and *Residential* land use strata provide the greatest benefits and avoid approximately 60,478 m^3 and 47,982 m^3 of stormwater runoff, respectively. This large contribution is based on the prominent natural woodlands that fall on large agricultural and residential properties.

Green infrastructure, and in the case of King, the forest specifically, provide a host of services relevant to stormwater runoff. Foliage and branches intercept precipitation which functionally reduces a portion of precipitation that may otherwise become runoff. Additionally, canopies reduce soil erosion caused by direct rain fall and allow soils to store larger volumes of precipitation (Brandt, 1988). At the ground level, runoff infiltrates the soil, and pollutants are naturally filtered and broken down by roots and microbial life (Schloter et al., 2018).

In urban spaces, to continue to have a healthy, functional hydrological network, a balance between green and grey infrastructure should be considered in development planning. For example, green infrastructure provides shading which can improve pavement life while allowing for natural stormwater runoff controls and should be weighted in tandem with grey infrastructure.

Recommendation 18 - ST: Continue to apply subsurface (Silva) cells on a project-by-project basis and other enhanced rooting environment techniques for street trees, particularly in constrained spaces such as intensification areas. Explore incorporating this recommendation into King's Green Development Standards.

Utilizing these technologies at selected sites in the short-term may provide a cost-effective means of integrating these systems into the municipal budget. Silva cells can function to improve stormwater runoff channels.

Recommendation 19 - MT: Explore the opportunity to utilize the Sustainable Technology Evaluation Program Treatment Train Tool to evaluate and quantity the stormwater benefits of planting trees. See: Low Impact Development Treatment Train Tool.

The Low Impact Development Treatment Train Tool provides the ability to design and evaluate different urban tree planting scenarios at the site level to determine stormwater management benefits and can be a very effective way to demonstrate the benefits of urban tree planting.

5.2.3 Effect on Residential Energy Bills

Trees that are adjacent to buildings can reduce the demand for heating and air conditioning through their moderating influence on solar insolation and wind speed. In addition, trees ameliorate climate by transpiring water from their leaves, a process that has a cooling effect on the atmosphere. Thus, the effective placement of trees or shrubs can insulate or lower building temperatures. McPherson and Simpson (1999) report that by planting two large trees on the west side of a house, and one large tree on the east side of a house, homeowners can reduce their annual air conditioning costs by up to 30 percent. Potential greenhouse gas emission reductions from forests are likely to be greatest in regions with large numbers of air-conditioned buildings and long cooling seasons. However, in colder regions where energy demands are high during winter months, trees that are properly placed to create windbreaks can also substantially decrease heating requirements and can produce savings of up to 25 percent on winter heating costs (Heisler, 1986). This reduction in demand for heating and cooling in turn reduces the emissions associated with fossil fuel combustion (Simpson & McPherson, 2000). In King the annual demand for heating and cooling was reduced by approximately 16,768.3 MWH, with an associated annual financial savings of almost $439,311. The relatively small benefit to residential owners is likely influenced by much of the tree cover in King occurring in natural woodlands, plantations, and large spaces removed from direct influence on residential properties[38].

Given King's colder winter climate, there were greater savings associated with the reduction of heating ($338,353) than cooling ($100,958), primarily related to a decrease in the need for natural gas ($289,135). This may also be due to current tree species and placement, which can have significant impact on potential energy savings. For example, evergreen species planted along the south facing wall of a building will block the heat from the winter sun and will increase the need for daytime heating. In contrast, large deciduous trees planted on the east and west sides of a house will shade buildings during hot summer months, but after their leaves have dropped, will allow heat to reach homes in the winter (Ko, 2018). Public education and outreach will be required to communicate these benefits and to provide direction for strategic planting around buildings to enhance energy savings.

Recommendation 20 - LT: Following the Township of King's Official Plan recommendation to encourage tree planting to reduce summer heat (see Section 3.2.1 of the OP), consider including the potential of trees to provide energy savings when developing planting guidelines or standards. Also, consider including the potential of tree-based energy savings under the green infrastructure component of the Sustainable King: Green Development Standards Program.

Tree species selection and placement should be targeted to provide summer shade and reduce winter wind speeds around residential buildings.

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[38] The i-Tree Eco model estimated the effects of trees (≥ 6.1m in height and within 18.3m of a residential building, excluding high rises) on building energy use due to shading, windbreak effects, and local micro-climate amelioration

5.2.4 Climate Change Mitigation and Adaptation

Trees can mitigate climate change by sequestering atmospheric carbon and storing it as woody biomass. During photosynthesis, atmospheric carbon dioxide (CO_2) enters the leaf through surface pores, where it is combined with water and converted into cellulose, sugars, and other materials in a chemical reaction catalyzed by sunlight. Most of these materials then become fixed as wood, while a small portion are respired back as CO_2 or are utilized in the production of leaves that are eventually shed by the tree (Larcher, 1980). In King, trees sequester approximately 28,490 tonnes of carbon annually (value of $29.7 million annually), with net sequestration at 12,790 tonnes per year (value of $13.3 million), and store approximately 1 million tonnes of carbon (value of $1.06 billion). The annual gross carbon sequestration by trees in King is equivalent to the annual carbon emissions from 23,248 automobiles or energy use of 13,166 single family homes[39].

The forest can also decrease carbon dioxide levels by reducing the demand for heating and air conditioning in residential buildings, subsequently avoiding carbon emissions by power plants. In King, the annual demand for heating and cooling was reduced by approximately 15,403 MWH for natural gas use (heating) and 1,365 MWH for electricity (heating and cooling). Ontario's energy grid is currently nuclear and hydro dominant, with relatively low carbon emissions. However, as nuclear power plants are being closed for refurbishment or decommissioned, Ontario may become more dependent on natural gas. Therefore, the reduced demand for heating due to the forest may have a more substantial impact on natural gas use in the future.

Nowak and Crane (2002) argued that carbon released through tree management activities must be accounted for when calculating the net effect of forests on atmospheric carbon dioxide. Tree care practices often release carbon into the atmosphere due to fossil fuel emissions from maintenance equipment. To compensate for the carbon emissions associated with planting, establishment, pruning, and tree removal, trees planted in the urban landscape must live for a minimum amount of time, dependent on the species. If trees succumb to early mortality, sustaining the tree population will lead to net emissions of carbon throughout the life cycle of that population (Nowak & Crane, 2002). This observation further highlights the importance of selecting low maintenance, well-adapted native species with the goal of maximizing tree health and longevity. Additionally, there should be a shift towards the use of electric tools to reduce the small-scale carbon emissions directly associated with maintenance.

When selecting trees for planting, it is also important to consider which have a greater potential for carbon sequestration and storage. In King, sugar maples store the greatest volume of carbon (approximately 20% of total carbon stored) and are also responsible for the most annual net sequestration (34% of total net sequestered carbon and 15.8% of gross sequestration). This a native species with only moderate climate change vulnerability, but planting should also consider the diversity of the forest. Sugar maple currently dominates forest composition so other species should also be considered. The second species to sequester the most carbon was the highly vulnerable eastern white cedar, which is not recommended for additional planting. Eastern white

[39] Values approximated using King's gross annual carbon sequestration value in the United States EPA Greenhouse Gas Equivalencies Calculator: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

cedar was followed by freeman maple (*Acer x freemanii*), American basswood and white ash. With respect to net sequestration, the second most dominant species is freeman maple and is followed by red maple, black cherry (*Prunus serotina*) and American basswood.

As climate change worsens, the role of trees, and to a larger extent the forest, will become increasingly more important as a means to mitigate heat stress especially in urban areas which are already warmer than surrounding regions due to more impervious surfaces. Shade trees can decrease near-surface air temperatures by an average of 3 °C by intercepting solar radiation and evapotranspiration, improving pedestrian thermal comfort, and decreasing human mortalities during heatwaves (Wang et al., 2018; Wong et al., 2021). Thus, by improving and maintaining the forest, King is investing in public health.

Recommendation 21 - MT: Consider including species' capacity for carbon storage and sequestration and tolerance to future projected climates when developing planting lists or guidelines and future (urban) forest management plans.

5.3 Sustaining a Healthy Forest

5.3.1 Soil Health

The chemical and physical properties of soil influence its fertility and the capacity for plant growth (Pickett et al. 2011). The primary concerns for rural soils, predominant in King, are field runoff impacts and the consequent pollution deposits, soil stripping, and erosion from large precipitation events. This is of specific concern given that most active agricultural lands are routinely tilled and provide channels for runoff which exacerbates soil stripping and eventually leads to soil erosion (Zhang et al., 2016). In contrast, soils in urbanized areas are highly vulnerable to disturbances and often become modified due to direct effects such as construction activities and indirect effects such as pollution (Lehmann & Stahr 2007, Pouyat et al. 2019, Foldal et al. 2022). Consequently, urban soils often have disrupted natural soil structures, mixed soil horizons, and are blended with man-made materials (e.g., bricks, glass, crushed stones) (Pouyat et al. 2007, 2019, Foldal et al. 2022). Additionally, urban soils are characterized by high levels of compaction, salinity, and alkalinity because of intensive human management and deposition of toxic elements from impermeable surfaces (Lehmann & Stahr 2007, Pickett et al. 2011, Pouyat et al. 2007, Pouyat et al. 2019, Foldal et al. 2022).

Results of the King soil health assessment showed that soils on public properties (including Conservation Authority lands) across the municipality have higher mean and median salinity and higher mean pH than soil on private properties. In King, public lands tend to be associated with more urbanized properties and right-of-ways, whereas most natural cover and forest patches occur on private lands. Consistent with this finding, soil in plots occurring in the *Open Space – Natural Cover* (mostly municipal parks and protected areas) and *Agriculture* land use types (soil measurements largely taken from remnant woodlands), had lower compaction, salinity (excluding outliers), and pH than plots in built or developed land uses. The observed patterns of higher compaction, salinity, and pH levels in developed areas are aligned with prior research examining the properties of urban soils altered by human activities (e.g., soils on developed land, soils adjacent to roads) (Foldal et al. 2022). While this study found that tree condition increased as soil compaction and pH increased this seemingly unexpected result can be explained by the fact that natural areas – which were the least compacted and had lower pH levels – had higher proportions of dead trees due to EAB and less intensive management strategies than urban trees.

Rural or agricultural soils were found to be significantly healthier than their urban counterparts. For example, soil compaction is often considered the greatest inhibitor to tree health since compaction functions to reduce water and nutrient availability for trees. The difference between urban and rural compaction is corroborated by this study, where soils of the *Agricultural* and *Open Space – Natural Cover* strata (> 50 % of measured plots recorded as uncompacted) were less compacted than the *Residential* and *Other Urban* strata (only 24 % recorded as uncompacted).

The *Residential – Other Urban* land use type had the highest median salinity at 129.3 (µS/cm) likely due to the application of road salts. Salinity stress is one of the largest limiting factors to the productivity of crop plants and should continue to be monitored to ensure soil and crop health (Shrivastava and Kumar, 2015). Rural soils are often composed of a larger representation of microbial communities as well which are shown to reduce salinity stress and have greater function with less available carbon than urban microbial communities (Yuangen et al., 2006). Findings suggest that reduced microbial communities in urban soils may function as an indicator of pollutant heavy metal stress on soil health.

While rural soils may experience less pollutant metal stress due to a general lack of major industrial plants and lighter vehicular traffic, the stresses unique to active agricultural lands may still eventually deteriorate future rural soil conditions. It should be noted that the immense hydrological benefits, and more specially avoided runoff, provided by King's forests helps alleviate runoff stress across the Township. However, as much of King's lands are converted agricultural croplands, there is need to consider private landowner engagement programs to promote monitoring and management strategies to alleviate runoff stress and continue to promote the high functioning rural soils of King. The planting of hedgerows and buffer trees and vegetation around fields may help to reduce runoff and erosion.

Human disturbance that causes movement of soil, particularly for construction, in combination with the intensity of land use in urban areas contributes to higher compaction levels in urban soils, impeding healthy plant growth (McDonnell & Pickett 1990, Kaye et al. 2006, Pouyat et al. 2007, Foldal et al. 2022). Higher compaction is typical of urban soils, leading to reduced root growth, lower soil water-holding capacity, restricted oxygen penetration, and greater surface water flow (Pickett et al. 2011, Pouyat et al. 2007). Better management is essential to reduce the compaction of soils and increase their productivity (De Kimpe & Morel 2000, Scharenbroch et al. 2005). Preventing soil compaction is more cost-effective than implementing corrective actions and can be achieved by reducing foot and vehicular traffic on root zones of trees during construction and ensuring adherence to proper soil installation procedures (PCCP 2021). Mulch and underplanting are useful amendments because they help mitigate compaction and protect exposed soils from external pollutants (Pickett et al. 2011, PCCP 2021). Remedial measures should also be considered to improve compacted soils. For example, aerating compacted urban soils, particularly in exposed areas, would be beneficial to improve air flow to roots (De Kimpe & Morel 2000). Additionally, increasing organic matter content by adding topsoil or compost to urban soils can help add nutrients and soil decomposers to soils (Pickett et al. 2011).

In urban environments, there is concern about the application of road salts in winter resulting in salt accumulation in adjacent soils. Road salts are composed of sodium, calcium, magnesium, and potassium chlorides (Sustainable Technologies Evaluation Program, n.d.). Excess salts hinder plant growth by affecting the soil-water balance. They also decrease soil microorganism activity which in turn impacts important soil processes such as respiration, residue decomposition, nitrification, and denitrification. Soils with a high concentration of sodium salts (sodic conditions) have additional problems, such as poor soil structure, poor infiltration or drainage, and toxicity for many plants (USDA, n.d.). Higher exposure to heavy metals and other pollutants as well as saline or sodic conditions are also indicative features of urban soils (Manta et al. 2002, Pouyat et al. 2007, Pickett et al. 2008, 2011). The results of the salinity analysis were consistent with findings in the literature, showing higher salt levels in the soils of built and developed land use types. The Township should engage private landowners so that they can be more aware of the harmful impacts salt has on tree growth and encourage the use of less harmful alternatives to salts for de-icing where feasible.

Urban soils commonly have an increased pH due to leaching of cement or masonry from the built environment (Pouyat et al. 2007; Lehmann & Stahr 2007; Foldal et al. 2022). pH levels influence nutrient availability, uptake, and tree growth (MSU 2019). Soil bacteria transform nutrients in organic matter, making them accessible to trees. These bacteria are most effective in slightly acidic soils, so soils with higher pH levels have a lower availability of certain nutrients. However, it is important to recognize that tree species have different preferred pH levels and tolerances (MSU 2019). Therefore, a finer scale soil assessment in the future would provide a more thorough understanding of the relationship between soil pH and tree health. Species-specific pH tolerances should be considered when tree planting sites are identified in future initiatives.

The Township of King is less urbanized in comparison to several other Greater Toronto Area municipalities, but the negative impact of development should not be overlooked. Despite the Township having a large natural forest cover system, as development pressures intensify and populations increase, the impacts on urban soils may grow. The Township should consider soil remediation, enhancing and buffering techniques to avoid urban soil degradation as urbanization expands.

Recommendation 22 – LT: Ensure best practices for healthy soils are implemented in King's public and private urban areas in the planning of planting programs from site selection and appropriate soil volume considerations to assessment of species selection. Sustainable King: Green Development Standards Program provides guidelines for soil quality and quantity that should be applied.

Recommendation 23 – MT: Educate private homeowners and industrial and commercial landowners about planting trees and shrub species based on soil types.

For example, education opportunities should be leveraged through planning application processes to ensure developers are aware of soil best practices.

5.3.2 Invasive Plant Species

Invasive species' capacity to outcompete native plants and change plant community composition is a growing biodiversity, economic, and social concern. In King, the most commonly found invasive plant species in terms of proportion of vegetated plots affected are European buckthorn (*Rhamnus cathartica,* 21%), Manitoba maple (*Acer negundo*, 12%), garlic mustard (*Alliaria 85etiolate*, 8%), Norway maple (*Acer platanoides*, 8%), and dog strangling vine (*Cynanchum rossicum,* 7%). These species are known to dominate ground vegetation and have various strategies to limit competition with native flora. Some examples of their impacts include the explosive establishment and growth of dog strangling vine from forest edge to interior, the allelopathic properties of garlic mustard to limit native species success while establishing a seed bank (Blossey et al. 2017), and the shade density of a broad-leaved Norway maple canopy which can inhibit new growth (Martin 1999). Additionally, European buckthorn's prolific seed production and dispersal ability can lead to the development of blanket thickets of seedlings that, once established along disturbed edges or urban environments, allows the species to easily displace native flora from the ground level up. The capacity for European buckthorn to spread is compounded by other invasive properties, severely limiting the establishment of native plant species in natural, peri-urban, and urban settings.

With respect to the percentage of total stems across the municipality, European buckthorn is the largest concern, and in terms of total leaf area Manitoba maple is the most dominant invasive plant species. Additionally, European buckthorn is the most dominant invasive species across all land use types, followed by Manitoba maple, and garlic mustard, which permeate nearly all land use strata at a lower intensity. These three species are the most abundant invasive plant species overall and disproportionately represent invasive plant establishment across all land use strata.

An overall invasive score, derived from multiplying the average spread and the average number of invasive species, shows that the spread of invasives in *Other – Institutional* (score of 6.4) is the greatest concern, followed by *Open Space – Natural Cover* (6.0) and *Residential* (4.8). In the *Open Space – Natural Cover* and *Residential* land use strata, over 52 percent and 78 percent of vegetated plots, respectively, have at least one invasive plant species present. *Residential* and *Open Space – Natural Cover* strata often exhibit a tandem effect where residential invasive populations escape and drive the spread of invasives in natural areas leading to cascading negative effects on the capacity of natural areas to deliver ecosystem services (Hands et al. 2018). The high prevalence of invasives in the *Residential* stratum is of special concern to King given this tandem effect.

Natural forested areas and woodlot patches in rural municipalities tend to be largely connected. However, as urbanization expands, and the presence of developed lands will slowly increase the vulnerability of natural areas in the Township to invasion. Forests and woodlot edges are typically degraded and comprised of a microclimate and species composition uncharacteristic of typical, large intact woodlots (Kowarik & Lippe 2011). These exposed forest edges can enable invasive species to gain a footing in woodland patches, which expand further into the woodlot over time (Cadenasso & Pickett 2008). Residential areas in particular are a common source of invasive species (with an average of 3.4 invasive species per residential plot found in this study). Restoring and protecting the edge of urban woodlots and forests with native pioneer species and resilient herbaceous plantings can help provide a buffer against the common dispersal strategies of garden escapees.

Given that invasive plant species tend to have few natural controls to prevent establishment relative to their propagation rate, continued monitoring and action will be required to curb current numbers and limit spread. European buckthorn, dog strangling vine, and garlic mustard should be considered high priority and given special emphasis in targeted management and education given their abundance and their potential to outcompete and displace native trees at the ground layer.

Continued effort in selecting healthy and resilient native stock for plantings across all urban land use strata will improve the native species capacity to outcompete invasive species. Additionally, some hybrid cultivars are well adjusted to harsher environments like the disturbed sites on *Commercial – Industrial* and *Other – Institutional*. Planting species like honey locust (*Gleditsia triacanthos*), silver maple (*Acer saccharinum*), and their hybrids can limit the success of invasive species like phragmites (*Phragmites australis*) and European buckthorn at the sites where they go unchecked.

Lastly, continuing to share information with the public will help foster the collective effort and citizen science required to mitigate large scale invasive spread. An educational outreach program on common invasive plant species, their consequences on the landscape and next steps for limiting impact should be developed. There are many existing educational resources developed by conservation authorities and other environmental agencies that the Township can use and leverage with minimal investments. Staff should also be trained and educated on current best practices for invasive species so that they can best deliver resources to the public (for example, promoting volunteer removal events as part of staff-led seminars).

Recommendation 24 – LT: Promote the implementation of natural buffers along the edges of urban woodlots to protect against the encroachment of invasive species.

Restoration initiatives should be pursued along the edges of woodlots in municipal parks near residential areas to promote native plant diversity. Restoration plantings along the forest edges will create a buffer against wind seed dispersal and anthropogenic dispersal (foot traffic), as well as limit invasive establishment by alleviating edge effects. TRCA’s Guideline for Ecosystem Compensation provides recommendations for restoration planting as well as recommended species lists. In new development areas, vegetation protection zones should be established and re-planted with dense woody vegetation to protect forest edges before residents move in. Fences can be considered where the impacts on wildlife would be acceptable.

Recommendation 25 – MT: Continue targeted removal of high priority invasive plant species at high priority sites following best management practices recommended by the Ontario Invasive Species Council [40].

The Township's invasive species mapping tool, based on citizen reported sightings, provides an excellent basis to identify high priority sites for targeted invasive species removal.

Recommendation 26 – ST: Explore the development and implementation of a municipal-led invasive plant, pest, and disease education and volunteer program to enhance awareness of invasive plants, pests, and pathogens and proper removal practices. Develop a monitoring and action strategy for invasive species, pests, and diseases, and continue taking proactive approaches to address new and emerging invasive species, such as hemlock woolly adelgid and oak wilt.

5.3.3 Tree Pests and Diseases

Exotic insect pests pose a serious threat to the health of forests and street trees as no natural controls have been developed to regulate these non-native species. Consequently, infestations commonly result in a substantial loss of canopy cover and associated ecosystem services, an increase in municipal maintenance costs, a loss of species diversity, and a shift to earlier age class distributions.

Invasive pest species of particular interest are emerald ash borer (EAB, *Agrilus planipennis*) and spongy moth (*Lymantria dispar dispar*). The recent infestation of spongy moth across King was pervasive, with the moth present at 30 percent of plots. I-Tree Eco analysis suggests that 25.1 percent of the Township's tree population – with a replacement value of $540 million – are susceptible to defoliation by spongy moth. Spongy moth has a cyclical life cycle, with outbreaks occurring every 7 to 10 years. Spongy moth caterpillars – which emerge between early May to mid-July before metamorphosis – do not show strong preferences for select tree species. Most healthy deciduous trees can tolerate one to several years of defoliation by spongy moth since they can recover each growing season. However, coniferous trees that have been defoliated will face severe, detrimental effects as only a small proportion of needles are replenished each year (Ontario Wildlife and Nature, 2014). Thus, there will be a continued need for appropriate management responses.

Unlike spongy moth, EAB specifically targets ash trees (*Fraxinus* spp.). EAB was observed on 18 percent of field plots in this study. The number of ash trees showing signs of EAB represents a large proportion of the ash in King. At this stage, EAB has decimated most ash populations in King with the remaining population's overall condition being very poor (~38%). A large portion of the green (*Fraxinus pennsylvanica*), white ash (*Fraxinus americana*), and black ash (*Fraxinus nigra*) have died due to EAB. However, mature urban ash trees deemed to be high value should be continually monitored and treated with TreeAzin following the recommended schedule.

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[40] Refer to Ontario Invasive Plant Council's Best Management Practices series: https://www.ontarioinvasiveplants.ca/resources/best-management-practices/

Tree diseases have also become a more prevalent concern as novel diseases begin to shift northwards as their ranges expand. While beech bark disease (BBD, *Neonectria faginata*) presence is relatively low, their impacts on natural tree populations are still of concern because King falls just on the edge of the Carolinian Forest Region, which is typically characterized by sugar maple and American beech. In the remnant Carolinian forest patches and woodlots, the prevalence of BBD can have long term consequences on beech health and should be monitored.

Additionally, Dutch elm disease was spotted across all land use strata except *Other Urban*. The presence of Dutch elm is likely driven by the prevalence of elm in the natural woodlands of King where the species ranked fifth in percent of the tree population.

Other pests and diseases that were not observed in King, include Asian long-horned beetle (*Anoplophora glabripennis*), hemlock woolly adelgid (HWA, *Adelges tsugae*), and oak wilt (*Bretziella fagacearum*). HWA and oak wilt are impending threats for southern Ontario, given their rapid spread and the damage and mortality they have caused in nearby regions south of the border. Newly discovered established HWA populations have been reported in south-eastern Ontario. The Invasive Species Centre and the Canadian Food Inspection Agency (CFIA) have issued a notice to record and report any sightings of HWA and have encouraged practitioners to adopt the CFIA protocol for surveying for HWA. Furthermore, while oak wilt was not observed in King yet, a proactive approach to managing the disease should be considered as it begins to appear at the southern extent of the Canadian border and elsewhere in the province.

To address future pest outbreaks, the Township should incorporate a species diversification program with consideration to the potential damage of multi-host pests. The Pest Vulnerability Matrix (PVM) is a model developed to visualize and assess the susceptibility of the forest to outbreaks of insects and diseases based on species composition and diversity (Laçan & McBride, 2008). The model predicts how the introduction of certain tree species, or a new pest species, will affect the overall vulnerability of the forest. The model has been applied for Toronto, in research by Vander Vecht, & Conway (2015), which explored the vulnerability of Toronto's forest to pests using the PVM. Using a model such as the PVM during tree species selection will help account for potential damage by future pest outbreaks, particularly by multi-host pests.

The Township should consider implementing survey protocols to monitor and report pests and diseases of concern that have yet to reach King (e.g., hemlock woolly adelgid and oak wilt) and plan for responsive actions in the case they reach the municipality. King should also continue to develop and implement a management plan for managing spongy moths investigate the potential use of biotic control agents.

Recommendation 27 – MT: Investigate the utility and potential application of pest vulnerability tools, such as the Pest Vulnerability Matrix (PVM) during species selection for municipal tree and shrub planting.

Given the anticipated increase in invasive pest outbreaks as a consequence of climate change, it is essential to enhance the diversity of the forest to ensure it is resilient to insect and disease outbreaks. Using a model such as the PVM during tree species selection will help account for potential damage by future pest outbreaks, particularly by multi-host pests.

5.4 Past and Future

5.4.1 Trajectory and Future Projections

The i-Tree Eco suite includes a forecast component that utilizes structural estimates generated via the i-Tree Eco model, such as number of trees, species composition and size, alongside growth, mortality, and planting rates to estimate future forest conditions across a thirty-year span. The forecast predicted a positive trajectory for canopy cover, exceeding the recommended canopy range by 2053 under all three simulation scenarios. All scenarios included expected canopy growth and the continued impact of EAB, spongy moth (*Lymantria dispar dispar*), and beech bark disease (*Neonectria faginata*). The first scenario included King's current planting programs and predicted that canopy cover would reach 47.15 percent by 2053. In the second, planting inputs were doubled, and canopy cover was forecast to reach 47.25 percent by 2053. Lastly, under a no planting scenario, canopy cover was expected to 47.0 percent by 2053. Assuming planting programs are implemented as planned and tree maintenance and management are sustained, the potential increase in canopy cover is likely achievable. However, it should be noted that i-Tree Eco does not include loss of trees from urbanization and decisions made by private landowners. While the potential increase in canopy cover output by the forecast model may be feasible, the projected loss of trees due to increased mortality as trees mature should be considered in King's planting plans. By 2053, the tree population, as derived from the forecast model, is expected to decline from 9,588,224 to 6,788,106 under the current planting scenario, to 6,853,969 under the doubled planting scenario, or to 6,721,716 under the no planting scenario. As the canopy across King continues to mature (largely consisting of existing trees that have shifted into larger size classes) the overall expected losses are anticipated to outpace the rate of canopy growth eventually. While the contrast between scenarios is not drastic, expected tree numbers across each scenario further highlights the need to continue plantings and required maintenance in priority areas. Maintaining planting plans for thirty years would reduce some of the loss associated with high mortality rates for trees in urban spaces. Furthermore, to ensure the success of new plantings, there is a need to develop a post-tree planting management strategy to alleviate some of the causes associated with high mortality rates in young, newly planted urban trees (Smith et al., 2019). Ultimately, while the projected canopy cover and tree number estimates provide a lens to the future of King's forest, they should be considered in the context of an ever-changing climate, future land use changes, and the impacts of urban conditions on tree health.

The forecast cannot accurately account for complex changing conditions, specifically climate change. One example being the exclusion of natural regeneration from the model's consideration which accounts for the vast majority of turnover in natural forested systems. In the case of King, given the extensive natural forest cover, this exclusion is a specific concern as the vast majority of tree recovery comes in the form of natural regeneration. Additionally, frost-free days were increased in King to account for a changing climate, however this does not completely capture the dynamic nature and compounded effects of climate change. One such impact is the shifting geographical ranges of common and dominant tree species. For example, eastern white cedar is at its southernmost extent in King and is at risk of being extirpated (as detailed in the climate vulnerability assessment, see Section 5.4.3). Given that the species accounts for the second largest tree population, this risk is of the utmost concern. Actions should be taken to encourage planting alternative, less vulnerable native and naturalized species, where possible, and eastern white cedar should be monitored in natural settings for restoration management as they dominate fresh-moist ecosites.

Additionally, the northward shift of species' range can function to introduce pests and diseases novel to the region. As of 2023, oak wilt (*Bretziella fagacearum*) has now crossed into Canada from the United States and has been reported in Niagara. Hemlock woolly adelgid (HWA, *Adelges tsugae*) has been reported in the Niagara Peninsula at Wainfleet, Fort Erie, and most recently in Hamilton. Both are of concern to King in the near future and should be monitored. Successful planning for the future would benefit the resiliency of the Township against such stressors, these practices are predicated on the provincial, regional, and town-wide control responses and proactive management.

The forecast outputs should be considered critically given the limited capacity to consider all possible factors that influence future canopy cover in the model and the uncertainty surrounding future climatic changes. However, the results of the forecast are currently encouraging, and provide guidance to suggest the Township should continue with restoration, tree planting, replacement, maintenance, and monitoring on public and private property – especially as King continues to urbanize.

5.4.2 Climate Vulnerability and Resilience

Changes in climate conditions are expected to profoundly alter the environmental conditions across Southern Ontario, limiting the capacity of many tree species to cope as their optimal climatic ranges shift. A critical assessment of the climate vulnerability of King's most common species was conducted to understand the expected impacts on the Township's forest, and ensure the adequate protection, planning, planting, and monitoring of trees across the municipality.

The results of the climate vulnerability' assessment showed that of the twenty most abundant tree species in King, thirteen of the species were rated as highly or extremely vulnerable to climate change under the "business-as-usual" emissions scenario[41], including the three of the top five species (eastern white cedar; white ash; white spruce). These thirteen species make up 47 percent of the total population of trees across the King Forest. While the proportion is high, it is better than more urbanized municipalities in the Region, where the highly vulnerable population tends to make up a larger proportion of the forest. Only two of the top twenty species were assigned a low vulnerability score, one of which is not recommended for planting because it is invasive, i.e., Manitoba maple. Five species were given a moderate vulnerability score.

Promoting diversity in urban areas will function to reduce the forests' vulnerability to the impacts of climate change. The second most dominant species – eastern white cedar – accounts for 9.7 percent of the tree population in King and is the largest single contributor to the highly vulnerable population. Eastern white cedar represents the largest concern with respect to climate vulnerability, given that it is the second most prevalent species across the township and represents a tenth of the tree population. The species is currently at the southern extent of its suitable climatic range, and as a result there is a risk the species could be extirpated from King under this scenario. There is a strong need to monitor the population as the impacts of climate change worsen. Eastern white cedar is planted extensively by private landowners, particularly in hedgerows. Therefore, King should actively encourage private landowners to plant alternative species in place of eastern white cedar.

[41] This was assessed under RCP 8.5 conditions (see Section 3.7 for details on the assessment method).

With respect to invasive species, while European buckthorn is only the fourteenth most pervasive species in King, climate change impacts could potentially help efforts to control this species because it is highly sensitive to drought. Nonetheless, effective European buckthorn removal and restoration programs are necessary to control the population across King (see Section 5.3.2). Effective control of the species will allow for natural regeneration of less vulnerable, native forest species found in the region such as sugar and red maple. However, unlike European buckthorn, Manitoba maple is projected to do quite well in future climate conditions with a vulnerability score of low. Manitoba maple should be monitored, primarily around edges of natural woodlands for encroachment and eventually establishment in key natural areas across King.

Another important factor for the vulnerability of King's forest to climate change is the size distribution of the dominant species. The populations of the top five most common species (with the exception of white spruce) are primarily small, measuring less than 15.2 cm diameter with the majority falling into the second smallest size class (7.7 – 15.2 cm diameter class), largely in part to natural forest regeneration. This younger tree population is more susceptible to the impacts of climate change. Climate change can also affect seedling establishment due to warming, drought reducing germination capacity, and sapling mortality particularly in natural areas as they continue to become more fragmented. Protecting existing natural woodlands will function to alleviate stress from shifts in land use and promote buffers against climate change impacts.

Trees that are already in poor condition are more vulnerable to the stressors of climate change. While the condition score for excellent, good, and fair trees in the forest is 68 percent, white and green ash (third and sixth most abundant) have the worst condition scores at 35 percent and 42 percent, respectively. This is within expected conditions for ash species due to the impacts of EAB. However, the other prevalent species that are highly and extremely vulnerable to climate change impacts will require greater maintenance and monitoring, given that they are likely to decline in condition and suffer higher mortality rates due to more extreme precipitation and flood events and increased drought.

The resilience of King's forest to climate change can be improved through the adoption of the following recommendations, in conjunction with those of the York's Region Forest Management Plan, King's Corporate Strategic Plan and King's Tree Management Plan. One of the objectives of the King's Corporate Strategic Plan is to promote tree canopy growth and enhance natural lands. The plan calls for future-oriented objectives aligned with this climate vulnerability assessment which include increasing biodiversity, increasing township wide canopy cover to 36 percent, and supporting habitat. Given that 65 percent of the top twenty trees species across King are considered highly or extremely vulnerable to climate change, the future health and survival of the Township's forest is at risk if proactive, adaptive management is not undertaken.

Recommendation 28 – MT: Increase proactive, long-term monitoring of species identified as highly and extremely vulnerable to climate change to assess and evaluate the condition of the at-risk species as incremental climate change impacts advance.

Recommendation 29 – ST: Assess the Township's current recommended planting list based on the climate vulnerability of each species. Shift recommendations to native and appropriate non-native, non-invasive species that have a higher tolerance and lower vulnerability to climate change impacts.

Recommendation 30 – LT: Assisted range expansion and assisted migration of trees should be investigated. The Township should undertake systematic testing of species from warmer ecodistricts that could be suitable

to replace the thirteen highly vulnerable and extremely vulnerable species that are at the greatest risk due to climate change.

Reference **Table 26** for the vulnerability assessment of the top twenty tree species across the Township.

5.5 Forestry and Asset Management

Asset management planning is intended to support the management of municipal assets over their entire life cycle to ensure sustainable service delivery, manage risks, and keep costs to a minimum. In recognition of the essential role played by green infrastructure in municipal service provision, *Ontario Regulation 588/17 Asset Management Planning for Municipal Infrastructure* (*O.Reg.588/17*) directs municipalities to include green infrastructure assets in asset management plans by July 2024. The regulation defines green infrastructure as "an infrastructure asset consisting of natural or human-made elements that provide ecological and hydrological functions and processes and includes natural heritage features and systems, parklands, stormwater management systems, street trees, urban forests, natural channels, permeable surfaces, and green roofs."[42] This presents an opportunity to prioritize green infrastructure assets in conjunction with traditional assets to support their long-term funding needs for development, maintenance, enhancement, and replacement.

The Township of King Asset Management Plan (AMP) for core assets was finalized in 2016 and revised in 2022. Green infrastructure has yet to be incorporated and should be considered for the next iteration of the AMP. King's street tree inventory would provide an excellent basis for incorporating street trees into the next AMP. Ideally, the inventory would be expanded to include other individual trees occurring in King parks and on other properties. King's Corporate Strategic Plan and Community Services Strategic Plan have identified an action to conduct a natural asset inventory, which includes woodlands, by 2026. The natural asset inventory will be an essential first step towards the insertion of woodlands and other natural assets within the AMP.

Climate change, forestry, and asset management planning are closely interrelated. As discussed in Section 5.4.2, trees are vulnerable to the impacts of climate change. Climate change alters asset life cycles, decreases life spans, and increases risks. Asset management planning must incorporate these climate change impacts and considerations into its life cycle and risks assessments. However, forests also help to mitigate and adapt to climate change. Levels of service can be set for forests around climate change mitigation and adaptation which support best management and financing to support the provision of these services, while maintain forest resilience to reduce risks.

The forest's role in climate change mitigation and adaption are aligned with the vision outlined in King's Climate Action Plan, currently being developed, specifically a vision of a low carbon community that continues to encapsule the rural culture of King. This plan will address innovations within the climate space, community action, and forms of resiliency to de-carbonize the Township. The plan is set to be delivered to the Council for approval in early 2024. Goals and management objectives from the Climate Action Plan should be included within King's asset management plan and should be particularly relevant to sections on forestry.

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[42] Definition sourced from *O.Reg.588/17* at https://www.ontario.ca/laws/regulation/r17588.

Recommendation 31 – ST: Consider integrating forests and individual trees into the asset management planning process, starting with the development of a natural asset inventory

6.0 SUMMARY OF RECOMMENDATIONS

Recommendations identified in the discussion (Section 5) are summarized below. In addition, they are assigned a priority or suggested time horizon for completion.

Recommendation Priority:

- **Short-term (ST): Next one to two years**
- **Medium-term (MT): Next two to five years**
- **Long-term (LT): Next five to ten years**

Recommendation 1 – MT: Finalize the Township's Tree Management Plan in 2025 which will address: local canopy targets, species diversity, and forest health, maintenance, and monitoring.

As part of the Tree Management Plan update, reassess tree care and maintenance practices for trees in highly urbanized areas. Consider indicators associated with street tree mortality, including plant hardiness and tolerances to harsher urban conditions, tree pit enhancements, direct tree care/stewardship, and assessing local traffic, and building conditions. Develop a post-tree planting management and monitoring procedure to complement King's tree maintenance program to ensure tree survivorship and mitigate common stressors in the urban environment.

Consider the inclusion of a naturalization and restoration procedure section within King's Tree Management Plan to bolster planting inputs in the natural heritage system and other naturalized areas.

Recommendation 2 – MT: The Township should strongly consider alignment with targets for canopy cover outlined in the York Region Forest Management Plan.

Recommendation 3 – MT: Develop canopy cover targets for land use types within the Official Plan.

Recommendation 4 – ST: Work with York Region to customize and utilize the Region's tree planting prioritization tool for King to improve equitable canopy cover distribution, the maximization of ecological benefits and ecosystem services, and target areas impacted by invasive pests.

Recommendation 5 – MT: Develop mechanisms and education programs to encourage and support private landowners (particularly of commercial, industrial, and agricultural spaces, and property developers) to plant, protect and enhance trees and employ best practices for tree maintenance.

Recommendation 6 – LT: Continue assessing forest structure, function, and distribution every ten years through the Forest Studies and canopy cover every five years through the York Region Canopy Cover Assessment.

Recommendation 7 – LT: Consider developing an understory planting program targeting natural forest woodlands and historically managed woodlots or plantations.

Recommendation 8– LT: In line with current practices, continue to establish a diverse tree population in *intensively managed urban areas*, in which no species represents more than five percent of the tree population, no genus represents more than ten percent of the tree population, and no family represents more than twenty percent of the intensively managed tree population.

Recommendation 9 – MT: Consider the development of a campaign focused on educating private landowners and the public about the ecosystem benefits across the Township's forest and the importance of species diversity for a resilient forest, particularly in the context of climate change. Incentivize private landowners to plant a greater diversity of native species to increase the functional diversity of species planted in King and encourage private landowners to plant alternatives to eastern white cedar given its high vulnerability to climate change.

Recommendation 10 – MT: Utilize native and appropriate non-native, non-invasive planting stock in both intensively and extensively managed areas. Increase genetic diversity of tree populations by using the guidance provided by the Ontario Tree Seed Transfer Policy. This policy is intended to help managers source seed based on the projected changes in climate to increase the likelihood of producing trees well-adapted to current and future conditions.

Recommendation 11 – LT: Evaluate and develop the strategic steps required to maintain the number and proportion of medium and large trees across King's forest including in the natural heritage system, street and park trees, and trees on private lands, where feasible.

Recommendation 12 – MT: Review and enhance tree preservation requirements in municipal guidelines and regulations for sustainable streetscape and subdivision design standards to support tree establishment and eliminate conflict between natural and grey infrastructure. Continue to apply ThinKING Green to ensure sustainability of new developments.

Recommendation 13 – ST: Continue to apply Section 2.3, Natural Environment: Tree Canopy of the Sustainable King: Green Development Standards Program – Single Family Dwellings to maintain the mature tree population in new residential developments and incorporate enhancement plantings where appropriate. Track canopy cover losses associated with corporate plantings projects, development applications and residential site alterations. Consider incorporating site alteration applications for residential dwellings (e.g. pool permit applications).

Recommendation 14 – ST: Host an annual knowledge sharing meeting between the Region and Township to educate staff on by-laws, particularly the Forest Conservation Bylaw, to improve awareness about the applicability of York bylaws for the Township.

Recommendation 15 – LT: Where appropriate, select and plant long lived, low maintenance, and low volatile organic compound (VOC) emitting tree species.[43]

Recommendation 16 – LT: Bolster the evergreen tree population across the municipality to improve year-round pollution removal services.

Recommendation 17 – MT: Engage in strategic tree planting in high emissions zones.

[43] Some evergreen species emit high levels of VOCs, however this should not preclude them from planting programs. When possible and appropriate, consider planting low VOC emitting species.

Recommendation 18 – ST: Continue to apply subsurface (Silva) cells on a project-by-project basis and other enhanced rooting environment techniques for street trees, particularly in constrained spaces such as intensification areas. Explore incorporating this recommendation into King's Green Development Standards.

Recommendation 19 – MT: Explore the opportunity to utilize the Sustainable Technology Evaluation Program Treatment Train Tool to evaluate and quantify the stormwater benefits of planting trees. See: Low Impact Development Treatment Train Tool.

Recommendation 20 – LT: Following the Township of King's Official Plan recommendation to encourage tree planting to reduce summer heat (see Section 3.2.1 of the OP), consider including the potential of trees to provide energy savings when developing planting guidelines or standards. Also, consider including the potential of tree-based energy savings under the green infrastructure component of the Sustainable King: Green Development Standards Program.

Recommendation 21 – MT: Consider including species' capacity for carbon storage and sequestration and tolerance to future projected climates when developing planting lists or guidelines and future (urban) forest management plans.

Recommendation 22 – LT: Ensure best practices for healthy soils are implemented in King's public and private urban areas in the planning of planting programs from site selection and appropriate soil volume considerations to assessment of species selection. Sustainable King: Green Development Standards Program provides guidelines for soil quality and quantity that should be applied.

Recommendation 23 – MT: Educate private homeowners and industrial and commercial landowners about planting trees and shrub species based on soil types.

Recommendation 24 – LT: Promote the implementation of natural buffers along the edges of urban woodlots to protect against the encroachment of invasive species.

Recommendation 25 – MT: Continue targeted removal of high priority invasive plant species at high priority sites following best management practices recommended by the Ontario Invasive Species Council[44].

Recommendation 26 – ST: Explore the development and implementation of a municipal-led invasive plant, pest, and disease education and volunteer program to enhance awareness of invasive plants, pests, and pathogens and proper removal practices. Develop a monitoring and action strategy for invasive species, pests, and diseases, and continue taking proactive approaches to address new and emerging invasive species, such as hemlock woolly adelgid and oak wilt.

Recommendation 27 – MT: Investigate the utility and potential application of pest vulnerability tools, such as the Pest Vulnerability Matrix (PVM) during species selection for municipal tree and shrub planting.

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[44] Refer to Ontario Invasive Plant Council's Best Management Practices series: https://www.ontarioinvasiveplants.ca/resources/best-management-practices/

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Recommendation 29 – ST: Assess the Township's current recommended planting list based on the climate vulnerability of each species. Shift recommendations to native and appropriate non-native, non-invasive species that have a higher tolerance and lower vulnerability to climate change impacts.

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Recommendation 31 – ST: Consider integrating forests and individual trees into the asset management planning process, starting with the development of a natural asset inventory.

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APPENDIX A: MPAC LAND USE CATEGORIES

Table 29: Description of Land Use Classes (Canopy cover metrics by MPAC land use for each class are listed in Appendix C)

	Generalized Land Use Class	MPAC Land Uses within each Generalized Class
1	Open space	Municipal parks, golf courses, cemeteries, and campgrounds. Open space was combined with the natural cover land use class for this report.
2	Residential Low	Single family detached houses, semi-detached houses, residence with a commercial unit, residence with commercial/industrial use building, linked homes, community lifestyle homes, townhouse/row houses, clergy residences, house-keeping cottages, group homes, student housing, bed & breakfasts. The residential low land use category was combined with the residential medium/high land use stratum.
3	Residential Medium / High	Townhouse blocks, row housing (3 – more) under single ownership, residential property with four-self contained units, rooming or board houses; bachelorettes, cooperative housing, multi-residential (7 or more), condominium units. Residential medium/high was combined with the residential land low use class.
4	Commercial	Office buildings, retail, Beer Stores or LCBOs, restaurants, cinemas, concert halls, entertainment complexes, automotive service centres, fuel stations, automotive shops/dealers, shopping centres, department stores, banks and financial institutions, supermarkets, hotels, motels, lodges, inns, resorts, commercial condominiums, parking lots or garages, funeral homes, bowling alleys, casinos, crematoriums, vacant commercial lands. The commercial land use category was combined with industrial land use.
5	Utilities & Transportation	Communication buildings, hydraulic, fossil or nuclear generating stations, transformer stations, Hydro Rights-of-Ways, wind turbines, airports, public transportation-easements and rights, bridges/tunnels, pipelines, compressor stations, railway rights-of-ways, railway buildings and lands, rail stations/yards, airport leasehold or hangers, subway stations, transit garages, public transportation, lighthouses, wharves and harbours, canals and locks, navigational facilities, historic site/monuments, communication. Utilities & transportation lands were combined with rights-of-way for the i-Tree Eco assessment.
6	Industrial	Mines, mine tailings, oil/gas wells, sawmill/lumber mills, forest products, heavy manufacturing, pulp and paper mills, cement/asphalt manufacturing, steel mills, automotive assembly or parts plant, shipyards, steel production, smelters, foundries, distilleries/breweries, grain elevators and handling, process elevators, slaughterhouses, food processing plants, freezer plants, warehouses, dry cleaning, R&D facilities, other industrial, printing plants, truck terminals, major distribution centres, petro-chemical plants, oil refineries, tank farms, bulk oi,/fuel distribution terminals, gravel pits, quarries, sand pits, peat moss operations, heat or steam

	Generalized Land Use Class	MPAC Land Uses within each Generalized Class
		plants, sewerage treatments, water treatments, recycling plants, power dams, vacant industrial lands. The industrial land use category was combined with the commercial land use category.
7	Institutional	Post-secondary educational, educational residence, school, day care, other education, institutional residence, hospital, senior care facility/retirement/nursing/old age homes, other heath care facilities, penitentiary or correctional facilities, places of worship, museums or art galleries, libraries, conference centres, banquet or assembly halls, clubs, research facilities, military properties, post offices/depots, fire halls, ambulance stations, police stations. The institutional land use category was combined with the other land use category for this assessment.
8	Agricultural	Farms with or without buildings, farms with or without residence, wineries, grain/seed and feed operations, tobacco farms, ginseng farms, exotic farms, nut orchards, farms with gravel pit, farms with campground, intensive farm operations, large scale greenhouses, large scale swine or poultry operations, agricultural research facilities, farms with oil/gas, portion being farmed
9	Natural Cover	Managed forest properties, provincial or federal parks, lands designated/zoned for open space, conservation authority lands. Natural cover was combined with the open space land use class for this report.
10	Other	Water, marina, billboard, island, time-share, seasonal/recreational dwelling, mining lands, non-buildable land walkways, buffer/berm, stormwater management pond, vacant residential land, vacant lot, residential dockominium, boathouse, vacant recreational, common land, co-ownership, life lease, racetrack, exhibition/fair grounds, sports complex, amusement park, sport club, golf centre/driving range, condominium development land, property in process of redevelopment, residential development land, cooperative housing, vacant land condominium, condominium parking space/locker unit The other land use category was combined with the institutional land use category for this assessment.
11	Rights-of-way	Rights-of-ways including smaller roads and adjacent ROW. Added to land use layer by UVM by filling in the gaps between parcel boundaries. Rights-of-ways were included in the utilities & transportation stratum for this report.

APPENDIX B: PARAMETERS USED FOR I-TREE FORECAST

Table 30: General simulation parameters used for i-Tree Forecast

Parameter	Value	Comments
Simulation period	• 2023 – 2052 (30 years)	
Length of frost-free season	• 178 days	Average of current frost-free season and projected frost-free season according to Historical and Future Climate Trends in York Region
Base annual tree mortality rate for healthy trees (dieback < 50 %)	• 1.6%	The base annual mortality rate for health trees was set at 4.0 % by i-Tree Eco. However, the York Region Green Infrastructure Asset Management Plan listed an annual mortality rate of 1.3% for rural trees, 1.6% for suburban trees, and 2% for urban trees. Given that King contains a mix of land uses, the average value was used for healthy trees.
Base annual tree mortality rate for sick trees (dieback 50-75 %)	• 13.1% (default)	Default values were used as no locally applicable data on the impact of health on annual mortality.
Base annual tree mortality rate for dying trees (>76 % dieback)	• 50% (default)	
Base annual tree mortality rate for dead trees (100% die back)	• 100% (default)	

Table 31: Simulation parameters for pests and pathogens

Insect	Start of outbreak and duration	Annual mortality rate from outbreak[45]	Plant host trees during event (i.e. plant trees affected by pest/disease)?	Notes
Emerald ash borer (EAB)	2021, 3 years	Default value: 3.3%[46]	No	Mortality rates in Michigan at the peak of the outbreak were as high as 100% (Klooster et al., 2014). However, since we are passed the peak in Ontario the lower value recommended by i-Tree Eco will be used. EAB is nearing past its peak and phasing out in Ontario according to TRCA staff.
Spongy moth	2021, 3 years	4.4%	No	Mortality rate depends on the crown condition prior to defoliation, the extent of defoliation, and the number of years defoliation was seen (Davidson et al., 1999). Davidson et al. (1999) found that mortality rates within five years could be as high as 50% following two consecutive severe defoliations of a tree with fair crown condition and as low as 7% for a single year of defoliation in a tree with good crown condition. The default value of 10% annual mortality rate is consistent with assuming two severe defoliations of a tree with fair or poor crown condition. A more conservative estimate would be to assume two years of defoliation of a tree in good crown condition. Davidson et al. (1999) found a mortality rate of 22% over five years, translating to an annual mortality rate of 4.4%. The default value provided by i-Tree Eco is 10.0 %.
Beech bark disease (BBD)	2021, 10 years	2.35% (Default is 4.7%)	No	According to Reed et al. (2021) BBD has been in Ontario since the 2000s and is moving eastwards and northwards. Mortality also occurs within a long time frame of five to 10 years. So it is anticipated that it will be here for still many years. Their study of plots around Lake Erie indicated that 4% of Beech trees were affected. Mortality rate for trees with a high density of scale was 50% within 10 years. That translates to 0.5% per year. Therefore, the annual mortality rate was reduced from the default mortality rate of 4.7% to 2.35% (0.5 x 4.7). The default value provided by i-Tree Eco is 4.7%.

[45] Mortality rates only apply to species affected by pest.

[46] Default morality rates are based on a synthesis of literature by the i-Tree Eco team.

Insect	Start of outbreak and duration	Annual mortality rate from outbreak[45]	Plant host trees during event (i.e. plant trees affected by pest/disease)?	Notes
Dutch elm disease	2021, 30 years	2.7% (default value)	No	Dutch elm disease continues to be highly infectious with most infected trees dying within one to three years of infection. All native elms are susceptible. (Government of Ontario, 2021)

King Tree Planting Parameters

- Naturalized plantings in King average on 5,962 units/year, based on data from the last 3 years. This program does not have a planned end date.

Table 32: Tree planting simulation parameters for King

Stratum/Strata	Annual Planting Rate	DBH at planting	Start	Duration (years)	Comments
Open Space – Natural Cover	5,962 / year	2 cm	2023	30	From **naturalized plantings** in King

APPENDIX C: LAND COVER AND CANOPY COVER METRICS FOR KING AND MPAC LAND USES

Existing and potential canopy cover were calculated per MPAC (2019) land use stratum using the UVM land cover dataset (current to 2019). Section 3.1 provides details on the mapping method, the MPAC land use categories, and definitions for possible vegetated and impervious canopy, as well as unsuitable.

Please note that all percentages are computed out of the total land area which excludes water, while the “Total Area” column includes water.

Table 33. Canopy cover metrics by MPAC Land uses in the Township of King

General Land Use	Total Area	Existing Canopy Area	Possible Vegetated Canopy Area	Possible Impervious Canopy Area	Total Possible Canopy Area	Unsuitable Area	Existing Canopy Percent	Possible Vegetated Canopy Percent	Possible Impervious Canopy Percent	Unsuitable Percent	Total Possible Canopy Percent	Canopy Cover as a Percent of Total CC
	ha	ha	ha	ha	ha	ha	%	%	%	%	%	%
Agriculture	20,727.58	4,783.19	15,412.67	188.38	15,601.05	128.49	23.3	75.1	0.9	0.6	76.06	42.0
Commercial	582.86	201.02	334.90	15.96	350.86	2.16	36.3	60.4	2.9	0.4	63.33	1.8
Industrial	1,037.65	539.05	404.33	31.51	435.84	13.74	54.5	40.9	3.2	1.4	44.09	4.7
Institutional	106.44	23.76	50.45	18.67	69.12	6.42	23.9	50.8	18.8	6.5	69.61	0.2
Natural Cover	280.63	139.28	92.60	35.38	127.98	11.56	50.0	33.2	12.7	4.1	45.90	1.2
Open Space	1,583.93	937.00	568.76	47.68	616.44	11.69	59.9	36.3	3.0	0.7	39.39	8.2
Other	28.45	11.39	11.20	1.46	12.66	3.88	40.8	40.1	5.2	13.9	45.34	0.1
Residential Low	5,693.87	3,085.41	2,127.1948	154.85	2,282.05	252.13	54.9	37.9	2.8	4.5	40.61	27.1
Residential Medium / High	2,065.61	1,365.70	620.66	15.64	636.30	5.36	68.0	30.9	0.8	0.3	31.70	12.0
ROW	60.98	8.37	36.09	7.78	43.87	8.69	13.7	59.2	12.8	14.3	72.00	0.1
Utilities & Transportation	1,472.55	286.04	603.41	143.86	747.26	423.27	19.6	41.4	9.9	29.1	51.30	2.5

APPENDIX D: FOREST COMPOSITION AND STRUCTURE

Table 34. King Forest Composition and Structure Metrics

Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
		Number	SE	(ha)	SE	(metric ton)	SE	(metric ton)	SE	(%)
Acer saccharum	Sugar maple	1,279,932	±332,162	27,077.320	±7,600.350	16,312.621	±4,578.800	424,396.668	±138,523.687	94.84
Thuja occidentalis	Northern white cedar	931,921	±368,139	3,686.061	±1,084.848	7,088.578	±2,086.247	223,770.711	±113,560.145	57.89
Fraxinus americana	White ash	784,473	±221,473	1,335.945	±411.540	759.10	±233.843	97,596.222	±30,050.942	34.56
Picea glauca	White spruce	585,477	±266,471	5,450.031	±2,251.257	8,755.070	±3,616.476	78,439.090	±31,403.990	83.67
Ulmus americana	American elm	411,585	±135,412	1,572.164	±553.016	1,143.475	±402.222	32,065.178	±9,380.319	55.77
Fraxinus pennsylvanica	Green ash	303,538	±132,468	513.96	±261.390	335.24	±170.498	21,961.141	±13,890.980	42.20
Acer rubrum	Red maple	271,732	±93,118	4,091.902	±1,222.541	2,755.861	±823.371	70,239.446	±24,529.172	90.75
Pinus sylvestris	Scots pine	268,311	±109,116	1,531.873	±648.192	1,476.504	±624.763	49,919.557	±20,259.340	76.21
Prunus serotina	Black cherry	256,002	±119,577	2,188.683	±1,015.483	1,697.443	±787.563	75,239.730	±34,610.381	77.44
Tilia americana	American basswood	255,991	±65,379	7,001.218	±2,415.260	2,044.032	±705.144	105,928.312	±44,197.961	88.82
Fraxinus	Ash spp	231,376	±112,029	0.00	±0.000	0.00	±0.000	63,848.474	±37,685.702	0.00
Fagus grandifolia	American beech	228,863	±100,129	1,408.972	±689.353	600.41	±293.754	70,789.119	±39,737.616	68.42
Pinus strobus	Eastern white pine	222,249	±57,615	4,039.894	±1,334.335	2,598.170	±858.148	56,859.317	±21,296.831	83.63
Pinus resinosa	Red pine	215,274	±149,488	1,234.378	±1,009.748	1,815.262	±1,484.924	35,013.233	±22,727.964	74.15
Magnolia	Magnolia spp	202,974	±83,887	0.00	±0.000	0.00	±0.000	40,520.754	±24,086.633	0.00
Rhamnus cathartica	European buckthorn	199,062	±57,176	339.03	±100.926	150.68	±44.856	6,910.049	±2,109.446	72.93
Populus tremuloides	Quaking aspen	193,392	±78,910	1,685.936	±591.273	1,327.613	±465.606	44,140.391	±16,077.536	64.96
Quercus rubra	Northern red oak	192,468	±100,307	2,948.309	±1,414.350	2,349.250	±1,126.972	70,676.890	±43,775.241	88.11
Acer negundo	Boxelder	189,479	±70,476	2,899.542	±1,216.834	2,652.586	±1,113.195	56,366.116	±29,985.079	81.06
Betula alleghaniensis	Yellow birch	187,867	±120,607	1,402.933	±891.936	580.92	±369.332	28,312.041	±17,582.570	76.62
Tsuga canadensis	Eastern hemlock	177,008	±60,642	3,458.260	±1,511.373	3,212.205	±1,403.839	58,965.619	±25,509.323	85.24
Acer x freemanii	Freeman maple	163,697	±101,757	3,085.479	±2,525.258	1,736.635	±1,421.320	66,687.674	±46,771.604	73.68
Malus pumila	Paradise apple	127,279	±45,753	609.25	±393.086	525.26	±338.896	26,851.312	±12,660.992	46.99
Picea abies	Norway spruce	120,163	±101,728	1,603.347	±1,125.823	2,672.246	±1,876.371	19,695.770	±13,685.006	99.20
Populus balsamifera	Balsam poplar	116,908	±89,337	707.03	±540.779	510.16	±390.201	7,929.676	±5,844.042	81.19
Picea pungens	Blue spruce	110,186	±37,108	1,658.480	±662.570	2,761.372	±1,103.181	23,964.039	±10,664.189	89.56
Betula papyrifera	Paper birch	107,115	±34,975	543.64	±211.733	380.20	±148.075	12,949.636	±5,765.825	78.72
Fraxinus nigra	Black ash	93,875	±38,099	46.42	±25.343	27.63	±15.086	4,532.305	±2,188.400	23.02
Ostrya virginiana	Eastern hophornbeam	89,989	±40,054	714.49	±327.846	466.44	±214.027	2,890.110	±1,359.939	96.94
Populus grandidentata	Bigtooth aspen	81,674	±63,089	1,701.174	±1,092.258	867.95	±557.274	31,239.507	±19,084.079	78.69
Carpinus caroliniana	American hornbeam	79,063	±46,138	293.02	±214.449	176.53	±129.194	2,432.297	±1,537.395	84.86

Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Juglans nigra	Black walnut	67,930	±29,364	1,214.825	±844.039	973.65	±676.476	16,070.382	±12,790.898	96.86
Crataegus punctata	Dotted hawthorn	59,754	±59,743	0.00	±0.000	0.00	±0.000	1,858.665	±1,858.338	0.00
Salix bebbiana	Bebb willow	56,616	±39,512	139.22	±120.898	88.19	±76.585	2,200.443	±1,862.821	75.55
Pinus banksiana	Jack pine	52,574	±47,411	112.23	±112.220	93.52	±93.516	7,897.886	±7,538.825	21.16
Acer platanoides	Norway maple	46,615	±26,363	1,259.950	±601.163	680.06	±324.479	23,700.268	±14,075.516	93.75
Acacia excelsa	Ironwood	43,652	±27,460	150.78	±88.227	364.47	±213.262	1,076.428	±648.280	85.76
Pinus nigra	Austrian pine	42,143	±26,428	400.79	±207.709	386.30	±200.202	4,664.373	±2,375.928	87.21
Salix	Willow spp	41,385	±38,001	129.25	±122.140	79.79	±75.395	3,132.068	±2,832.687	73.67
Pyrus communis	Common pear	38,955	±23,685	142.78	±87.995	107.42	±66.201	7,042.601	±4,245.019	76.04
Crataegus mollis	Downy hawthorn	38,197	±31,662	14.67	±11.924	11.05	±8.982	1,973.479	±1,665.179	15.98
Rhus typhina	Staghorn sumac	38,169	±35,435	31.85	±31.848	28.31	±28.302	744.95	±712.246	74.19
Prunus virginiana	Common chokecherry	34,902	±15,167	49.02	±25.593	38.00	±19.839	734.87	±351.812	75.99
Cornus alternifolia	Alternateleaf dogwood	30,655	±16,041	45.86	±26.808	30.58	±17.873	426.99	±241.547	87.47
Abies balsamea	Balsam fir	29,661	±20,560	114.03	±82.160	118.79	±85.584	1,477.883	±1,138.928	77.34
Pinus	Pine spp	23,549	±23,547	0.00	±0.000	0.00	±0.000	333.73	±333.703	0.00
Quercus macrocarpa	Bur oak	21,482	±13,930	836.73	±557.420	822.18	±547.725	7,265.249	±4,660.733	98.70
Prunus pensylvanica	Pin cherry	20,507	±17,888	38.56	±30.308	18.61	±14.630	423.26	±326.273	99.50
Crataegus	Hawthorn spp	19,474	±9,554	26.90	±26.898	9.68	±9.676	373.27	±227.407	30.08
Alnus incana ssp. rugosa	Speckled alder	17,244	±17,241	14.44	±14.438	12.40	±12.395	370.91	±370.854	55.40
Malus	Apple spp	16,220	±11,257	34.92	±27.369	30.10	±23.596	2,475.447	±1,610.185	36.86
Carya cordiformis	Bitternut hickory	15,430	±8,843	66.34	±38.297	41.70	±24.074	859.08	±536.199	98.58
Acer saccharinum	Silver maple	12,785	±7,605	387.47	±306.387	203.94	±161.265	5,708.530	±4,662.786	98.15
Amelanchier arborea	Downy serviceberry	11,774	±11,773	7.47	±7.465	4.55	±4.552	1,031.356	±1,031.269	41.25
Prunus	Plum spp	10,548	±7,803	12.26	±10.658	9.49	±8.246	180.67	±162.288	99.50
Larix laricina	Tamarack	10,346	±7,633	271.73	±240.521	175.70	±155.516	4,233.460	±4,106.138	90.50
Pinus nigra ssp. nigra	Black pine	10,346	±10,345	492.33	±492.263	474.54	±474.470	5,896.883	±5,896.028	96.17
Morus alba	White mulberry	9,336	±6,822	333.44	±238.545	243.92	±174.503	11,574.039	±9,436.811	76.17
Elaeagnus umbellata	Autumn olive	8,925	±6,470	8.66	±6.167	4.50	±3.199	57.95	±41.608	89.59
Juglans cinerea	Butternut	8,723	±7,134	89.08	±74.017	49.21	±40.891	1,040.250	±853.941	85.01
Acer nigrum	Black maple	8,097	±8,096	354.69	±354.650	199.64	±199.612	2,456.241	±2,455.938	99.50
Hamamelis virginiana	Witch hazel	6,897	±6,896	3.80	±3.799	2.24	±2.235	33.71	±33.706	18.75
Populus alba	White poplar	6,897	±6,896	25.76	±25.755	22.40	±22.396	68.87	±68.860	88.50
Syringa reticulata	Japanese tree lilac	6,897	±4,815	59.61	±49.527	57.51	±47.778	1,382.277	±1,098.479	94.50
Acer tataricum ssp. ginnala	Amur maple	5,887	±5,887	6.79	±6.785	3.82	±3.819	103.91	±103.896	62.50
Prunus avium	Sweet cherry	5,887	±5,887	3.36	±3.362	2.60	±2.602	41.13	±41.129	94.50

Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Acer palmatum	Japanese maple	3,449	±3,448	3.08	±3.075	1.73	±1.731	21.33	±21.323	99.50
Amelanchier	Serviceberry spp	3,449	±3,448	5.39	±5.386	4.08	±4.081	129.52	±129.498	94.50
Magnolia liliiflora	Lily Magnolia	3,449	±3,448	8.45	±8.450	5.65	±5.646	158.52	±158.501	99.50
Platanus occidentalis	American sycamore	3,449	±3,448	14.31	±14.304	6.93	±6.930	64.75	±64.740	82.50
Syringa	Lilac spp	3,449	±3,448	1.43	±1.428	1.38	±1.378	18.65	±18.652	99.50
Viburnum lantana	Wayfaring tree	3,449	±3,448	1.36	±1.362	0.71	±0.713	10.83	±10.832	99.50
Amelanchier canadensis	Eastern service berry	2,845	±2,845	0.00	±0.000	0.00	±0.000	56.74	±56.731	0.00
Fagus sylvatica	European beech	1,826	±1,825	103.37	±103.338	51.73	±51.713	2,181.978	±2,181.380	99.50
Juniperus virginiana	Eastern red cedar	1,826	±1,825	6.62	±6.614	18.38	±18.378	69.95	±69.930	99.50
Salix amygdaloides	Peachleaf willow	1,826	±1,825	32.81	±32.802	20.79	±20.779	643.39	±643.213	94.50
Sorbus	Mountain Ash spp	1,826	±1,825	70.79	±70.773	56.18	±56.169	2,305.276	±2,304.644	94.50
King		**9,588,224**	**±1,179,056**	**91,955.933**	**±11,985.572**	**73,335.826**	**±8,902.990**	**2,035,702.821**	**±283,922.498**	**68.54**

Table 35. King Forest Composition and Structure Metrics by MPAC Land Use Category

Stratum	Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
			Number	SE	(ha)	SE	(metric ton)	SE	(metric ton)	SE	(%)
Agriculture	*Acacia excelsa*	Ironwood	5,887	±5,887	61.98	±61.971	149.81	±149.797	319.03	±319.007	99.50
	Acer tataricum ssp. ginnala	Amur maple	5,887	±5,887	6.79	±6.785	3.82	±3.819	103.91	±103.896	62.50
	Acer negundo	Boxelder	23,549	±14,279	503.91	±435.681	460.99	±398.574	8,070.337	±7,563.913	89.75
	Acer platanoides	Norway maple	11,774	±8,277	453.64	±362.908	244.85	±195.880	8,103.769	±6,783.756	99.50
	Acer rubrum	Red maple	123,631	±77,183	1,906.646	±939.105	1,284.109	±632.479	29,869.112	±19,463.608	91.38
	Acer saccharinum	Silver maple	5,887	±5,887	47.60	±47.600	25.06	±25.054	288.94	±288.911	99.50
	Acer saccharum	Sugar maple	824,209	±307,696	15,242.414	±6,535.211	9,182.730	±3,937.111	216,860.629	±118,937.355	97.48
	Amelanchier arborea	Downy serviceberry	11,774	±11,773	7.47	±7.465	4.55	±4.552	1,031.356	±1,031.269	41.25
	Betula alleghaniensis	Yellow birch	111,857	±111,847	754.95	±754.882	312.61	±312.581	14,883.434	±14,882.170	91.79
	Betula papyrifera	Paper birch	11,774	±8,277	90.37	±72.015	63.20	±50.364	810.73	±587.794	99.50
	Carpinus caroliniana	American hornbeam	29,436	±21,111	68.00	±52.658	40.97	±31.724	889.65	±628.907	76.20
	Cornus alternifolia	Alternateleaf dogwood	17,662	±13,102	29.16	±24.054	19.44	±16.037	174.48	±129.577	92.17

Stratum	Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
	Crataegus	Hawthorn spp	11,774	±8,277	26.90	±26.898	9.68	±9.676	251.73	±215.789	49.75
	Fagus grandifolia	American beech	164,842	±92,674	1,077.491	±660.753	459.15	±281.567	69,251.678	±39,729.742	61.14
	Fraxinus	Ash spp	76,534	±51,296	0.00	±0.000	0.00	±0.000	27,526.888	±23,583.121	0.00
	Fraxinus americana	White ash	365,007	±148,590	805.25	±377.062	457.56	±214.252	58,150.346	±25,730.269	30.68
	Fraxinus nigra	Black ash	23,549	±23,547	11.29	±11.287	6.72	±6.719	1,136.143	±1,136.046	23.63
	Fraxinus pennsylvanica	Green ash	17,662	±13,102	70.11	±70.105	45.73	±45.727	1,254.527	±890.726	60.67
	Juglans nigra	Black walnut	23,549	±18,550	68.93	±51.006	55.24	±40.880	396.21	±319.272	98.25
	Magnolia	Magnolia spp	76,534	±38,851	0.00	±0.000	0.00	±0.000	27,969.904	±23,239.645	0.00
	Malus pumila	Paradise apple	35,323	±21,824	452.49	±387.328	390.11	±333.932	13,896.798	±10,780.979	53.25
	Morus alba	White mulberry	5,887	±5,887	140.95	±140.942	103.11	±103.103	2,462.917	±2,462.707	62.50
	Ostrya virginiana	Eastern hophornbeam	35,323	±21,824	342.91	±244.103	223.86	±159.357	1,508.753	±1,002.717	97.00
	Pinus	Pine spp	23,549	±23,547	0.00	±0.000	0.00	±0.000	333.73	±333.703	0.00
	Picea abies	Norway spruce	100,083	±100,074	976.67	±976.590	1,627.788	±1,627.650	11,677.371	±11,676.379	99.50
	Pinus banksiana	Jack pine	47,098	±47,094	112.23	±112.220	93.52	±93.516	7,530.513	±7,529.874	23.63
	Picea glauca	White spruce	17,662	±13,102	64.75	±52.102	104.01	±83.699	623.90	±463.239	96.17
	Picea pungens	Blue spruce	47,098	±29,760	931.49	±598.630	1,550.937	±996.721	14,614.108	±10,045.194	80.69
	Pinus resinosa	Red pine	141,293	±129,905	1,107.856	±1,001.793	1,629.200	±1,473.225	23,539.554	±19,620.431	94.33
	Pinus strobus	Eastern white pine	58,872	±31,802	1,018.778	±691.876	655.21	±444.965	14,003.274	±10,687.321	68.65
	Pinus sylvestris	Scots pine	129,519	±74,527	945.54	±550.866	911.37	±530.956	30,113.049	±17,276.788	87.32
	Populus balsamifera	Balsam poplar	82,421	±82,414	499.38	±499.333	360.33	±360.295	2,798.237	±2,798.000	91.71
	Populus grandidentata	Bigtooth aspen	5,887	±5,887	288.47	±288.443	147.18	±147.165	6,272.294	±6,271.762	82.50
	Populus tremuloides	Quaking aspen	76,534	±65,681	353.25	±248.783	278.17	±195.908	12,204.270	±9,382.123	40.23
	Prunus avium	Sweet cherry	5,887	±5,887	3.36	±3.362	2.60	±2.602	41.13	±41.129	94.50
	Prunus pensylvanica	Pin cherry	17,662	±17,660	28.64	±28.641	13.83	±13.826	303.56	±303.531	99.50
	Prunus serotina	Black cherry	170,729	±114,095	1,718.394	±988.837	1,332.708	±766.897	58,818.886	±33,661.141	86.71
	Prunus virginiana	Common chokecherry	17,662	±13,102	33.99	±23.903	26.35	±18.529	430.13	±323.570	96.17
	Pyrus communis	Common pear	11,774	±11,773	69.54	±69.536	52.32	±52.314	1,114.310	±1,114.216	99.50
	Quercus macrocarpa	Bur oak	5,887	±5,887	466.22	±466.180	458.11	±458.072	3,112.280	±3,112.015	99.50
	Quercus rubra	Northern red oak	17,662	±10,077	585.59	±409.051	466.61	±325.937	7,783.796	±5,555.396	99.50
	Rhamnus cathartica	European buckthorn	47,098	±19,872	122.65	±55.652	54.51	±24.734	2,746.135	±1,365.627	79.69
	Rhus typhina	Staghorn sumac	35,323	±35,320	31.85	±31.848	28.31	±28.302	711.52	±711.462	80.17

Stratum	Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
	Salix bebbiana	Bebb willow	35,323	±35,320	120.15	±120.143	76.11	±76.108	1,836.186	±1,836.030	91.33
	Thuja occidentalis	Northern white cedar	412,105	±295,667	1,219.979	±784.505	2,346.113	±1,508.664	141,322.736	±110,258.388	30.76
	Tilia americana	American basswood	129,519	±45,261	4,268.739	±2,158.316	1,246.274	±630.128	77,049.403	±42,313.006	85.45
	Tsuga canadensis	Eastern hemlock	105,970	±53,706	1,783.387	±1,258.447	1,656.499	±1,168.909	28,828.170	±17,572.443	81.86
	Ulmus americana	American elm	182,503	±110,761	806.01	±487.955	586.23	±354.902	12,380.547	±6,527.389	64.35
		Total	**3,944,429**	**±913,810**	**39,726.161**	**±9,964.653**	**29,247.573**	**±6,694.761**	**945,400.372**	**±246,955.039**	**70.08**
Open Space - Natural Cover	*Abies balsamea*	Balsam fir	22,763	±19,988	81.93	±78.231	85.35	±81.490	1,151.281	±1,107.440	70.63
	Acacia excelsa	Ironwood	17,072	±17,069	45.33	±45.323	109.58	±109.556	504.77	±504.679	69.42
	Acer negundo	Boxelder	17,072	±11,792	351.03	±323.853	321.13	±296.270	4,722.893	±4,594.627	96.17
	Acer rubrum	Red maple	36,990	±21,307	552.18	±345.389	371.89	±232.617	12,394.294	±8,005.655	90.15
	Acer saccharum	Sugar maple	116,662	±49,528	1,498.093	±800.212	902.52	±482.085	9,087.817	±4,218.527	96.17
	Amelanchier canadensis	Eastern service berry	2,845	±2,845	0.00	±0.000	0.00	±0.000	56.74	±56.731	0.00
	Betula alleghaniensis	Yellow birch	11,382	±11,380	459.58	±459.495	190.30	±190.267	8,726.017	±8,724.484	91.50
	Betula papyrifera	Paper birch	19,918	±11,217	224.82	±140.008	157.23	±97.914	7,427.235	±4,936.141	91.79
	Carpinus caroliniana	American hornbeam	5,691	±5,690	15.51	±15.508	9.34	±9.343	91.05	±91.035	94.50
	Carya cordiformis	Bitternut hickory	11,382	±7,862	48.68	±33.983	30.60	±21.362	700.04	±512.077	98.25
	Cornus alternifolia	Alternateleaf dogwood	5,691	±5,690	7.80	±7.801	5.20	±5.201	56.63	±56.618	91.00
	Crataegus mollis	Downy hawthorn	31,299	±31,294	0.00	±0.000	0.00	±0.000	1,636.573	±1,636.285	0.00
	Crataegus punctata	Dotted hawthorn	59,754	±59,743	0.00	±0.000	0.00	±0.000	1,858.665	±1,858.338	0.00
	Fagus grandifolia	American beech	5,691	±3,931	3.15	±3.148	1.34	±1.341	620.61	±588.862	47.25
	Fraxinus	Ash spp	45,527	±42,639	0.00	±0.000	0.00	±0.000	6,003.840	±5,954.670	0.00
	Fraxinus americana	White ash	176,415	±120,599	230.36	±126.504	130.89	±71.881	7,078.799	±3,745.851	38.31
	Fraxinus pennsylvanica	Green ash	145,116	±102,097	138.12	±95.397	90.09	±62.225	15,866.881	±13,622.361	22.68
	Juglans nigra	Black walnut	2,845	±2,845	5.22	±5.219	4.18	±4.183	32.95	±32.942	99.50
	Magnolia	Magnolia spp	5,691	±5,690	0.00	±0.000	0.00	±0.000	851.04	±850.889	0.00

Stratum	Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
	Malus pumila	Paradise apple	31,299	±28,462	29.42	±29.418	25.37	±25.363	1,810.519	±1,461.056	59.68
	Ostrya virginiana	Eastern hophornbeam	51,217	±33,409	346.11	±217.365	225.95	±141.902	1,344.157	±917.938	96.72
	Pinus resinosa	Red pine	73,981	±73,968	126.52	±126.500	186.06	±186.029	11,473.679	±11,471.663	35.62
	Pinus strobus	Eastern white pine	17,072	±9,396	156.07	±105.604	100.37	±67.917	5,108.536	±3,357.257	73.92
	Pinus sylvestris	Scots pine	2,845	±2,845	7.83	±7.827	7.55	±7.544	119.40	±119.382	82.50
	Populus grandidentata	Bigtooth aspen	68,290	±62,588	1,242.640	±1,040.521	634.00	±530.878	21,521.177	±17,766.119	76.37
	Populus tremuloides	Quaking aspen	22,763	±12,752	287.53	±158.554	226.42	±124.856	8,213.096	±4,773.221	58.88
	Prunus pensylvanica	Pin cherry	2,845	±2,845	9.91	±9.911	4.79	±4.784	119.70	±119.678	99.50
	Prunus serotina	Black cherry	42,681	±32,809	150.25	±143.169	116.52	±111.035	5,624.682	±5,501.307	57.27
	Prunus virginiana	Common chokecherry	2,845	±2,845	0.00	±0.000	0.00	±0.000	45.01	±45.005	0.00
	Quercus rubra	Northern red oak	25,609	±12,838	413.86	±220.011	329.77	±175.308	5,735.645	±3,084.341	94.83
	Rhamnus cathartica	European buckthorn	19,918	±13,911	11.42	±11.418	5.08	±5.075	398.91	±293.260	42.64
	Rhus typhina	Staghorn sumac	2,845	±2,845	0.00	±0.000	0.00	±0.000	33.43	±33.423	0.00
	Thuja occidentalis	Northern white cedar	25,609	±25,604	422.86	±422.780	813.18	±813.039	11,790.069	±11,787.997	70.11
	Tilia americana	American basswood	65,444	±41,342	968.25	±695.058	282.68	±202.925	10,575.440	±7,562.411	93.67
	Tsuga canadensis	Eastern hemlock	28,454	±17,849	1,020.938	±669.399	948.30	±621.771	11,878.839	±8,033.413	92.10
	Ulmus americana	American elm	11,382	±11,380	24.18	±24.179	17.59	±17.586	218.57	±218.531	87.75
		Total	**1,234,907**	**±362,879**	**8,879.590**	**±2,870.383**	**6,333.272**	**±2,122.283**	**174,878.988**	**±50,933.977**	**56.44**
Residential	*Abies balsamea*	Balsam fir	6,897	±4,815	32.10	±25.105	33.44	±26.151	326.60	±265.959	99.50
	Acacia excelsa	Ironwood	20,692	±20,689	43.47	±43.466	105.08	±105.067	252.63	±252.590	95.33
	Acer x freemanii	Freeman maple	110,359	±88,938	2,634.558	±2,490.481	1,482.838	±1,401.745	44,219.523	±41,326.678	78.47
	Acer negundo	Boxelder	110,359	±64,279	1,612.649	±1,058.601	1,475.299	±968.439	39,459.959	±28,566.168	77.03
	Acer palmatum	Japanese maple	3,449	±3,448	3.08	±3.075	1.73	±1.731	21.33	±21.323	99.50
	Acer platanoides	Norway maple	6,897	±4,815	298.43	±208.520	161.08	±112.549	2,624.152	±1,832.100	97.00
	Acer rubrum	Red maple	82,769	±43,316	1,128.104	±608.282	759.77	±409.673	23,566.696	±12,050.285	87.31
	Acer saccharinum	Silver maple	6,897	±4,815	339.87	±302.667	178.89	±159.307	5,419.595	±4,653.827	97.00
	Acer saccharum	Sugar maple	265,551	±105,911	9,291.277	±3,761.968	5,597.492	±2,266.382	170,635.476	±68,552.105	90.10
	Alnus incana ssp. rugosa	Speckled alder	17,244	±17,241	14.44	±14.438	12.40	±12.395	370.91	±370.854	55.40

Stratum	Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
	Amelanchier	Serviceberry spp	3,449	±3,448	5.39	±5.386	4.08	±4.081	129.52	±129.498	94.50
	Betula alleghaniensis	Yellow birch	24,141	±24,138	86.75	±86.740	35.92	±35.917	1,503.884	±1,503.666	75.00
	Betula papyrifera	Paper birch	55,180	±29,982	179.51	±138.509	125.54	±96.866	3,691.018	±2,827.088	76.66
	Carpinus caroliniana	American hornbeam	3,449	±3,448	2.19	±2.187	1.32	±1.317	52.49	±52.481	82.50
	Crataegus mollis	Downy hawthorn	6,897	±4,815	14.67	±11.924	11.05	±8.982	336.91	±308.858	88.50
	Elaeagnus umbellata	Autumn olive	3,449	±3,448	4.84	±4.837	2.51	±2.509	34.11	±34.107	94.50
	Fagus grandifolia	American beech	13,795	±8,269	60.96	±41.022	25.98	±17.481	234.16	±136.592	99.50
	Fraxinus americana	White ash	51,731	±25,538	56.79	±32.685	32.27	±18.572	10,461.172	±7,416.550	33.70
	Fraxinus nigra	Black ash	37,936	±22,638	15.90	±15.901	9.47	±9.466	2,473.167	±1,790.787	9.05
	Fraxinus pennsylvanica	Green ash	110,359	±80,448	254.22	±230.136	165.82	±150.111	4,247.441	±2,532.823	54.03
	Hamamelis virginiana	Witch hazel	6,897	±6,896	3.80	±3.799	2.24	±2.235	33.71	±33.706	18.75
	Juglans cinerea	Butternut	6,897	±6,896	17.03	±17.024	9.41	±9.405	213.09	±213.058	82.50
	Juglans nigra	Black walnut	17,244	±14,133	252.98	±227.244	202.76	±182.130	2,851.921	±2,673.167	95.50
	Larix laricina	Tamarack	10,346	±7,633	271.73	±240.521	175.70	±155.516	4,233.460	±4,106.138	90.50
	Magnolia	Magnolia spp	24,141	±14,731	0.00	±0.000	0.00	±0.000	3,902.771	±2,495.127	0.00
	Malus	Apple spp	10,346	±10,345	25.82	±25.812	22.26	±22.254	1,174.708	±1,174.538	33.33
	Magnolia liliiflora	Lily Magnolia	3,449	±3,448	8.45	±8.450	5.65	±5.646	158.52	±158.501	99.50
	Malus pumila	Paradise apple	55,180	±27,875	127.34	±60.233	109.78	±51.929	11,067.635	±6,475.392	40.44
	Morus alba	White mulberry	3,449	±3,448	192.48	±192.456	140.81	±140.787	9,111.122	±9,109.801	99.50
	Ostrya virginiana	Eastern hophornbeam	3,449	±3,448	25.48	±25.477	16.64	±16.632	37.20	±37.194	99.50
	Picea glauca	White spruce	527,654	±264,677	5,326.662	±2,249.890	8,556.886	±3,614.282	73,373.156	±31,207.363	87.17
	Pinus nigra	Austrian pine	6,897	±4,815	142.30	±103.214	137.15	±99.483	1,413.827	±994.313	97.00
	Pinus nigra ssp. nigra	Black pine	10,346	±10,345	492.33	±492.263	474.54	±474.470	5,896.883	±5,896.028	96.17
	Picea pungens	Blue spruce	44,833	±20,017	554.17	±268.409	922.69	±446.901	6,674.315	±3,295.219	97.96
	Pinus strobus	Eastern white pine	62,077	±27,950	1,048.119	±503.293	674.08	±323.682	14,449.577	±8,836.232	97.44
	Pinus sylvestris	Scots pine	27,590	±17,258	160.69	±154.039	154.88	±148.471	4,597.541	±3,111.546	59.75
	Platanus occidentalis	American sycamore	3,449	±3,448	14.31	±14.304	6.93	±6.930	64.75	±64.740	82.50
	Populus alba	White poplar	6,897	±6,896	25.76	±25.755	22.40	±22.396	68.87	±68.860	88.50

Stratum	Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
	Populus balsamifera	Balsam poplar	34,487	±34,482	207.66	±207.628	149.84	±149.815	5,131.439	±5,130.695	56.05
	Populus grandidentata	Bigtooth aspen	3,449	±3,448	164.69	±164.667	84.03	±84.014	3,006.988	±3,006.552	99.50
	Populus tremuloides	Quaking aspen	72,423	±39,534	965.19	±508.602	760.05	±400.505	20,537.896	±11,973.231	88.19
	Prunus	Plum spp	6,897	±6,896	10.52	±10.513	8.14	±8.135	161.13	±161.109	99.50
	Prunus serotina	Black cherry	27,590	±12,313	105.74	±58.145	82.01	±45.095	4,082.873	±2,085.002	48.00
	Prunus virginiana	Common chokecherry	10,346	±5,821	15.03	±9.146	11.65	±7.090	190.53	±110.732	92.17
	Pyrus communis	Common pear	3,449	±3,448	11.69	±11.683	8.79	±8.789	178.50	±178.476	82.50
	Quercus macrocarpa	Bur oak	3,449	±3,448	296.57	±296.524	291.41	±291.367	3,383.712	±3,383.221	94.50
	Quercus rubra	Northern red oak	96,564	±86,285	1,179.289	±1,105.183	939.67	±880.624	40,640.267	±40,077.672	96.50
	Rhamnus cathartica	European buckthorn	58,628	±24,174	97.80	±44.341	43.47	±19.707	1,497.948	±608.176	70.32
	Salix	Willow spp	41,385	±38,001	129.25	±122.140	79.79	±75.395	3,132.068	±2,832.687	73.67
	Salix bebbiana	Bebb willow	17,244	±17,241	9.38	±9.376	5.94	±5.940	310.16	±310.111	37.60
	Syringa reticulata	Japanese tree lilac	6,897	±4,815	59.61	±49.527	57.51	±47.778	1,382.277	±1,098.479	94.50
	Syringa	Lilac spp	3,449	±3,448	1.43	±1.428	1.38	±1.378	18.65	±18.652	99.50
	Thuja occidentalis	Northern white cedar	182,782	±114,328	939.51	±419.215	1,806.749	±806.183	33,912.219	±18,456.286	89.86
	Tilia americana	American basswood	44,833	±15,952	1,748.905	±831.752	510.60	±242.833	18,004.298	±10,285.415	96.27
	Tsuga canadensis	Eastern hemlock	34,487	±20,224	626.75	±501.723	582.16	±466.026	18,112.297	±16,654.659	89.20
	Ulmus americana	American elm	96,564	±47,724	179.18	±75.918	130.32	±55.217	4,058.668	±2,431.589	55.36
	Viburnum lantana	Wayfaring tree	3,449	±3,448	1.36	±1.362	0.71	±0.713	10.83	±10.832	99.50
		Total	**2,521,014**	**±459,678**	**31,518.168**	**±5,356.326**	**27,410.937**	**±4,875.023**	**607,136.537**	**±108,791.928**	**78.55**
Other - Institutional	*Acer x freemanii*	Freeman maple	4,049	±4,048	34.59	±34.581	19.47	±19.464	567.71	±567.643	62.50
	Acer negundo	Boxelder	20,244	±16,427	338.55	±247.267	309.72	±226.207	2,183.023	±1,720.793	99.50
	Acer nigrum	Black maple	8,097	±8,096	354.69	±354.650	199.64	±199.612	2,456.241	±2,455.938	99.50
	Acer platanoides	Norway maple	24,292	±24,289	423.19	±423.138	228.42	±228.390	12,171.253	±12,169.750	89.17
	Acer rubrum	Red maple	28,341	±19,583	504.97	±351.264	340.09	±236.573	4,409.344	±3,680.815	98.79
	Acer saccharum	Sugar maple	60,731	±44,037	403.98	±320.384	243.38	±193.014	7,064.709	±5,437.462	76.57
	Betula alleghaniensis	Yellow birch	40,487	±36,389	101.66	±83.927	42.10	±34.753	3,198.706	±3,047.974	31.50
	Betula papyrifera	Paper birch	20,244	±11,402	48.94	±29.287	34.22	±20.482	1,020.651	±735.749	59.40

Stratum	Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
	Carpinus caroliniana	American hornbeam	40,487	±40,482	207.32	±207.293	124.90	±124.883	1,399.108	±1,398.935	90.00
	Carya cordiformis	Bitternut hickory	4,049	±4,048	17.66	±17.657	11.10	±11.100	159.04	±159.019	99.50
	Crataegus	Hawthorn spp	4,049	±4,048	0.00	±0.000	0.00	±0.000	35.05	±35.050	0.00
	Fagus grandifolia	American beech	44,536	±36,792	267.38	±192.147	113.94	±81.880	682.67	±510.256	88.45
	Fraxinus	Ash spp	109,316	±90,007	0.00	±0.000	0.00	±0.000	30,317.745	±28,785.247	0.00
	Fraxinus americana	White ash	182,193	±108,258	227.63	±99.322	129.34	±56.436	21,720.592	±13,113.213	37.21
	Fraxinus nigra	Black ash	32,390	±19,611	19.23	±16.187	11.45	±9.636	923.00	±539.976	38.94
	Fraxinus pennsylvanica	Green ash	12,146	±12,145	22.47	±22.466	14.66	±14.654	353.94	±353.897	70.67
	Juglans nigra	Black walnut	24,292	±17,615	887.70	±811.254	711.47	±650.200	12,789.299	±12,504.329	96.17
	Magnolia	Magnolia spp	72,877	±68,669	0.00	±0.000	0.00	±0.000	5,151.221	±5,112.591	0.00
	Malus	Apple spp	4,049	±4,048	9.10	±9.098	7.85	±7.844	221.51	±221.481	62.50
	Pinus nigra	Austrian pine	24,292	±24,289	167.78	±167.756	161.71	±161.693	1,830.342	±1,830.116	87.50
	Pinus strobus	Eastern white pine	76,926	±37,498	1,696.145	±1,012.942	1,090.839	±651.452	22,194.723	±15,782.222	85.24
	Pinus sylvestris	Scots pine	80,975	±72,778	339.69	±294.637	327.41	±283.987	11,855.031	±9,581.283	78.25
	Populus grandidentata	Bigtooth aspen	4,049	±4,048	5.38	±5.375	2.74	±2.742	439.05	±438.994	94.50
	Populus tremuloides	Quaking aspen	16,195	±12,543	69.34	±61.504	54.61	±48.432	2,750.689	±2,032.828	81.75
	Prunus serotina	Black cherry	4,049	±4,048	6.36	±6.362	4.94	±4.934	31.40	±31.395	99.50
	Prunus virginiana	Common chokecherry	4,049	±4,048	0.00	±0.000	0.00	±0.000	69.20	±69.188	0.00
	Quercus macrocarpa	Bur oak	12,146	±12,145	73.95	±73.939	72.66	±72.653	769.26	±769.163	99.50
	Quercus rubra	Northern red oak	52,633	±48,477	769.58	±750.485	613.21	±597.996	16,517.181	±16,421.826	65.62
	Rhamnus cathartica	European buckthorn	4,049	±4,048	5.89	±5.889	2.62	±2.617	93.41	±93.401	99.50
	Salix bebbiana	Bebb willow	4,049	±4,048	9.69	±9.688	6.14	±6.137	54.10	±54.094	99.50
	Thuja occidentalis	Northern white cedar	271,265	±181,786	926.43	±421.781	1,781.605	±811.117	33,607.981	±15,806.582	72.19
	Tilia americana	American basswood	16,195	±16,193	15.33	±15.323	4.47	±4.474	299.17	±299.134	75.50
	Tsuga canadensis	Eastern hemlock	8,097	±8,096	27.19	±27.183	25.25	±25.249	146.31	±146.294	88.50
	Ulmus americana	American elm	80,975	±49,646	292.45	±191.318	212.71	±139.151	9,553.088	±5,032.965	25.65
		Total	**1,396,810**	**±410,758**	**8,274.236**	**±2,405.348**	**6,902.626**	**±1,902.616**	**207,035.745**	**±61,331.032**	**57.87**

Stratum	Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Other Urban	*Acer x freemanii*	Freeman maple	49,289	±49,275	416.34	±416.221	234.33	±234.266	21,900.437	±21,894.438	63.87
	Acer negundo	Boxelder	18,255	±14,907	93.40	±64.868	85.45	±59.343	1,929.904	±1,339.588	59.65
	Acer platanoides	Norway maple	3,651	±3,650	84.69	±84.667	45.71	±45.700	801.09	±800.875	99.50
	Acer saccharum	Sugar maple	12,779	±6,740	641.56	±401.186	386.50	±241.693	20,748.038	±17,203.620	98.07
	Cornus alternifolia	Alternateleaf dogwood	7,302	±7,300	8.90	±8.899	5.94	±5.933	195.88	±195.829	73.38
	Crataegus	Hawthorn spp	3,651	±2,529	0.00	±0.000	0.00	±0.000	86.49	±62.613	0.00
	Elaeagnus umbellata	Autumn olive	5,477	±5,475	3.83	±3.826	1.99	±1.985	23.84	±23.831	86.50
	Fagus sylvatica	European beech	1,826	±1,825	103.37	±103.338	51.73	±51.713	2,181.978	±2,181.380	99.50
	Fraxinus americana	White ash	9,128	±7,454	15.92	±15.914	9.05	±9.043	185.31	±139.375	69.20
	Fraxinus pennsylvanica	Green ash	18,255	±18,250	29.03	±29.021	18.94	±18.930	238.35	±238.285	89.05
	Juglans cinerea	Butternut	1,826	±1,825	72.05	±72.033	39.81	±39.795	827.16	±826.935	94.50
	Juniperus virginiana	Eastern red cedar	1,826	±1,825	6.62	±6.614	18.38	±18.378	69.95	±69.930	99.50
	Magnolia	Magnolia spp	23,732	±23,725	0.00	±0.000	0.00	±0.000	2,645.819	±2,645.094	0.00
	Malus	Apple spp	1,826	±1,825	0.00	±0.000	0.00	±0.000	1,079.231	±1,078.935	0.00
	Malus pumila	Paradise apple	5,477	±5,475	0.00	±0.000	0.00	±0.000	76.36	±76.339	0.00
	Picea abies	Norway spruce	20,081	±18,268	626.67	±560.133	1,044.457	±933.555	8,018.398	±7,137.334	97.68
	Pinus banksiana	Jack pine	5,477	±5,475	0.00	±0.000	0.00	±0.000	367.37	±367.272	0.00
	Picea glauca	White spruce	40,161	±27,941	58.62	±58.607	94.17	±94.147	4,442.032	±3,478.003	32.18
	Pinus nigra	Austrian pine	10,953	±9,234	90.72	±65.938	87.44	±63.555	1,420.203	±1,143.264	80.42
	Picea pungens	Blue spruce	18,255	±9,518	172.82	±92.725	287.75	±154.387	2,675.616	±1,400.194	91.80
	Pinus strobus	Eastern white pine	7,302	±5,702	120.78	±106.067	77.68	±68.215	1,103.207	±952.624	92.75
	Pinus sylvestris	Scots pine	27,383	±27,375	78.12	±78.096	75.29	±75.274	3,234.533	±3,233.647	33.53
	Populus tremuloides	Quaking aspen	5,477	±5,475	10.62	±10.613	8.36	±8.357	434.44	±434.321	78.83
	Prunus	Plum spp	3,651	±3,650	1.75	±1.748	1.35	±1.353	19.53	±19.527	99.50
	Prunus serotina	Black cherry	10,953	±6,064	207.94	±171.727	161.27	±133.184	6,681.890	±5,494.858	77.58
	Pyrus communis	Common pear	23,732	±20,260	61.55	±52.643	46.31	±39.605	5,749.789	±4,092.292	63.46
	Rhamnus cathartica	European buckthorn	69,370	±45,606	101.26	±70.411	45.01	±31.294	2,173.644	±1,456.098	77.68
	Salix amygdaloides	Peachleaf willow	1,826	±1,825	32.81	±32.802	20.79	±20.779	643.39	±643.213	94.50
	Sorbus	Mountain Ash spp	1,826	±1,825	70.79	±70.773	56.18	±56.169	2,305.276	±2,304.644	94.50

Stratum	Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
	Thuja occidentalis	Northern white cedar	40,161	±36,537	177.28	±170.480	340.93	±327.845	3,137.706	±3,091.094	86.43
	Ulmus americana	American elm	40,161	±34,589	270.34	±157.404	196.63	±114.484	5,854.305	±3,753.993	69.45
		Total	**491,064**	**±208,366**	**3,557.779**	**±1,282.420**	**3,441.417**	**±1,597.978**	**101,251.179**	**±37,864.813**	**65.59**
King			**9,588,224**	**±1,179,056**	**91,955.933**	**±11,985.572**	**73,335.826**	**±8,902.990**	**2,035,702.821**	**±283,922.498**	**68.54**

APPENDIX E: LEAF AREA AND STEM COUNT BY NATIVE OR NON-NATIVE TREE SPECIES

Table 36. Number of Trees and Leaf Area for Native Species

Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
		Number	SE	(ha)	SE	(metric ton)	SE	(metric ton)	SE	(%)
Acer saccharum	Sugar maple	1,279,932	±332,162	27,077.32	±7,600.350	16,312.62	±4,578.800	424,396.67	±138,523.687	94.84
Thuja occidentalis	Northern white cedar	931,921	±368,139	3,686.06	±1,084.848	7,088.58	±2,086.247	223,770.71	±113,560.145	57.89
Fraxinus americana	White ash	784,473	±221,473	1,335.95	±411.540	759.10	±233.843	97,596.22	±30,050.942	34.56
Picea glauca	White spruce	585,477	±266,471	5,450.03	±2,251.257	8,755.07	±3,616.476	78,439.09	±31,403.990	83.67
Ulmus americana	American elm	411,585	±135,412	1,572.16	±553.016	1,143.48	±402.222	32,065.18	±9,380.319	55.77
Fraxinus pennsylvanica	Green ash	303,538	±132,468	513.96	±261.390	335.24	±170.498	21,961.14	±13,890.980	42.20
Acer rubrum	Red maple	271,732	±93,118	4,091.90	±1,222.541	2,755.86	±823.371	70,239.45	±24,529.172	90.75
Prunus serotina	Black cherry	256,002	±119,577	2,188.68	±1,015.483	1,697.44	±787.563	75,239.73	±34,610.381	77.44
Tilia americana	American basswood	255,991	±65,379	7,001.22	±2,415.260	2,044.03	±705.144	105,928.31	±44,197.961	88.82
Fraxinus	Ash spp	231,376	±112,029	0.00	±0.000	0.00	±0.000	63,848.47	±37,685.702	0.00
Fagus grandifolia	American beech	228,863	±100,129	1,408.97	±689.353	600.41	±293.754	70,789.12	±39,737.616	68.42
Pinus strobus	Eastern white pine	222,249	±57,615	4,039.89	±1,334.335	2,598.17	±858.148	56,859.32	±21,296.831	83.63
Pinus resinosa	Red pine	215,274	±149,488	1,234.38	±1,009.748	1,815.26	±1,484.924	35,013.23	±22,727.964	74.15
Magnolia	Magnolia spp	202,974	±83,887	0.00	±0.000	0.00	±0.000	40,520.75	±24,086.633	0.00
Populus tremuloides	Quaking aspen	193,392	±78,910	1,685.94	±591.273	1,327.61	±465.606	44,140.39	±16,077.536	64.96
Quercus rubra	Northern red oak	192,468	±100,307	2,948.31	±1,414.350	2,349.25	±1,126.972	70,676.89	±43,775.241	88.11
Betula alleghaniensis	Yellow birch	187,867	±120,607	1,402.93	±891.936	580.92	±369.332	28,312.04	±17,582.570	76.62
Tsuga canadensis	Eastern hemlock	177,008	±60,642	3,458.26	±1,511.373	3,212.21	±1,403.839	58,965.62	±25,509.323	85.24
Acer x freemanii	Freeman maple	163,697	±101,757	3,085.48	±2,525.258	1,736.64	±1,421.320	66,687.67	±46,771.604	73.68
Populus balsamifera	Balsam poplar	116,908	±89,337	707.03	±540.779	510.16	±390.201	7,929.68	±5,844.042	81.19
Betula papyrifera	Paper birch	107,115	±34,975	543.64	±211.733	380.20	±148.075	12,949.64	±5,765.825	78.72
Fraxinus nigra	Black ash	93,875	±38,099	46.42	±25.343	27.63	±15.086	4,532.31	±2,188.400	23.02
Ostrya virginiana	Eastern hophornbeam	89,989	±40,054	714.49	±327.846	466.44	±214.027	2,890.11	±1,359.939	96.94
Populus grandidentata	Bigtooth aspen	81,674	±63,089	1,701.17	±1,092.258	867.95	±557.274	31,239.51	±19,084.079	78.69
Carpinus caroliniana	American hornbeam	79,063	±46,138	293.02	±214.449	176.53	±129.194	2,432.30	±1,537.395	84.86
Juglans nigra	Black walnut	67,930	±29,364	1,214.83	±844.039	973.65	±676.476	16,070.38	±12,790.898	96.86
Salix bebbiana	Bebb willow	56,616	±39,512	139.22	±120.898	88.19	±76.585	2,200.44	±1,862.821	75.55
Pinus banksiana	Jack pine	52,574	±47,411	112.23	±112.220	93.52	±93.516	7,897.89	±7,538.825	21.16
Acacia excelsa	Ironwood	43,652	±27,460	150.78	±88.227	364.47	±213.262	1,076.43	±648.280	85.76
Salix	Willow spp	41,385	±38,001	129.25	±122.140	79.79	±75.395	3,132.07	±2,832.687	73.67
Rhus typhina	Staghorn sumac	38,169	±35,435	31.85	±31.848	28.31	±28.302	744.95	±712.246	74.19

Prunus virginiana	Common chokecherry	34,902	±15,167	49.02	±25.593	38.00	±19.839	734.87	±351.812	75.99
Cornus alternifolia	Alternateleaf dogwood	30,655	±16,041	45.86	±26.808	30.58	±17.873	426.99	±241.547	87.47
Abies balsamea	Balsam fir	29,661	±20,560	114.03	±82.160	118.79	±85.584	1,477.88	±1,138.928	77.34
Pinus	Pine spp	23,549	±23,547	0.00	±0.000	0.00	±0.000	333.73	±333.703	0.00
Quercus macrocarpa	Bur oak	21,482	±13,930	836.73	±557.420	822.18	±547.725	7,265.25	±4,660.733	98.70
Prunus pensylvanica	Pin cherry	20,507	±17,888	38.56	±30.308	18.61	±14.630	423.26	±326.273	99.50
Alnus incana ssp. rugosa	Speckled alder	17,244	±17,241	14.44	±14.438	12.40	±12.395	370.91	±370.854	55.40
Carya cordiformis	Bitternut hickory	15,430	±8,843	66.34	±38.297	41.70	±24.074	859.08	±536.199	98.58
Acer saccharinum	Silver maple	12,785	±7,605	387.47	±306.387	203.94	±161.265	5,708.53	±4,662.786	98.15
Amelanchier arborea	Downy serviceberry	11,774	±11,773	7.47	±7.465	4.55	±4.552	1,031.36	±1,031.269	41.25
Prunus	Plum spp	10,548	±7,803	12.26	±10.658	9.49	±8.246	180.67	±162.288	99.50
Larix laricina	Tamarack	10,346	±7,633	271.73	±240.521	175.70	±155.516	4,233.46	±4,106.138	90.50
Juglans cinerea	Butternut	8,723	±7,134	89.08	±74.017	49.21	±40.891	1,040.25	±853.941	85.01
Acer nigrum	Black maple	8,097	±8,096	354.69	±354.650	199.64	±199.612	2,456.24	±2,455.938	99.50
Hamamelis virginiana	Witch hazel	6,897	±6,896	3.80	±3.799	2.24	±2.235	33.71	±33.706	18.75
Populus alba	White poplar	6,897	±6,896	25.76	±25.755	22.40	±22.396	68.87	±68.860	88.50
Prunus avium	Sweet cherry	5,887	±5,887	3.36	±3.362	2.60	±2.602	41.13	±41.129	94.50
Amelanchier	Serviceberry spp	3,449	±3,448	5.39	±5.386	4.08	±4.081	129.52	±129.498	94.50
Platanus occidentalis	American sycamore	3,449	±3,448	14.31	±14.304	6.93	±6.930	64.75	±64.740	82.50
Amelanchier canadensis	Eastern service berry	2,845	±2,845	0.00	±0.000	0.00	±0.000	56.74	±56.731	0.00
Juniperus virginiana	Eastern red cedar	1,826	±1,825	6.62	±6.614	18.38	±18.378	69.95	±69.930	99.50
Salix amygdaloides	Peachleaf willow	1,826	±1,825	32.81	±32.802	20.79	±20.779	643.39	±643.213	94.50
Sorbus	Mountain Ash spp	1,826	±1,825	70.79	±70.773	56.18	±56.169	2,305.28	±2,304.644	94.50
King		**8,255,374**	**±1,073,199**	**80,415.90**	**±10,454.067**	**61,027.10**	**±7,933.523**	**1,788,501.50**	**±232,505.195**	**71.95**

Table 37. Number of Trees and Leaf Area for Non-Native Species

Species	Common Name	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
		Number	SE	(ha)	SE	(metric ton)	SE	(metric ton)	SE	(%)
Pinus sylvestris	Scots pine	268,311	±109,116	1,531.87	±648.192	1,476.50	±624.763	49,919.56	±20,259.340	76.21
Rhamnus cathartica	European buckthorn	199,062	±57,176	339.03	±100.926	150.68	±44.856	6,910.05	±2,109.446	72.93
Acer negundo	Manitoba maple	189,479	±70,476	2,899.54	±1,216.834	2,652.59	±1,113.195	56,366.12	±29,985.079	81.06
Malus pumila	Paradise apple	127,279	±45,753	609.25	±393.086	525.26	±338.896	26,851.31	±12,660.992	46.99
Picea abies	Norway spruce	120,163	±101,728	1,603.35	±1,125.823	2,672.25	±1,876.371	19,695.77	±13,685.006	99.20
Picea pungens	Blue spruce	110,186	±37,108	1,658.48	±662.570	2,761.37	±1,103.181	23,964.04	±10,664.189	89.56
Crataegus punctata	Dotted hawthorn	59,754	±59,743	0.00	±0.000	0.00	±0.000	1,858.67	±1,858.338	0.00
Acer platanoides	Norway maple	46,615	±26,363	1,259.95	±601.163	680.06	±324.479	23,700.27	±14,075.516	93.75
Pinus nigra	Austrian pine	42,143	±26,428	400.79	±207.709	386.30	±200.202	4,664.37	±2,375.928	87.21
Pyrus communis	Common pear	38,955	±23,685	142.78	±87.995	107.42	±66.201	7,042.60	±4,245.019	76.04
Crataegus mollis	Downy hawthorn	38,197	±31,662	14.67	±11.924	11.05	±8.982	1,973.48	±1,665.179	15.98
Crataegus	Hawthorn spp	19,474	±9,554	26.90	±26.898	9.68	±9.676	373.27	±227.407	30.08
Malus	Apple spp	16,220	±11,257	34.92	±27.369	30.10	±23.596	2,475.45	±1,610.185	36.86
Pinus nigra ssp. nigra	Black pine	10,346	±10,345	492.33	±492.263	474.54	±474.470	5,896.88	±5,896.028	96.17
Morus alba	White mulberry	9,336	±6,822	333.44	±238.545	243.92	±174.503	11,574.04	±9,436.811	76.17
Elaeagnus umbellata	Autumn olive	8,925	±6,470	8.66	±6.167	4.50	±3.199	57.95	±41.608	89.59
Syringa reticulata	Japanese tree lilac	6,897	±4,815	59.61	±49.527	57.51	±47.778	1,382.28	±1,098.479	94.50
Acer tataricum ssp. ginnala	Amur maple	5,887	±5,887	6.79	±6.785	3.82	±3.819	103.91	±103.896	62.50
Acer palmatum	Japanese maple	3,449	±3,448	3.08	±3.075	1.73	±1.731	21.33	±21.323	99.50
Magnolia liliiflora	Lily Magnolia	3,449	±3,448	8.45	±8.450	5.65	±5.646	158.52	±158.501	99.50
Syringa	Lilac spp	3,449	±3,448	1.43	±1.428	1.38	±1.378	18.65	±18.652	99.50
Viburnum lantana	Wayfaring tree	3,449	±3,448	1.36	±1.362	0.71	±0.713	10.83	±10.832	99.50
Fagus sylvatica	European beech	1,826	±1,825	103.37	±103.338	51.73	±51.713	2,181.98	±2,181.380	99.50
King		**1,332,851**	**±173,271**	**11,540.03**	**±1,500.204**	**12,308.73**	**±1,600.135**	**247,201.32**	**±32,136.172**	**74.88**

APPENDIX F: INVASIVE PLANTS, PESTS, AND DISEASES

Table 38. Invasive Plant Metrics by MPAC Land Use Category

Metric/Invasive Species	Agriculture	Open Space - Natural Cover	Other - Institutional	Other Urban	Residential	King
Number of Plots	87	23	16	26	41	193
Percentage of plots with invasive	28.7	52.2	62.5	50.0	78.0	47.7
Average number of invasive plants per plot	3.2	3.5	4.0	2.4	3.4	3.3
Average invasive plant spread	1.5	1.7	1.6	1.1	1.4	1.4
Percentage of plots with Manitoba maple	9.1	17.4	18.7	20.0	19.5	14.5
Average spread of Manitoba maple	1.2	1.2	1.3	1.2	1.4	1.3
Percentage of plots with Norway maple	2.3	0	12.5	16.0	9.8	6.2
Average spread of Norway maple	1.0	0	1.5	1.0	1.0	1.1
Percentage of plots with black locust	0	0	0	0	2.4	0.5
Average spread of black locust	0	0	0	0	1.0	1.0
Percentage of plots with ivory silk lilac	0	0	0	0	4.9	1.0
Average spread of ivory silk lilac	0	0	0	0	1.0	1.0
Percentage of plots with tree of heaven	0	0	0	0	0	0
Average spread of tree of heaven	0	0	0	0	0	0
Percentage of plots with black alder	0	0	0	0	0	0
Average spread of black alder	0	0	0	0	0	0
Percentage of plots with Callery pear	0	0	0	0	0	0
Average spread of Callery Pear	0	0	0	0	0	0
Percentage of plots with common buckthorn	11.4	30.4	50.0	32.0	43.9	26.4
Average spread of common buckthorn	1.5	1.4	1.1	1.5	1.3	1.4
Percentage of plots with non-native honeysuckle	5.7	21.7	18.7	16.0	21.9	13.5
Average spread of non-native honeysuckle	1.2	1.0	1.3	1.0	1.1	1.1
Percentage of plots with winged spindle tree	1.1	0	0	0	0	0.5
Average spread of winged spindle tree	1.0	0	0	0	0	1.0
Percentage of plots with Japanese knotweed	0	0	0	0	0	0
Average spread of Japanese knotweed	0	0	0	0	0	0
Percentage of plots with dog strangling vine	4.5	4.3	6.2	4.0	12.2	6.2
Average spread of dog strangling vine	1.7	1.0	2.0	1.0	1.2	1.4
Percentage of plots with wintercreeper euonymus	0	0	0	0	2.4	0.5
Average spread of wintercreeper euonymus	0	0	0	0	1.0	1.0
Percentage of plots with lily-of-the-valley	0	8.7	0	4.0	4.9	2.6
Average spread of lily-of-the-valley	0	2.5	0	1.0	1.0	1.6
Percentage of plots with goutweed	0	0	0	0	4.9	1.0
Average spread of goutweed	0	0	0	0	2.0	2.0
Percentage of plots with periwinkle	0	0	6.2	4.0	12.2	3.6
Average spread of periwinkle	0	0	1.0	1.0	1.0	1.0
Percentage of plots with Oriental bittersweet	0	0	6.2	0	0	0.5
Average spread of Oriental bittersweet	0	0	1	0	0	1.0
Percentage of plots with Himalayan balsam	0	0	0	0	0	0
Average spread of Himalayan balsam	0	0	0	0	0	0
Percentage of plots with garlic mustard	6.8	13.0	12.5	8.0	26.8	9.8
Average spread of garlic mustard	1.2	1.7	1.0	1.0	1.3	1.2
Percentage of plots with phragmites	0	0	0	4.0	0	0.5

Metric/Invasive Species	Agriculture	Open Space - Natural Cover	Other - Institutional	Other Urban	Residential	King
Average spread of phragmites	0	0	0	1.0	0	1.0
Percentage of plots with wild parsnip	0	0	0	0	0	0
Average spread of wild parsnip	0	0	0	0	0	0

Table 39. Invasive Pests and Diseases by MPAC Land Use Category

Metric/Pest/Disease	Agriculture	Open Space - Natural Cover	Other - Institutional	Other Urban	Residential	King
Number of plots	87.0	23.0	16.0	26.0	41.0	193.0
Percentage of plots with *Lymantria dispar dispar* or spongy moth	20.5	39.1	50.0	12.0	51.2	30.6
Average spread of *Lymantria dispar dispar* or spongy moth	2.1	2.2	1.9	1.7	1.9	2.0
Percentage of plots with emerald ash borer	12.5	26.1	37.5	4.0	24.3	17.6
Average spread of emerald ash borer	1.8	2.5	2.0	1.0	1.6	1.9
Percentage of plots with Asian long-horned beetle	0	0	0	0	0	0
Percentage of plots with hemlock woolly adelgid	0	0	0	0	0	0
Percentage of plots with Dutch elm disease	3.4	4.3	12.5	0	7.3	4.7
Average spread of Dutch elm disease	1.3	1.0	2.0	0	1.7	1.6
Percentage of plots with beach bark disease	3.4	4.3	12.5	0	0	3.1
Average spread of beach bark disease	2.0	1.0	1.0	0	0	1.5
Percentage of plots with beach leaf disease	1.1	0	0	0	0	0.5
Average spread of beach leaf disease	3.0	0	0	0	0	3.0

APPENDIX G: OVERVIEW OF OPTIONAL TREE HEALTH ASSESSMENT FIELD PROTOCOL

The field data collection procedure and ratings are outlined for each criterion below. However, some indicators listed here are not always indications of poor health as certain species naturally show these signs, for example, self-pruning limbs in spruce and silver maples. In such cases, relevant indicators were not given poor scores even if observed.

Trunk Integrity Indicator

- Rot/Cavities/Wounds in the Trunk
  - Rated from very poor (1) showing signs of advanced cankers or rot to good (4) being a perfect trunk with no indications of injury, rot or wounds.
- Lean
  - Rated for lean from very poor (1) tree showing signs of extreme lean, 45° from vertical or 90°, to good (4) with no/very minor signs of lean.
- Girdling Roots
  - Rated from girdled roots from very poor (1) to good (4), no signs of girdled roots.
- Root Damaged or Exposed
  - Rated with damage are rated from very poor (1), showing signs of root damage and/or exposed roots with signs of damage to good (4), with no signs of root damage and/or exposed roots
- Fruiting bodies/Conks
  - Rated as presence/absence along the stem

Canopy Structure

- Poor stem/branch attachment
  - Rated from very poor (1), V-shaped union present with integrated bark and/or split/failure of stems to good (4), branches properly attached
- Dead/broken branches
  - Rated from very poor (1), one or more large dead/broken major branches to good (4), no dead/broken branches (small branches excluded)
- Damaged crown
  - Rated as presence/absence if over 25% of the crown is missing due to weather event/extreme pruning etc.
- Unbalanced crown
  - Rated from very poor (1), crown is extremely unbalanced to good (4), health/balanced crown

Canopy Vigour

- Dieback
  - Rated from very poor (1), significant crown dieback of over 50%, to good (4), no signs of dieback
- Defoliation
  - Rated from very poor (1), high defoliation in crown of over 50%, to good (4), no signs of defoliation
- Chlorosis
  - Rated from very poor (1), majority of foliage is chlorotic to good (4), foliage shows no signs of chlorosis
- Weak Foliage
  - Rated from very poor (1), leaves are small or malformed to good (4), leaves are standard shape and size
- Foliage Abnormalities

- Rated for presence for the following foliage abnormalities:
    - Mottling, spot or blotches
    - Marginal scorching
    - Interveinal scorching
    - White coating
    - Black coating
    - Stippling
    - Yellow/orange/white pustules
    - Foliage/twigs distorted or galls
    - Witches' broom
    - Other

Cases where there were more than 24 trees in a plot

To support data collection, a maximum of 24 trees were assessed per plot across all land uses. In natural forested areas, the field crew only assessed the health of trees that had a DBH of 5 cm or more, in line with the i-Tree Eco protocol.

Trees were selected in a manner to reduce bias. Trees were observed starting with the tree closest to north and moving clockwise. Every *x* number of trees was observed where *x* = 24 / number of trees per plot.

Dead Trees

Dead trees were included by giving the worst score for each option.

Toronto and Region Conservation Authority