Stantec

URBAN FOREST MANAGEMENT STRATEGY

City of Fredericton Urban Forest

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City of Fredericton

Prepared by:
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Acronyms / Abbreviations / Units

°C	Degrees Celsius
AR	Assessment report (IPCC)
AR5	Assessment Report 5 (IPCC)
BBD	Beech bark disease
CAO	Chief Administrative Officer
CCAP	Climate Change Adaptation Plan
CDA	Census Dissemination Area
City	Cit of Fredericton
cm	Centimetres
CP	Critical path
DBH	Diameter at breast height
DED	Dutch elm disease
EAB	Emerald ash borer
EO	Engineering and Operations Department
GHG	Greenhouse gasses
GIS	Geographic information system
ha	Hectare
HWA	Hemlock woolly adelgid
IPCC	Intergovernmental Panel on Climate Change
IV	Importance value
LiDAR	Light detection and ranging
LID	Low Impact Development
LPP	Lands for Public Purposes
m	Metres
mm	Millimetres
m^2	Square metres
NDVI	Normalized Difference Vegetation Index
NIR	Near infrared imagery
NRCan	Natural Resources Canada
PD	Planning and Development Department
RCP 8.5	Representative Concentration Pathways 8.5
ROW	Right-of-way
UGB	Urban Growth Boundary
UFMS	Urban Forest Management Strategy
UFTR	Urban Forest Technical Report

1 Introduction

Nkocicihtunen eli yut Kci-uten eliwihtasik Eqpahak otek eleyimok Wolastoqey ktahkomiq, ’kihtakomikumuwa Wolastoqewiyik, eli-wewinasik naka eluwikhasik nihtol sankewitahasuweyal naka witapeweyal lakutuwakonihkuk weci-lihtuhtit sasokiyak nisoluhkewakon 'ciw tetpi-elokimqok mawuhkacikil. Nit sip sapicuwok Kci-utenek li-nonasu tahalu Wolastoq, ewikulticik Wolastoqewiyik, “pomawsuwinuwok toleyak welinaqok naka milikok sipok.”

I/we acknowledge that the City of Fredericton is situated on traditional Wolastoqey territory. The territory of the Wolastoqiyik People are recognized in the Peace and Friendship Treaties to establish an ongoing relationship of peace, friendship and mutual respect between equal nations. The river that runs through our City is known as the Wolastoq, along which lived the Wolastoqiyik, “the People of the beautiful and bountiful river.”

1.1 Purpose

The Urban Forest Management Strategy (UFMS) is the guiding document for the management of Fredericton’s urban forest for the next 25 years. The urban forest is defined as all trees within the geographic City of Fredericton including street trees, forests, private lands, parks, and natural areas. The UFMS builds on the Urban Forest Technical Report (UFTR) (Stantec, 2023). The UFTR is a summary of the current state of the urban forest and the management of this resource. The UFMS takes the knowledge of the urban forest from the UFTR and combines it with stakeholder feedback from internal City departments and the public to determine how the urban forest should be managed.

Fredericton is the third largest city in New Brunswick (by population) and has been experiencing substantial population growth for several years. This period of growth is expected to continue for many more years. The Growth Strategy and Municipal Plan are the primary municipal policies guiding this growth. The UFMS will be implemented alongside these planning policies to ensure Fredericton remains a great place to live for this growing population.

A large portion of the Fredericton urban forest is located on private land and managed by individuals, institutions, and private companies. The portion of the urban forest located on City property is managed by the Parks and Trees Department. There are different rules and policies for management for publicly and privately owned lands but the impacts of the urban forest are felt throughout the City. For this reason the report includes the whole urban forest even though the management recommendations are mostly restricted to public lands.

1.1.1 VISION

Fredericton is a leader in urban forestry with one of the most impressive and well managed urban forests in Canada. The urban forest is a big reason Fredericton great place to live and an important part of peoples’ image of the City. The vision for this strategy is to sustain a biodiverse urban forest throughout the City for a resilient environment and healthy people.

1.2 Key Findings from the Urban Forest Technical Report

The UFTR combined several existing reports and data sets regarding street trees and some park areas with remote sensing data and ground-truthed tree inventory. The remote sensing and ground-truthing work was designed to fill knowledge gaps between existing reports and to setup a repeatable study methodology for future data collection and analysis. This section will discuss the key findings of the UFTR to provide context for the management recommendations. The UFTR is appended to this report for more detailed information (Appendix A: Urban Forest Technical Report).

1.2.1 URBAN FOREST COVER DATABASE DEVELOPMENT

The development of a canopy cover database covering the entire City (2022 boundary) was identified as a need through a gap analysis and consultation with City staff. LiDAR[1] survey data was utilized to create a model of the tree canopy in the City and was subdivided into three height classes. This canopy model was combined with an existing street tree inventory provided by the City and a plot-based sample[2] of the rural portion of the City collected by Stantec in September 2022. The resulting GIS database provides an overview of the urban forest for the entire geographic area of Fredericton (2022 boundary). The GIS database was then used to analyse canopy cover in the City by ward, neighbourhood, census tracts, etc.

Canopy cover for the City of Fredericton was 63.4% for canopy heights greater than 2 m. Urban and rural areas had canopy cover of 44.2% and 69.6%, respectively (Table 1 and

Table 2). Urban was defined as the portion of the City where street tree inventory data was available, while rural was defined as the remainder of the City. This delineation was used because it would maximize the utility of the existing datasets. These areas of analysis were later changed to the Urban Growth Boundary (UGB) to align with Planning and Development. Canopy cover in Fredericton is relatively high for urban areas when compared with other Canadian cities (Table 3). This is partially attributable to the amount of forested area that has been retained in the urban portion of the City. The canopy cover numbers in these charts include both private and public lands.

Table 1: Total Canopy Cover – City of Fredericton

Canopy Height Range	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Total	4.6	11.6	47.1	36.6

[1] LiDAR data is collected by a survey plane bouncing a laser pulse off objects below it and recording the height of each point.
[2] A plot-based sample measures several randomly selected areas and uses statistics to estimate the remainder of the data. This is done to reduce the labour in measuring every tree in an area.

Table 2: Canopy Cover Urban/Rural Split – City of Fredericton

Canopy Height Range	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Urban	3.5	8.8	32	55.8
Rural	5	12.6	52.1	30.4

Table 3: Canadian Cities Urban Forest Comparison – Canopy Cover and Targets

City (Province)	Canopy Cover (year)	Canopy Cover Target (year)
Cambridge (ON)[1]	27% (2015)	30% (2034)
Charlottetown (PEI)[2]	21% (2020)	N/A
Fort McMurray (AB)[3]	41% (2015), 25% (2016)*	25% (2025)
Guelph (ON)[4]	29% (2015)	40%
Halifax (NS)[5]	43% (2013)	(Targets per community)
Hamilton (ON)[6]	21% (2018)	30%
Kelowna (BC)[3]	16% (2013)	20%
London (ON)[7]	24% (2015)	34% (2065)
Mississauga (ON)[8]	19% (2014)	N/A
Montreal (QC)[3]	20% (2012)	25% (2025)
Oakville (ON)[9]	28% (2015)	40% (2057)
Ottawa (ON)[10]	25% (2021)	40%
Toronto (ON)[11]	27% (2013)	40% (2050)
Vancouver (BC)[12]	18% (2018)	22% (2050)
Winnipeg (MB)[13]	17% (2018)	24% (2065)

*Decline due to large forest fire

Sources:

[1] Urban Forest Innovations Inc., Beacon Environmental Ltd. 2015; [2] City of Charlottetown 2020; [3] Rosen 2019, [4] City of Guelph 2019; [5] Halifax Regional Municipality 2013; [6] City of Hamilton 2020; [7] B.A. Blackwell & Associates Ltd. 2014.; [8] City of Mississauga 2014; [9] Town of Oakville 2016; [10] City of Ottawa n.d.; [11] City of Toronto 2018;[12] City of Vancouver 2018; [13] City of Winnipeg 2022

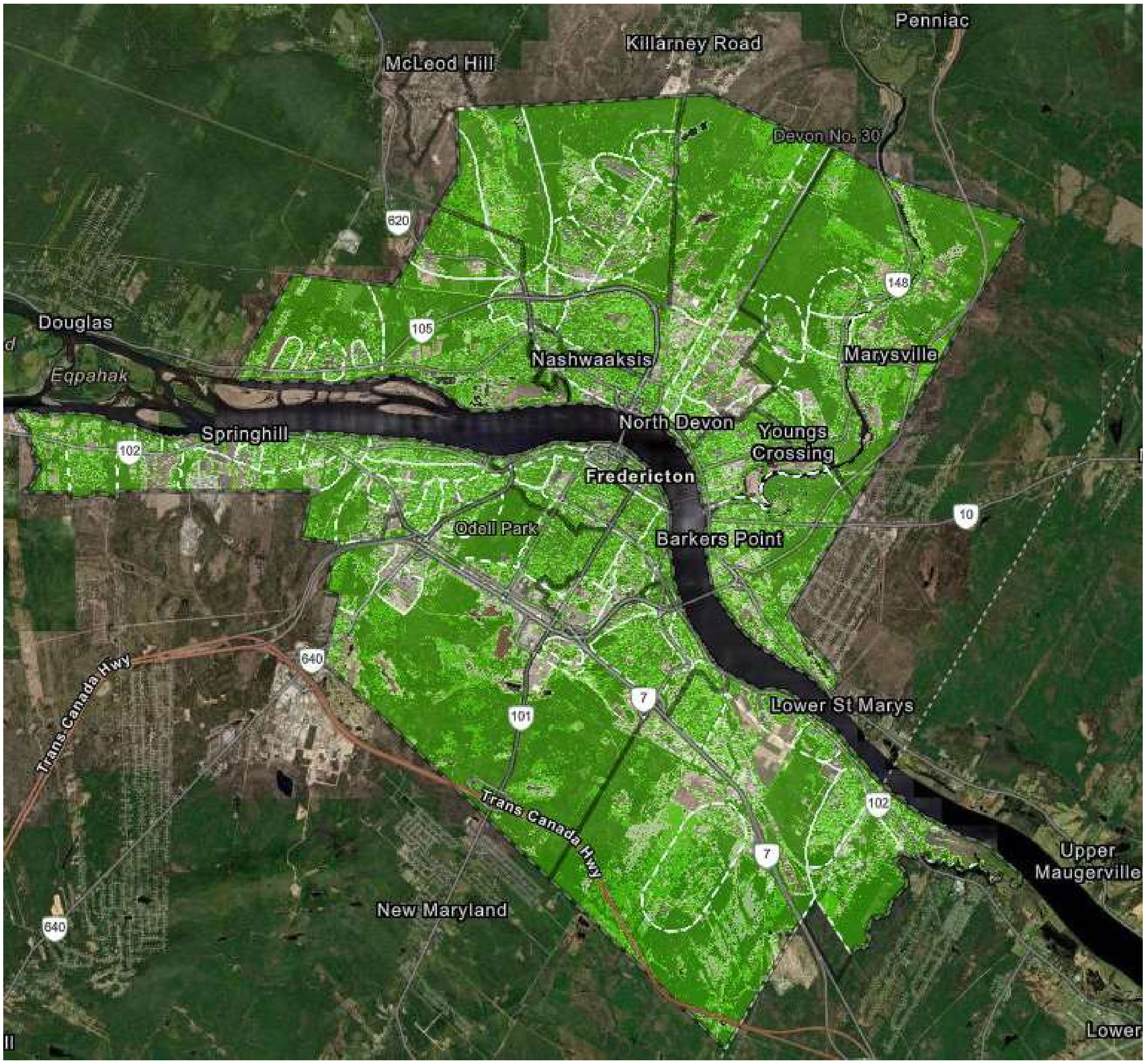

Figure 1: Spatial extents of the canopy model (green represents modelled canopy)

1.2.2 URBAN FOREST FUNCTIONS

The health and species composition of the urban forest was modelled in i-Tree software[3] (U.S. Forest Service, Northern Research Station 2022) using the street tree inventory in urban areas and the plot sample data in rural areas. More detailed analyses are available in the UFTR and appendices.

[3] i-Tree software takes in data collected on the urban forest and estimates the functions of these trees such as pollution removed. These estimates are based on research conducted on the different species of trees. The software can also estimate growth rates and other management information.

The rural forest of Fredericton has an estimated 4,616,000 trees with a density of 348 trees/ha. The three most common species are balsam fir (41.8 percent), red maple (11.4 percent) and red spruce (8.9%), with 89% of all observed trees being native to North America. In rural Fredericton, the species with the largest leaf area are red maple, silver maple, and balsam fir. Leaf area is a key metric in urban forest modelling. It is defined as the area that would be covered by arranging all the leaves on a tree, flat on the ground and measuring that area. Leaf area is a significant characteristic of an urban forest since all ecological functions of a tree including carbon sequestration and pollution removal are directly proportional to leaf surface area. Some of the key functions, or ecosystem services, provided by the rural portion of the urban forest include:

- Number of trees: 4,616,000.
- Most common species of trees: Balsam fir, Red Maple, Red spruce.
- Percentage of trees less than 15.2 cm diameter: 57.0%.
- Carbon Storage: 525 thousand metric tons ($60.4 million).
- Carbon Sequestration: 14.04 thousand metric tons ($1.6 million/year).
- Oxygen Production: 15.4 thousand metric tons/year.
- Avoided Runoff: 48.8 thousand cubic meters/year ($113 thousand/year).
- Replacement value: $2.6 billion.

These methods were repeated with the urban portion of the City. The urban forest of Fredericton has 19,288 trees and the prevalent common genus is maple (*Acer*). The three most common species are Norway maple (18.5%), red maple (12.5%), and sugar maple (12%). Approximately 59% of urban trees inventoried in Fredericton are species native to North America, with 22% of non-native trees originating in Europe and Asia. In urban Fredericton, the most dominant species by leaf area are Norway maple, American basswood, and sugar maple. Some of the key functions, or ecosystem services, provided by the rural portion of the urban forest include:

- Number of trees: 19,288.
- Tree Cover: 63.99 hectares.
- Most common species of trees: Norway maple, Red maple, Sugar maple.
- Percentage of trees less than 15.2 cm diameter: 37%.
- Carbon Storage: 9.336 thousand metric tons ($1.07 million).
- Pollution Removal: 1.88 metric tons ($8.01/thousand/year).
- Carbon Sequestration: 124.4 metric tons ($20.8 thousand/year).
- Oxygen Production: 331 metric tons/year.
- Avoided Runoff: 10.9 thousand cubic meters/year ($37 thousand/year).

- Replacement value: $35 million.

1.2.3 FORECASTING THE URBAN FOREST

To assess the sustainability of the urban forest the street tree inventory was modelled via the i-Tree Forecast module (U.S. Forest Service, Northern Research Station 2022) using the existing City target planting scenario of 500 trees planted annually. This model only includes the street trees that are managed by Parks and Trees. Two main scenarios were modelled which both considered the actual tree size and health in Fredericton. Both scenarios included a severe weather event which caused considerable damage, an emerald ash borer (EAB) infestation, continued Dutch elm disease (DED) infection, and an arrival of hemlock woolly adelgid (HWA). The difference between the models is that one considered the proactive street tree maintenance that the City currently does, and the other model used a passive management approach. A proactive approach can include regular pruning of trees, monitoring for pests, and watering newly planted trees. A passive approach usually involves responding to calls from other departments or the public to deal with dead or hazardous trees on a case-by-case basis (see Section 1.2.5).

In both scenarios the leaf area in the urban forest declines over a 30-year period. The decline is much less severe in the proactive management scenario. Table 4 shows the results of the two scenarios. The key implications of this outcome are:

- The proactive management approach by the City is valuable to the sustainability of the urban forest.
- Fredericton's urban forest has a higher than typical proportion of mature trees (Figure 2). Older trees are more prone to storm damage and natural decline. The loss of each large tree is impactful to leaf area as leaf area grows exponentially as tree size increases.

Table 4: Forecast Model Results for Leaf Area

<table>
<tr><th>Scenario</th><th>2023 Leaf Area</th><th>2053 Leaf Area</th></tr>
<tr><td>Low Mortality (Proactive)</td><td rowspan="3">472.8 ha</td><td>429.0 ha</td></tr>
<tr><td>Average Mortality (Passive)</td><td>229.5 ha</td></tr>
<tr><td>Low Mortality (1000 trees planted annually)</td><td>446.0 ha</td></tr>
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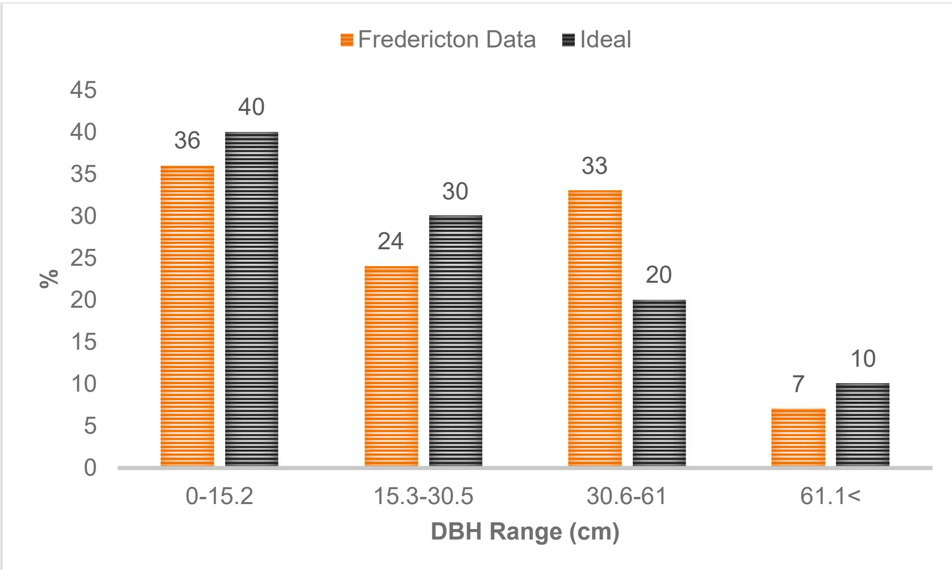

Figure 2: Fredericton Urban Tree Size Versus Ideal Population by Size

The decline in leaf area for both scenarios highlights a planting deficiency if the target is to maintain or grow the leaf area of the urban forest. The magnitude of the deficiency is difficult to estimate because the potential range of storm damage is wide, and the timing is also unknown. Substituting approximately 900 trees planted per year into the low mortality scenario nets leaf area growth at 30 years with no major storm event. With 1000 trees planted per year in the low mortality scenario the 2053 leaf area is projected at 446 ha. Extrapolating this result the City would likely need to plant 1500 – 2000 trees to maintain leaf area in the low mortality scenario. Leaf area will fluctuate based on mortality, species, and planting and should not be expected to follow a linear increase.

If the forecast is completed using Fredericton's actual mortality rate (approximately 250 tree removals per year) from the last several years, the outlook for sustainability of the urban forest leaf area is more positive. Under this scenario the existing replanting rate of 500 trees per year approximately sustains the leaf area over the 30-year period. This is another example of how important the City's proactive approach is in this context. However, the existing mortality rate does not include any increases for the recent EAB infestation, and even the best maintenance cannot halt mortality in the aging population. Therefore, an increase in planting is advisable at this point to allow leaf area growth in the small trees prior to eventual losses in the mature trees. The existing proactive management approach will remain very important to maintain low mortality rates. Particularly given that climate change will likely increase mortality rates due to increased storm damage, change in precipitation patterns, and additional invasive pests.

1.2.4 SPECIES DIVERSITY

Species diversity contributes to resiliency to climate change, native and introduced pests, and development pressures impact individual species in different ways. Species diversity can hedge against these changes and contributes to ecosystem function. One way to quantify diversity is through importance value (IV) which is a sum of the percent a species within the population and the percent leaf area in the urban forest. This is a relevant metric because the percent of the population demonstrates the vulnerability of the urban forest, and the percent leaf area shows the magnitude of the impact a species has on ecological benefits such as carbon sequestration, etc. A more diverse population tends to be more resilient to pests that target specific species or genera[4] because a smaller number will be susceptible. Table 5 summarizes the importance value of the most common rural and urban species in Fredericton.

Table 5: Most Important Species in Rural and Urban Fredericton

Common Name	Rural IV	Urban IV
Balsam fir	51	-
Red maple	34	22
Silver maple	16	8
Red spruce	15	-
Eastern hemlock	8	-
Norway maple	-	39
Sugar maple	-	22
Littleleaf linden	-	21
Green ash	-	19
Other species	76	69
Total	**200**	**200**

Within the urban portion, maples comprise 91 IV. The relative importance of red and silver maples is less in the urban portion than the rural portion, however a large contribution from Norway maple and sugar maple increases the maple genus proportion. Linden (*Tilia*) and green ash (*Fraxinus*) are the other two genera represented in the top five species by urban importance. The top three urban genera contribute 131.3 IV out of a total 200 IV (66%), representing low diversity in terms of ecological services. Maples are not currently threatened by major pests and make up a high proportion of the Acadian forest. Therefore, it is not surprising to see maples make up such a high proportion of the urban forest, but it could be a future vulnerability. The typical guideline is to not exceed 30% of trees from a single family, 20% from a single genus, and 10% from a single species. Figure 3 shows the current breakdown of population by family.

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[4] Tree species are related in varying degrees of separation. The three levels of separation important to urban forest management are species, genus, and family. Red maple (*Acer rubrum*) is part of the *Acer* genus which includes all maples including Norway, sugar, silver, etc. The first word in the Latin name is the genus and the second word is the species. The name for all maples start with *Acer,* but all species have a unique species name. Maples are a part of the soap berry family (*Sapindaceae*) which includes several other genera (plural of genus). Beech and oak are both in the family *Fagaceae* which means they are more closely related than to species of a different family like maples.

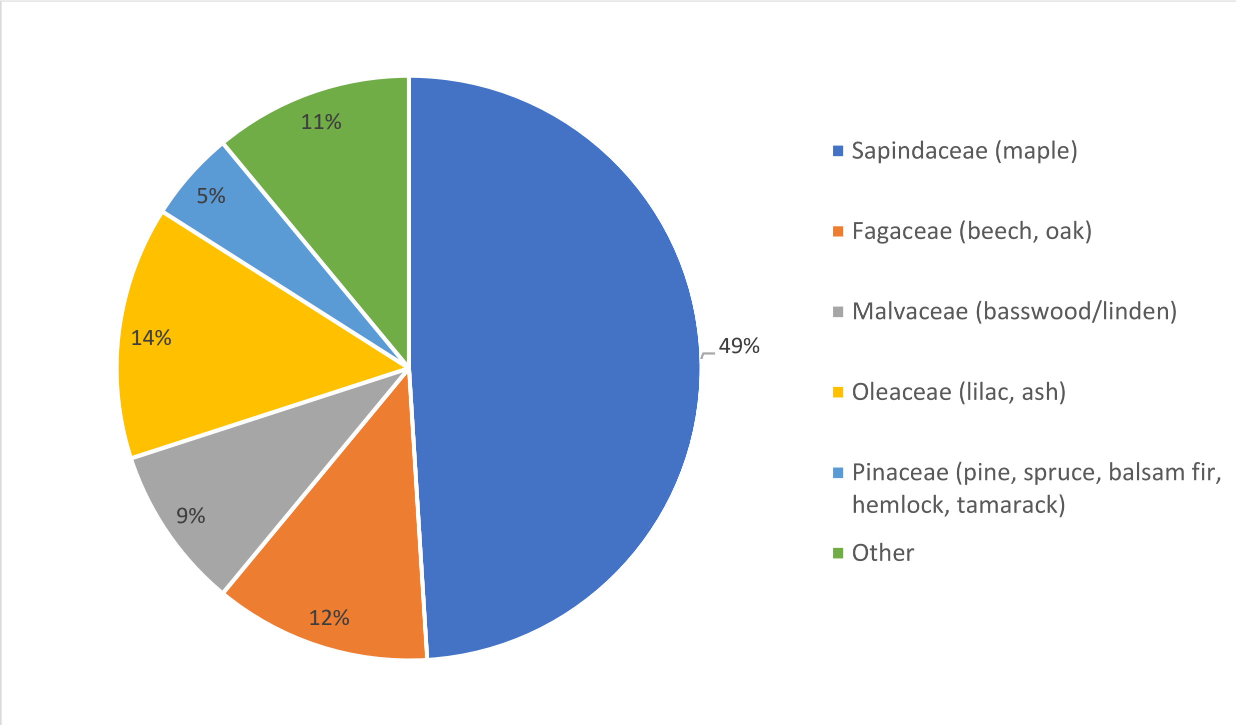

Figure 3: Urban Tree Diversity by Family

1.2.5 URBAN FOREST MANAGEMENT

Urban forest management can encompass a wide range of actions including tree removal, planting, pruning, pest management, development of by-laws or policies, and planning activities. At one end of the spectrum is wholly reactive management where trees are felled or cleaned up when they fail but no other actions are taken. At the other end would be a management plan that includes pest management, proactive pruning cycles, and in-depth planning exercises. Fredericton uses a proactive approach to manage street trees, and a more passive approach in woodlots and natural parkland.

1.2.5.1 Staff

Parks and Trees staff include foresters, arborists, forest technicians, and horticultural technicians. This team plants and maintains trees, prunes street trees in a seven-year rotation, monitors pests, and treats infested or infected trees for DED and EAB. Compared to other municipalities, Fredericton is more proactive with their management style and contracts out less work. In many municipalities large-scale removals and some street tree pruning are often performed by contractors. Fredericton's ability to handle urban forest management work without external contractors is likely dependant on the continuing proactive management of the forest. The pruning cycle allows for more consistent work, helping to avoid labour requirement peaks following storm events, which are typically required to be filled by external contracts in many municipalities.

1.2.5.2 Pest Management

EAB was detected in Fredericton in February 2021. Since its detection the City has adopted a proactive management approach, which includes selecting trees as candidates for TreeAzin® injection. TreeAzin® is a pesticide that kills EAB when they feed on the tree. Tree selection is based on percentage of dieback with trees with less than 1/3 canopy dieback selected for injection. This is a very proactive approach which some municipalities have used. This approach maximizes ash retention and lengthens the period of mortality rather than experiencing a mortality peak approximately 5 to 10 years into an infestation.

Elm trees have a special history and cultural significance in Fredericton. The Parks and Trees division is responsible for the identification and treatment of white elm trees (*Ulmus americana*) on City property within the Dutch elm disease management area, which includes the neighbourhoods of the Downtown Core and Devon. The City uses DutchTrig® which is an annual injection intended to immunize the tree from DED. The injections are partnered with a monitoring program which identifies trees infected with DED and determines which require removal.

1.2.5.3 Tree Planting

City crews plant approximately 500 trees annually with planting occurring in spring. Trees are maintained through three seasons by a watering crew. The objective of this program is to plant a tree in front of every residential property or business if site conditions are appropriate. Tree species are selected based on the site constraints with small stature trees planted where overhead wire conflicts exist. Where possible, trees are planted in advance of removing unretainable ash trees to proactively offset canopy loss.

Parks and Trees has broken ground on an exciting new zero-carbon greenhouse project. When complete, the greenhouse will support the City's street and park tree planting program, providing better planting stock of native tree species grown from locally sourced seeds. This will reduce the carbon footprint of transporting nursery trees from greenhouses out of province. By using seeds collected from local sources and growing them in a City-owned greenhouse located in Fredericton, the trees will already be optimized to the local climate when planted in ROWs and will not be at risk of transporting non-native pests or diseases to the City from out of province.

1.2.5.4 Policy and Management

By-Law No. L-18 A By-Law for the Management of Trees Within the City of Fredericton. Enacted January 13, 2020, the by-law defines the authority of the City over publicly owned trees and some limited authority over privately owned trees. This is the key policy providing protections to the trees of the urban forest. The prohibitions, exemptions, and authority given to the City are all in agreement with what would be expected of a City of Fredericton's size.

The next level of tree protection would be a by-law providing prohibitions and exemptions of trees located on private property and a policy defining the expectations of tree retention through development. In New Brunswick this would be implemented via the Zoning By-law per the (provincial) Community Planning Act (Subsection 53(2)(vii) and (xiv)). These are common in larger cities with set canopy targets and strong development pressures. These by-laws vary in detail regarding the minimum protected size of tree, protections of certain species, and number of trees but all generally require some type of permit for a landowner to remove trees. Two by-laws with two standards for tree permits are common in many cities with urban centres and large rural areas. In some cases, the by-law requirements are only applied to the urban portion of a city.

Administration of tree protection bylaws and permit processes can have an important impact on the workload of urban forestry departments. Varying levels of dedicated staff are required depending on the volumes of permits submitted with some departments understaffed. This can lead to frustrated applicants and workplace morale issues. These issues are important considerations for any bylaw changes.

1.2.5.5 Urban Planning

The specific urban planning policies from the *Fredericton Growth Strategy* and *Imagine Fredericton: The Municipal Plan* are referenced in Section 1.2 of this report. The policies can be summarized as below.

- Policies requiring or encouraging street tree planting in development areas and existing neighbourhoods. This is the most frequent area of policy related to trees in the documents.
- Policies encouraging retention of mature, healthy trees.
- Policies encouraging the sustainable management of all trees in the urban forest and growth of the urban forest.

Specific targets noted in the policies include an increase in street trees and an increase in tree canopy. This is likely feasible when strictly considering the numbers of street trees. There is adequate plantable space to increase the number of street trees under existing conditions. Future development will increase the plantable space by constructing new roads with boulevards in some locations.

The *Growth Strategy* identifies 200 ha of undeveloped land within the urban area and an additional 400 to 525 ha in the rural area required to accommodate the 2041 population projections. A further 45.2 ha are projected to accommodate employment growth in the following land uses: retail and commercial service employment (18.9 ha), institutional employment (12.8 ha), industrial employment (11.0 ha), and commercial office employment (2.5 ha). Currently there is a total canopy cover greater than 2 m in height of 81.7% (per 2015 LiDAR) in areas zoned as Future Development. It would be expected that post development, this figure would shrink to 20-30% considering the canopy cover in development areas reported by comparator cities. Even accounting for more street tree planting this amount of reduction is not typically feasible to offset the planting numbers in boulevards alone.

1.2.5.6 Natural Areas

Most of the Parks and Trees planning, maintenance, and planting efforts are expended on urban street trees and maintained grass areas of parks. Trees are cleared from official trails as required by hazard level or to clear trails. Management of these areas would therefore be considered more passive in comparison to the rest of Fredericton operations. This is similar to many municipalities with split urban and rural areas.

1.2.6 INVASIVE FOREST PEST VULNERABILITY

The vulnerability of an urban forest is impacted by the ability of pests to proliferate, the presence of pest vectors, and the presence of host species. There are many native pest species, as well as several invasive species, which are present and invasive species that have the capability to expand their range into Fredericton. Interactions between these species and their hosts are likely to change along with climate and management activities. Known native and invasive pests were analysed for their potential impact and the potential changes in impact due to climate change. The UFTR contains a matrix with all the considered species and a brief account of methods.

Several forest pests and diseases are likely to impact Fredericton in the near to medium term in addition to the existing challenges currently being managed. EAB is the most significant emerging threat as ash trees have a high importance value within the urban forest and rural areas. City staff have been proactively monitoring for the arrival of EAB and are familiar with the management principles having already begun treatment of suitable trees. The potential complication of ash yellows could be significant but there is little previous experience to draw on with that situation. The impacts of EAB are likely to be very significant in areas that are not managed as it is not feasible to treat these trees.

HWA, beach bark disease (BBD), and butternut canker are likely to have an impact on the woodlots and rural portions of the City. It may be possible to mitigate some of the impacts within urban woodlots through management, however there is likely to be increased mortality.

1.2.7 EXISTING URBAN FOREST DIVERSITY

Existing species in the urban canopy were reviewed for prevalence to understand the representation at species, genus, and family levels. The data used to complete this exercise were the street tree inventory provided by the City. The prevalence of species, genus, and family were reviewed with the industry best practice guideline of 10% species, 20% genus, and 30% family. Three species of maple (Norway, red, and sugar) had prevalence proportions greater than 10%. No other species exceeded 10%. Maples (*Acer*) account for 49% of diversity at the genus level – no other genus exceeded 20%. *Sapindaceae* (the family which includes maples) accounts for 49% of family diversity – no other family exceeded 30%.

1.2.8 PLANTED SPECIES SUITABILITY

The suitability of trees for the Fredericton urban forest was assessed considering suitability for urban conditions, projected climate suitability, and additional limitations. Species that have been suggested in previous reports, species planted recently by the City, and species that are commonly used landscape trees in other similar regions were tested against these criteria.

1.2.8.1 Projected Climate Suitability

The projected climate of Fredericton was modelled using scenarios adopted by the IPCC for AR5 that are based on various future greenhouse gas concentration trajectories. The highest Representative Concentration Pathways (RCP) 8.5 was used for the mode because current global GHG concentrations are closer to following the RCP 8.5 pathway, despite global agreements/targets for GHG emissions reductions. The following Table 6 shows the model outputs relating to plant hardiness for two time periods.

Table 6: Summary of Project Change in Climate Variables Associated with Tree Habitat Suitability

Climate Variable	Baseline (1981-2010)	Near Future (2050s)	Far Future (2080s)
Annual Mean Temperature (°C)	5.6	8.5	10.6
Minimum Temperature of Coldest Month (°C)	-15.0	-10.7	-7.8
Maximum Temperature of Hottest Month (°C)	25.5	28.6	30.9
Annual Precipitation (mm)	1070	1155	1204
Precipitation of Warmest Quarter (mm)	256	262	270
Precipitation of Coldest Quarter (mm)	263	298	316

(Source: Natural Resources Canada, 2022)

Natural Resources Canada has utilized projected climate data to develop potential plant species distribution maps for the future. These maps are based on the climate parameters of know ranges of each species. These models were used to assess the suitability of existing tree species in Fredericton, as well as the suitability of trees from warmer ecosystems. Refer to Appendix A: Urban Forest Technical Report.

for detailed methods and results relating to climate projections. Figure 4 provides an example of shifting climate suitability for Norway maple which currently has the highest importance value in Fredericton's urban forest.

(Source: NRCan Composite AR5 ANUCLIM model)

Figure 4: Climate suitability for Norway maple: 2011-2040, 2041-2070, 2071-2100

The following Table 7 contains the recommended species by category. Both urban and natural/rural species have been included. Refer to the UFTR for further details on classifications. Trees with an asterisk and bold font are considered suitable for some street tree applications. Consideration of site-specific moisture soil moisture, sun exposure, and growing space is required to decide on the appropriate species from this list.

Table 7: Species and Planting Frequency Recommendations

Recommended Use	Frequency of Use	Species
Street	Increase current planting rate	Catalpa *(Catalpa speciosa)* Hackberry *(Celtis occidentalis)* Ginkgo *(Ginko biloba)* Honey locust *(Gleditsia triacanthos)* Kentucky coffee tree *(Gymnocladus dioicus)* Black walnut *(Juglans nigra)* Ironwood *(Ostrya virginiana)* Sycamore *(Platanus occidentalis)* London plane tree *(Plantanus x acerifolia)* White oak *(Quercus alba)* Scarlett oak *(Quercus coccinea)* Burr oak *(Quercus macrocarpa)* Black oak *(Quercus velutina)*
	Maintain current planting rate	Serviceberry *(Amelanchier canadensis)* Chokecherry *(Prunus virginiana)* Pin oak *(Quercus pallustris)* Red oak *(Quercus rubra)* Japanese lilac *(Syringa reticulata)* Basswood *(Tilia americana)*
	Decrease current planting rate	Norway maple *(Acer platanoides)* Red maple *(Acer rubrum)* Silver maple *(Acer saccharinum)* Sugar maple *(Acer saccharum)* White ash *(Fraxinus americana)* Black ash *(Fraxinus nigra)* Green ash *(Fraxinus pennsylvanica)* Swamp white oak *(Quercus bicolor)* Northern pin oak *(Quercus ellipsoidalis)* Linden *(Tilia cordata)*
	Trial	Buckeye *(Aesculus glabra)* Yellow wood *(Cladrastis kentuckea)* Sweetgum *(Liquidambar styraciflua)* Tulip tree *(Liriodendron tulipifera)* Tupelo *(Nyssa sylvatica)* Elm *(Ulmus americana)* (DED resistant cultivars)
Parks and Natural Areas*	Increase current planting rate	Eastern red cedar *(Juniperus virginiana)* Larch *(Larix decidua)* (park only) Norway spruce *(Picea abies)* Colorado spruce *(Picea pungens)* (park only) Austrian pine *(Pinus nigra)* (park only) Red pine *(Pinus resinosa)* White pine *(Pinus strobus)* Black cherry *(Prunus serotina)* Slippery elm *(Ulmus rubra)* Various fruit trees in select areas for fruit forests

Table 7: Species and Planting Frequency Recommendations

Recommended Use	Frequency of Use	Species
	Maintain current planting rate	Tamarack *(Larix laricina)* Aspen *(Populus tremuloides)* Pin cherry *(Prunus pensylvanica)* Staghorn sumac *(Rhus typhina)* Black willow *(Salix nigra)* Cedar *(Thuja occidentalis)* Hemlock *(Tsuga canadensis)*
	Decrease current planting rate	Balsam fir *(Abies balsamea)* Manitoba maple *(Acer negundo)* Black maple *(Acer nigrum)* Striped maple *(Acer pensylvanicum)* Mountain maple *(Acer spicatum)* Yellow birch *(Betula alleghaniensis)* White birch *(Betula papyrifera)* Grey birch *(Betula populifolia)* Beech *(Fagus grandifolia)* Butternut *(Juglans cinerea)* White spruce *(Picea glauca)* Black spruce *(Picea mariana)* Red spruce *(Picea rubens)* Jack pine *(Pinus banksiana)* Largetoothed aspen *(Populus grandidentata)*
	Trial	Heartleaf birch *(Betula cordifolia)* Cherry birch *(Betula lenta)* Blue beech *(Carpinus caroliniana)* Bitternutt hickory *(Carya cordiformis)* Pignut hickory *(Carya glabra)* Shellbark hickory *(Carya laciniosa)* Shagbark hickory *(Carya ovata)* Pecan *(Carya illinoinensis)* Chestnut *(Castanea dentata)* (canker resistant) Redbud *(Cercis canadensis)* False cypress *(Chamaecyparis thyoides)* Flowering dogwood *(Cornus florida)* Sassafrass *(Sassafras albidum)*
*Street trees can be used in parks and natural areas if they are native or not in a location where aggressive invasion of adjacent natural areas is likely. Grow native species in natural areas using the most local seed sources possible.		

1.2.9 SUMMARY OF KEY FINDINGS

This report developed an understanding of the existing urban forest condition and the state of urban forest management in Fredericton, NB. The findings of this report will inform the development of an urban forest management strategy with input from stakeholders. Discussion points are presented here as closing thoughts for initiating a management strategy. The intent is to present some of the most important findings to guide the initial stages of the management plan development.

The state of the urban forest in Fredericton is overall healthy. Canopy cover measured via LiDAR is substantially greater than most peer Canadian Cities. The distribution of age classes appears to be sustainable, and the spatial distribution of canopy coverage is relatively equitable when reviewed over several scales. There are neighbourhoods with low canopy coverage that would benefit from additional planting efforts (Section 2.3).

Management of the urban forest is proactive in terms of maintenance, pest management, and replanting efforts. This approach will be beneficial in the near term as the City is likely to face some additional pest challenges including EAB, BBD, and HWA. Fredericton has been a leader for many years in DED management and is well positioned to meet the first challenges of EAB. The impacts of EAB will be seen in both the urban and rural environments as ash are common street and natural woodland trees in New Brunswick. BBD and HWA impacts will be more focused on natural areas as beech and hemlock are not common urban species. Mature hemlock are prevalent in Odell Park and HWA has the potential to significantly impact these trees.

Urban forest biodiversity is good in terms of species presence but low when assessed for species prevalence. There is an overreliance on maple species beyond what is estimated in the rural area. Climate models suggest that maples will continue to grow well for the near term in the City, however this could be a significant vulnerability. Norway maples can also present a threat to native forest ecosystems, so caution is needed where that species forms part of the urban forest. No significant threat to maples has been identified for Fredericton in the near term, however any significant mortality event impacting maple trees would have a very negative impact on the urban forest. As such, building resilience through diversity will be important.

Climate change is projected to make Fredericton warmer and increase annual precipitation. Conditions will become less suitable for several native species but more suitable for some more southern species. The net change will likely increase the number of appropriate street tree species. The impacts to the forested areas are not fully understood but species migration should be monitored to prevent stand decline in City woodlots. There is also a heightened likelihood of severe weather events that may cause damage to Fredericton's trees. Current pruning practices are likely to mitigate some of these impacts on street trees, however, impacts to rural forests may increase.

Planned City population growth will likely be the largest impact to the City's canopy cover in the short term. Maintaining high canopy coverage in the City is important to Fredericton's status as a liveable City. Trees are an important cultural feature in Fredericton and will be an important source of resiliency in supporting population growth. Smart, collaborative management with planning and engineering City departments will be critical.

1.3 Knowledge Gaps

The UFTR was developed with predominantly existing data sources supported with some project specific field data. There were a few data limitations that were noted during the analysis of the figures and these gaps were recommended for further study in the next phase of developing the UFMS. The following Section 2 will describe the methods used to address these gaps and the outcomes of the work.

1. The LiDAR and aerial imagery used to develop the canopy model were created in 2015, and 2018 respectively. The City has experienced substantial development activity since 2015 so there was concern that older data may not be relevant. Current LiDAR data was beyond the budget of the project however, the gap could be partially addressed using near infrared imagery (NIR) which is much more affordable. This process is called an NDVI (normalized difference vegetation index). The NDVI analysis conjunction with the canopy model could provide an adequate measurement of canopy change from 2015 to the image date.

2. As a result of local governance reform, the City boundary changed in 2023 during the finalization of the UFTR. Additional LiDAR processing should be undertaken to expand the canopy model into the newly annexed lands.

3. Land surface temperature (heat island) measurements should be taken to study the equitability of canopy distribution in Fredericton. These measurements should be reviewed with demographic data as one factor in a planting prioritization framework.

2 New Technical Work

Studies to address the knowledge gaps identified in Section 1.3 Knowledge Gaps were undertaken as a part of the UFMS work. This included demographic analysis combined with land surface temperatures, expansion of the canopy model to the 2023 boundary, and canopy change analysis. These studies will be addressed in this section in simplified form with additional technical information provided in the appendices.

2.1 Canopy Model Expansion

As noted above, the City of Fredericton boundary increased in 2023 during the finalization process of the UFTR. The methods used to generate the canopy model were based on LiDAR data provided by the Province. Therefore, data acquisition was not impacted, and the additional areas only required additional data processing. The canopy model expansion followed the methods of the original canopy model creation. These methods are available in the UFTR.

The expanded canopy model was reviewed in conjunction with various administrative boundaries to update the canopy cover numbers for these areas. The updated canopy cover numbers are summarized in the following tables (Table 8 and Table 9). Areas that were not impacted by the expansion were not updated. The Urban Growth Boundary (UGB) was included as a new administrative boundary as it became the delineation between rural and urban portions of Fredericton.

Table 8: Total Canopy Cover – City of Fredericton 2015

Canopy Height Range	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Total	5.6	15.4	46.3	32.7

Table 9: Canopy Cover Urban/Rural Split (by Urban Growth Boundary) – City of Fredericton 2015

Canopy Height Range	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Urban Growth Boundary	3.3	7.8	34.9	54.0
Non-Urban Growth Boundary	7.0	19.9	53.0	20.1

The results indicate an increase in total canopy cover for the City. This is the expected result as the expanded areas includes many forested areas with the most notable exception being the airport. The area within the UGB has less canopy area than the area outside the UGB which was also expected based on the previous rural/urban divide. The reason for changing the urban/rural delineation was to align with planned growth which is focused on the area within the UGB.

2.2 Canopy Change Analysis

The main data source for the canopy cover model was 2015 LiDAR provided by the Province. This meant that the canopy model was a representation of the canopy in 2015 rather than 2023. There has been substantial development within Fredericton since 2015 so there was a need to understand change over that period. LiDAR data procurement is expensive on a city-scale so an alternative method for change analysis based on aerial imagery was utilized. The selected method was NDVI (normalized difference vegetation index) which detected areas of loss when overlaid with the canopy model (Appendix B: Canopy Change Detection Methods). The following Table 10 summarizes the change in canopy cover within the UGB from 2015 to 2023. Table 11 shows the losses per canopy height range in area and percentage. Note the percentages are higher in Table 11 because they are taken from the total canopy area not the total land area of the UGB.

Table 10: Canopy Cover Within Urban Growth Boundary (2023)

Canopy Height Range	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Urban Growth Boundary	3.2	7.4	33.9	55.5

Table 11: Canopy Cover Area Loss Within Urban Growth Boundary (2023)

Canopy Height Range	Total Canopy Area (2015)	Canopy Loss (2015-2023)	Canopy Loss % (2015-2023)
2–5 m	252.4 ha	8.6 ha	3.3
5-10 m	585.7 ha	19.1 ha	3.3
>10 m	2669.6 ha	87.4 ha	3.4
Total	3507.6 ha	115.1 ha	3.3

The results of the canopy change analysis show that Fredericton did lose canopy within the UGB between 2015 and 2023. The losses were proportional across the three canopy height ranges, but the total area of loss was highest in the >10 m range. The canopy cover percentage within the UGB (45.5%) remains in excess of most comparator City targets. While the total canopy loss was measured at 3.3% over the last 8 years, the City's population has grown by over 7% (population number provided by the City). The City of Fredericton is a growing city experiencing significant densification to support greater housing availability and other urbanization goals such as active transportation. Areas of canopy loss through construction can regenerate with replanting and increased planting within the UGB supports long-term canopy cover.

2.2.1 PLANTABLE AREA

To assess the potential for planting within the UGB, a plantable area analysis was completed. This was done by clipping the NDVI and LiDAR to a publicly owned lands file provided by the City. Areas of vegetation that did not include canopy were highlighted and then filtered to only areas greater than 10 m^2

to remove areas too small for tree planting. The results capture potential street tree planting locations as well as parkland and natural areas. These plantable areas need to be ground-truthed to generate a planting list, as many planting sites will be undesirable because they are used as recreational space or have insufficient soil volume for example. An example of plantable area captured is show in Figure 5 with the plantable area highlighted in red. In this example ground-truthing would eliminate street corner planting sites for sightline concerns, and potentially sites in conflict with utilities. The number of plantable spaces available (before ground truthing) exceeds the number of trees that could be planted at the current rate for the next 10 years. An increased planting effort and reforestation of naturalized areas could offset some losses in other areas of the City.

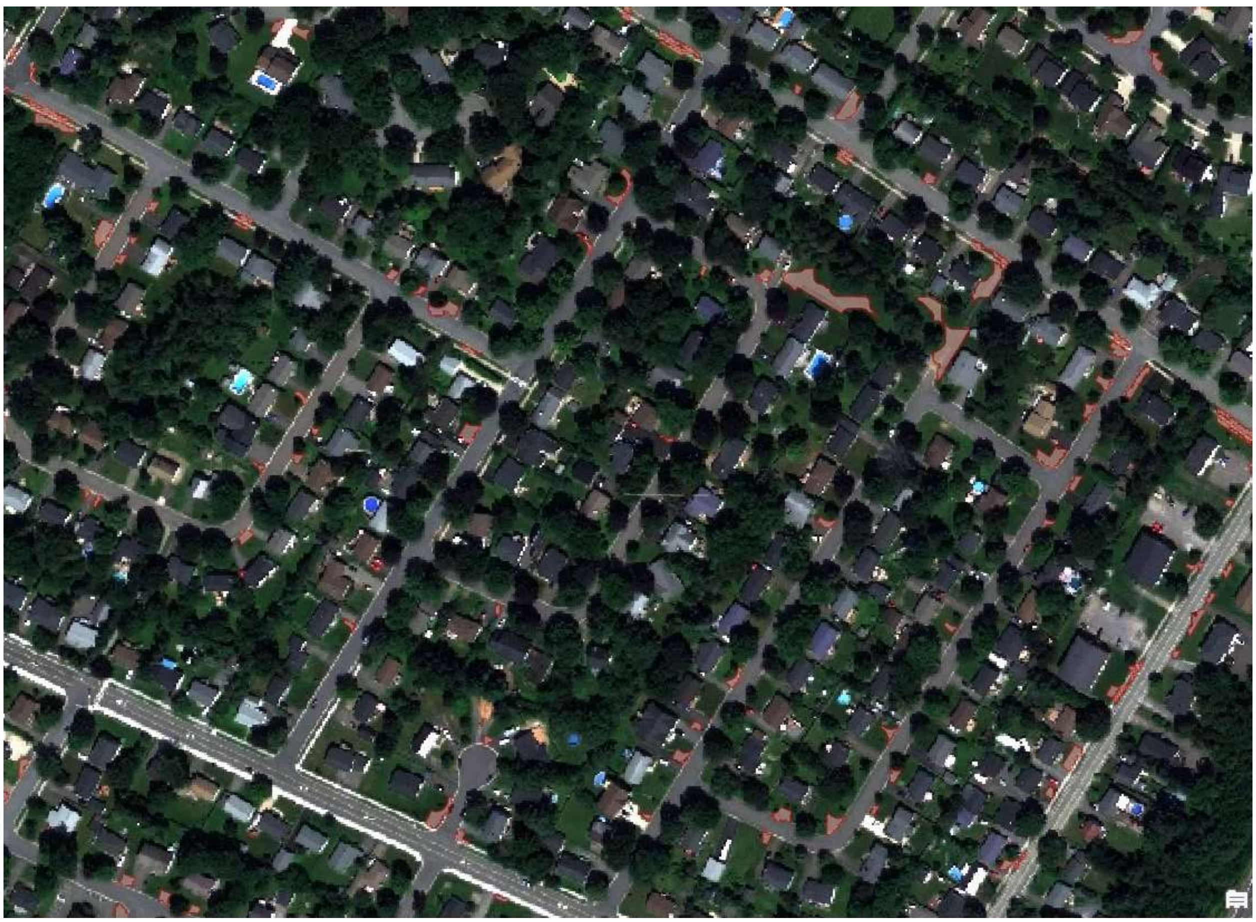

Figure 5: Plantable Area

2.3 Heat Island Analysis

The urban forest plays an important role in the temperature of a city. Areas with canopy cover tend to be cooler than areas with asphalt or buildings. Forested areas can be even cooler as less of the sun's radiation reaches the surface. Temperatures can vary by more than 10 degrees between nearby locations based on presence or absence of canopy. Areas of localized heat are referred to as heat islands and common areas where this occurs includes large parking lots and densely built downtown areas. Heat islands can discourage people from using recreation facilities, walking to destinations, increase cooling energy demands, and even impact health and wellbeing.

A measurement of land surface temperatures was undertaken using Landsat (NASA satellite program) imagery captured June 1, 2023. The recorded daily high temperature for that day was 31 °C. The methods used to measure the land surface temperatures are included in Appendix C: Heat Island and Demographic Analysis Methods. The result of that study showed that there is an unequal distribution of heat islands throughout the City. Neighbourhoods that are near the St. John River, or have established street tree canopy, or have large, forested parks have lower temperatures. Conversely, areas with large parking lots and wide roads have higher temperatures (Figure 6).

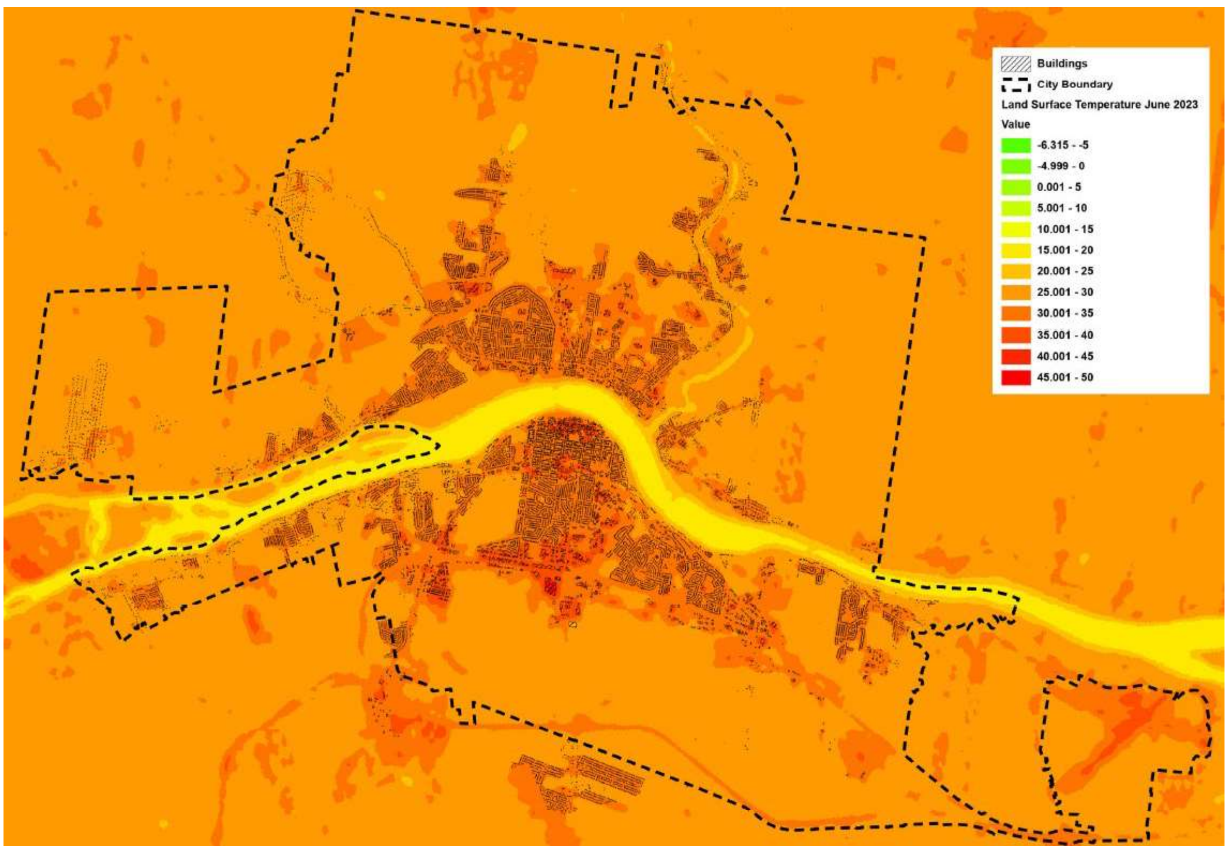

Figure 6: Land Surface Temperature[5]

The vulnerability of a population to the effects of a heat island depends on factors including existing medical conditions and age. Socioeconomic factors such as income, housing type or status, and

[5] A larger copy is included in Appendix C: Heat Island and Demographic Analysis Methods for more detailed review. The important idea here is the river and treed areas are cooler and heat islands appear around the built-up areas but some heat islands are more severe and often coincide with very large parking lots.

education level are often used as indicators of vulnerability at a population level where sensitive medical data is not available. A socioeconomic index was developed using census dissemination areas (CDAs - the smallest available census area). Median values for the CDAs were calculated for several census fields including education level and annual income. CDAs which compared favourably compared to others in the City were assigned a lower vulnerability while CDAs that compared poorly were assigned higher vulnerability.

The two datasets were then analysed to determine areas that had high exposure to heat islands and also were highly vulnerable to heat island effects. The results are shown in Figure 7 and in Appendix C: Heat Island and Demographic Analysis Methods. The heat island effect should be looked at as a climate change vulnerability as Table 6 shows the projected mean and peak monthly summer temperatures as increasing in the future. Building resilience and mitigating this effect will depend partially on developing canopy cover in these areas. This is one factor that should be considered when prioritizing future tree planting and protection of existing trees.

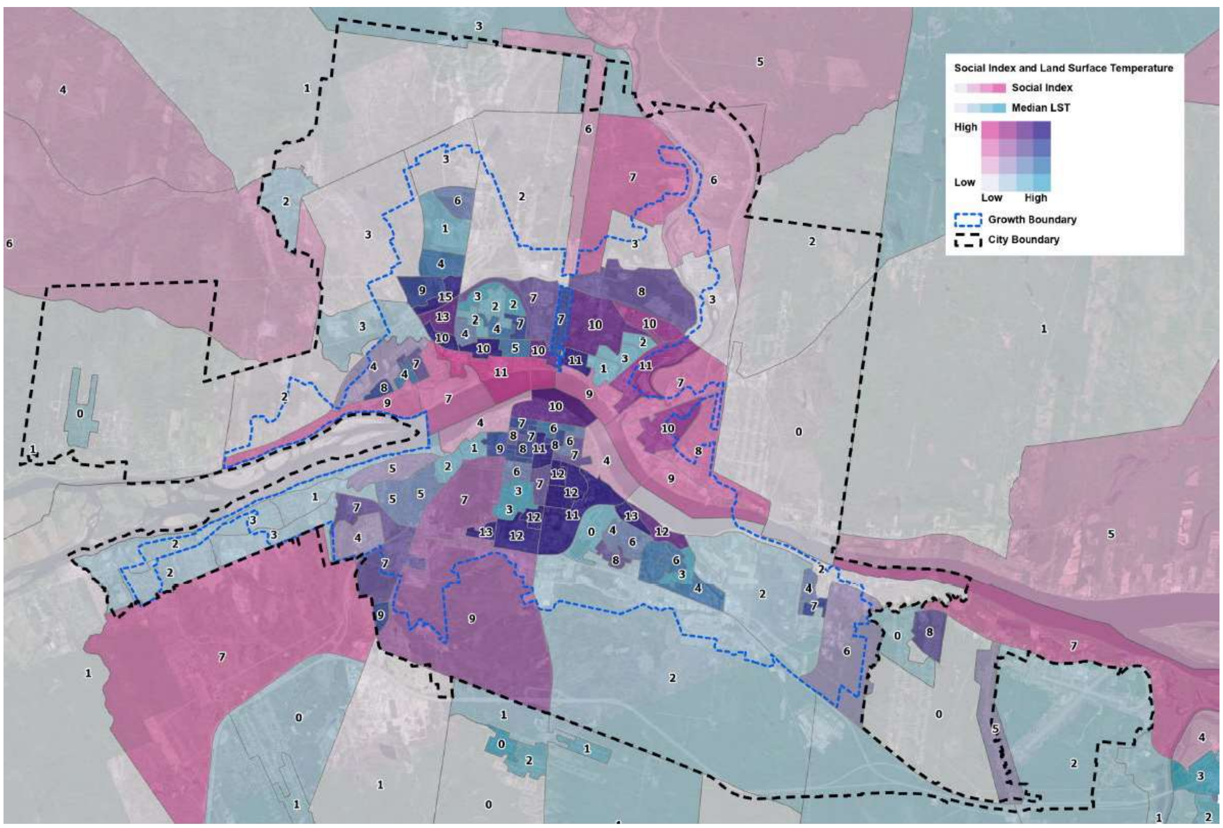

Figure 7: Social Index and Land Surface Temperature[6]

[6] A larger copy is included in Appendix C: Heat Island and Demographic Analysis Methods for more detailed review. There are 2 datasets combined in this image: median land surface temperature is a blue gradient, and the social index is a pink gradient. Where social index values (high numbers) indicate vulnerability and the median land surface temperature is high the gradients combine to make purple.

2.4 Fire Preparedness

Wildfires are a concern in cities with forested rural areas such as Fredericton. Recent fires in Halifax, Yellowknife, Jasper, and Fort McMurray have increased public awareness of this issue, All forests can be impacted by wildfires, but some types of forest are at a greater risk of catching fire. Forests with high proportions of conifers such as white, black, and red spruce are more likely to burn, and even burn out of control, when compared to deciduous forests. This is partially due to the drier conditions in many conifer-dominated forests and partly due to the flammability of resin-packed conifer wood. Some conifers (such as Jack pine) depend on fires to reseed.

While wildfires may be a part of some forest ecosystems, they are incompatible with urban forests because of the hazards they pose. The long-term stewardship of Fredericton's forest, including the restoration of mixed wood Acadian forest, is likely to reduce the risk of wildfires within the City. Wildfires within municipal limits are the responsibility of the municipality per Provincial law. Within Fredericton, wildfires are the responsibility of the Fredericton Fire Department. Parks and Trees would support the Fredericton Fire Department in the event of a fire within the City by providing equipment such as excavators, skid steers, loaders, water tanks, chainsaws, and equipment operators.

The Fredericton Fire Department recognizes the changing threat of forest fires within the City limits due to the expanded City boundary and the changing climate. Killarney Park and Odell Park are two areas of fire concern that have high recreational value and are of central importance to the City's urban forest. The Fredericton Fire Department has response plans for both parks. The nature of the Odell Park forest and the availability of both natural and municipal water sources along the perimeter of the park simplify timely response to fires within Odell. Killarney is more challenging due to its size, forest composition (more flammable species and higher ground temperatures), Parks and Trees will continue to work with the Fredericton Fire Department to develop wildfire response plans.

3 Engagement

3.1 Public Engagement

The public engagement for this project included one open house session held at Killarney Lake Lodge on June 12, 2024, and online engagement hosted on the Engage Fredericton platform including interactive mapping, video content, and the draft report. Comments were collected through in-person conversations, online submissions, and written submissions. Key points taken from these submissions have been summarized and grouped together for discussions at project meetings. Many of these submissions strengthened ideas that came out of parallel engagement exercises with City departments and external stakeholder groups. Other submissions highlighted the importance of ideas that were not considered priorities prior to engagement such as strong support for fruit or food forests within parks. All submissions were reviewed and considered in the process of drafting and revising recommendations.

1. **Fire Preparedness** – Several high-profile wildfires in the past few years have increased the level of concern in the public of potential wildfires in Fredericton. This concern is also growing because of the recent boundary changes which have increased the forested area in the City and the potential impacts of a warming climate. The large urban forest of Fredericton makes the wildfire risk within the City greater than many other municipalities and the public has concerns about Odell Park and Killarney Park in particular. Comments surrounding wildfire risk have strengthened the position of interdepartmental engagement and led to additional recommendations.

2. **Wildlife and Biodiversity** – Many comments encouraged the consideration of wildlife and biodiversity within the urban forest. Wildlife habitat improvement is an important consideration of urban forest management and the recommendations to increase riparian tree cover and focus on forest succession towards native Acadian forests are part of an effort to address this. There are also recommendations to partner with organizations which focus on conservation and habitat creation. An additional recommendation was added focusing on the connections between forested areas using stream and trail corridors has been added to further strengthen this aspect.

3. **Concerns Regarding Development** – The population growth of the City and the associated land development was one of the leading causes of concern noted through the public engagement process. This was identified early in the development of the management plan and has been the focus of significant interdepartmental engagement. Planning and Development is the City lead on land development issues and one of their considerations is the urban forest, however there are other important considerations such as housing a growing population without adding urban sprawl. Several recommendations have been developed in consultation with Planning and Development which are aimed at long-term stewardship of the urban forest within a growing City.

4. **Food/Fruit Forests** – The desire for food or fruit forests within the City was raised several times from individual residents as well as resident groups. A recommendation was added for the City to select a site and plant a food forest as a pilot project. The project could expand if neighborhood engagement

and interest remain high. Food forests are highly suited to parkland development in new neighbourhoods as they can be established much more quickly than canopy.

5. **Invasive Species** – The concern of invasive species impacts on native ecosystems was high. This concern applies to both invasive pests such as emerald ash borer and invasive tree species such as Norway maple. Some of this concern was extended to the planting of non-native species (such as Carolinian species) in the urban forest. The focus for natural areas is the succession of forests to the native Acadian forest and the management of invasive species is a part of assisting this succession. The focus for management of street trees within the urban forest is to select trees that can grow in the more restricted urban conditions but do not negatively impact the succession to Acadian forest. This means experimentation with additional species while avoiding species that are known to invade natural areas.

3.2 First Nation Engagement

Over the past several years the City has established a collaborative engagement process with the Wolastoqey Nation in New Brunswick (WNNB) as well as the Wolastoq Grand Council, as Rightsholders. The City initiated collaborative engagement with WNNB & the Grand Council in 2021 and continues to regularly meet monthly. Throughout the engagement process for the Urban Forest Management Strategy the City has had ongoing communication with WNNB as well as a First Nation consulting firm. Going forward as components of the strategy are implemented, the City will continue to collaborate with the Wolastoqey Nation seeking opportunities to braid First Nation knowledge together with western practices.

4 Recommendations and Implementation

The Fredericton urban forest is a valuable part of the City's character. Fredericton has very good canopy coverage compared with other Canadian cities – even exceeding the long-term goals set by other cities. The challenge for Fredericton will be to sustain this strong position through the ongoing population growth and the resulting development pressures. This will mean retaining canopy where possible and replanting other areas to offset losses where new homes and businesses are built. Parks and Trees is well positioned to do this as they have developed a progressive management style and excellent urban forestry, horticultural, and arboriculture experience. Some recommendations are extensions of the current management practices, others will require interdepartmental cooperation to be impactful.

The UFMS recommendations were developed through the discussion and interpretation of the UFTR findings during internal and public engagement processes. The engagement feedback was consolidated into distinct and actionable recommendations where it was supported by the UFTR data. These recommendations were also reviewed by City departments that will have shared ownership of them for compatibility with internal procedures and policy. The recommendations have been sorted into three categories: urban forest planning (Table 12), outreach and partnerships (Table 13), and operational excellence (Table 14). Section 0 will address the implementation timelines for each recommendation.

4.1 Recommendations

Table 12: Urban Forest Planning Recommendations

Recommendations	Ownership
Parks and Trees to support Planning and Development in reviewing and improving the tree planting and landscaping standards required by the City's Zoning By-law. The implementation of this strategy will be carried out over time, in several phases. The Planning and Development Department should explore land use planning tools, such as policy language, zoning provisions and subdivisions requirements, that, where possible, will discourage unnecessary tree removal and protect existing trees/tree stands to supplement public and private tree planning efforts. This should consider tree canopy targets, developed with input from Parks and Trees, pre-construction, post-construction, and a set period following construction. This may include standards for: • Topsoil quantity and quality in areas of tree planting. • Suitable species for planting considering size of planting site, site conditions, climate resilience, and composition of the urban forest. • Canopy retention targets if site conditions allow.	Planning and Development

Table 12: Urban Forest Planning Recommendations

Recommendations	Ownership
• Tree protection during construction such as tree protection fencing, minimum tree protection zones, etc. • Planting details and tree stock standards. • Setbacks from existing or proposed infrastructure and utilities. • Tree retention for ecological and climate change resilience such as watercourses, drainage areas, wildlife corridors and wetlands.	
Develop a policy to ensure Capital Planning considers the importance of green infrastructure and prioritizes tree protection rather than compensation for removal. Trees in potential conflict with proposed infrastructure expansion or renewal should be identified during preliminary stages. Enhancements to the tree planting root zones should be planned where removals are unavoidable. This could include standards for: • Stump removal. • Minimum planting site area or volume. • Topsoil quantity and quality in areas of tree planting. In the downtown core this could include structural soil cells. • Tree protection during construction. • Planting details and tree stock standards. • Suitable species for planting considering size of planting site, site conditions, climate resilience, and composition of the urban forest.	Parks and Trees
Manage the urban forest to maximize climate adaptation and resilience. This should include action on the current Climate Change Adaptation Plan (CCAP) goals. Priority areas include planting climate resilient species and increasing species diversity, monitoring and managing invasive species, and providing shade in recreational spaces. Parks and Trees should be an active contributor to CCAP goals when the document is periodically reviewed.	Shared – Environmental Strategist & Program Manager (Corporate Services Department) with Parks and Trees
Develop a tree planting prioritization framework to work alongside the fundamentals of Capital Planning Policy and Climate Change Adaptation Plan. This framework would guide the allocation of trees based on a rationale. The rationale could have many considerations such as equitable distribution of canopy cover, heat island reduction, demographics, ecological function, and riparian	Parks and Trees

Table 12: Urban Forest Planning Recommendations

Recommendations	Ownership
restoration. The framework should allocate planting quantities, based on availability, between streets, parks, and restoration areas.	
Establish appropriate urban forest canopy cover targets for City's Urban Growth Area based upon measurement of the tree canopy in relation to building footprint percentage. The potential upper limit for urban forest canopy cover correlates with the percent of land areas buildings occupy. As the building area increases, plantable space decreases and targets should reflect this. Where reasonable targets are established but canopy cover is lagging behind target, the most likely reasons are too few trees planted, the planted trees have not matured, or non-plantable area like parking lots are larger than typical. These targets should be revised when canopy cover is remeasured. Population growth projections, building standards, and appropriate housing availability are all expected to be important factors in determining reasonable targets.	Shared - Planning and Development with Parks and Trees
Develop a public forested areas management policy. Forested areas on City property are a key contributor to the urban forest. These areas support biodiversity and commonly have recreational trails. The policy should consider standard of care to ensure recreational safety, monitoring of species health in a changing climate, monitoring for invasive species – pathogens, pests, and plants. Forested areas should be considered as areas to build resiliency in the urban forest through biodiversity as more tree species can thrive in forests than on streets.	Parks and Trees
Consider street tree planting requirements for new public streets. Trees on City owned property are important and valuable corporate assets. Private sector land developers regularly construct and install services in public rights-of-way, which are eventually turned over to the City who ultimately own and maintain the assets. Street trees, however, are not currently included as part of the development requirements. This initiative could expand and build on the City's existing street tree planting program by establishing new street tree planting requirements for the development community as a contribution to the City's urban forest. Tree planting requirements could be directed to the new public streets and can be pursued through the subdivision requirements.	Shared – Planning and Development with Parks and Trees

Table 12: Urban Forest Planning Recommendations

Recommendations	Ownership
Enhance the urban forest along corridors such as trails and watercourses to increase forest connectivity. Corridors that pass through the fabric of the City, such as trails and watercourses, offer great opportunities to enhance connections between forested areas. Connections are important to the biodiversity that forested areas support including the trees as it promotes self-seeding and other natural forest processes that increase forest resilience.	Parks and Trees
Select a site and plant a fruit forest. The planting of a fruit forest is an opportunity to provide a new connection between the people of the City and the urban forest by providing a stewardship opportunity as well as providing healthy food. Fruit forests also provide pollinator habitat and opportunities to increase biodiversity in the overall urban forest. Compared to other parts of the urban forest a fruit forest is also quicker to establish – this makes new neighbourhoods with significant cleared area good candidates for implementation.	Parks and Trees

Table 13: Outreach and Partnerships Recommendations

Recommendations	Ownership
Develop an interdepartmental urban forest working group. Management of the urban forest is interdisciplinary and requires action from many stakeholders. Departments with roles in forestry, planning, operations, climate change and ecology, and public communications should be involved.	Shared
Re-establish the purpose of the Tree Commission to maximize its impact. The focus of the Tree Commission was to provide technical advice to Council on forestry issues. The need for technical advice has changed with Parks and Trees developing significant technical expertise. A revised role could focus on advocacy, partnerships, accountability, and/or public engagement.	Shared – Tree Commission with Parks and Trees

Table 13: Outreach and Partnerships Recommendations

Recommendations	Ownership
Braid knowledge with Sitansisk and other First Nations. The challenges of managing the urban forest are shared through changes in climate, species migration, and human modifications to the land. Braiding knowledge and experience between communities on invasive species, pests, climate adaptive species, and operational expertise benefits all. The City should commit to ongoing braiding with Sitansisk and other First Nations.	Shared – Sitansisk and Manager of First Nation Relations (City Administration)
Pursue targeted stewardship initiatives, partnerships, and funding sources. Local conservation and environmental stewardship groups should be engaged for initiatives including reforestation, riparian restoration, and monitoring. These groups could be a valuable resource to assist City staff in planting priority natural areas and monitoring of invasive species or planting success. Partnerships with stewardship organizations may also present funding opportunities for restoration projects.	Parks and Trees
Create and maintain a public education program. Public education will be important to the success of urban forest management as the majority of canopy cover in the City is on private lands. Information such as invasive species management, climate adaptive species to plant, and the importance of the urban forest to the wellbeing of the City should be included. Additional considerations include: • Continue public outreach through various forms such as, markets, schools, social media etc. • Make data collected through the Urban Forest Technical Report public on the City GIS open data site including the canopy model and land surface temperature mapping. • Consider creation of a plantable space on private property map to engage the public similar to the Solar Potential Map. • Engage homeowners adjacent to newly planted street trees with information about City maintenance practises and opportunities for voluntary supplemental assistance such as watering and mulching. • Partner with community groups so that they can use the information and amplify it for their audience.	Shared – Communications with Parks and Trees

Table 13: Outreach and Partnerships Recommendations

Recommendations	Ownership
• Link to climate change initiatives such as: the importance of trees and vegetation for storm water management, cooling/shade, air pollution removal, ecological habitat. • Guidance on appropriate species to plant, the maintenance of planted trees, and suitable planting locations.	

Table 14: Operational Excellence Recommendations

Operational Excellence	Ownership
Review the plantable area data in the field and develop a system for tracking the inventory of plantable area. A reliable inventory of plantable area in the City is important to implementing the planting prioritization. The inventory should be maintained in priority areas based on the number of available trees for the next three years. Priority areas would be determined by the development of a planting prioritization framework – see recommendation under Urban Forest Planning. The inventory should include recommended planting species based on the size of the site, soil conditions, and strategic species composition.	Parks and Trees
Consider low impact development (LID) solutions to stormwater, where practical, to provide adequate water to boulevard trees. Use of LID features such as stormwater tree trenches and bioretention features can increase the water availability for street trees. This can reduce the stormwater runoff to grey infrastructure but also allow the planting of trees that require more water to grow in these areas. It is possible to reduce watering requirements to establish newly planted trees if adequate stormwater can be provided. LID can also limit the land required for stormwater management. Action on this recommendation may be included in a review of stormwater guidelines.	Engineering and Operations

Table 14: Operational Excellence Recommendations

Operational Excellence	Ownership
Continue to focus on proactive maintenance. The continued proactive approach to urban forest health is critical to ensuring the sustainability of the canopy cover in Fredericton. The focus on structural pruning will be important as the number of severe weather events potentially increases due to climate change. Proactive maintenance is one reason the City currently has a low tree mortality rate. A significantly increased planting rate would be required to offset canopy losses if the mortality rate were to increase. The sustainability of the canopy in the short term would likely not be feasible in this case because of the lag time required for planted trees to mature.	Parks and Trees
Maintain the existing street tree inventory. Current inventory data is important for planning and managing the urban forest. City staff prune, monitor, and maintain trees on a rotation over a set period of time. This would be an ideal time to remeasure and reassess each street tree to ensure comprehensive and timely data collection.	Parks and Trees
Continue to monitor and manage urban forest pests and pathogens. The City is currently manging Dutch elm disease and emerald ash borer. Both pose significant threats to the urban forest with ash species being common street trees in the City. Oak wilt and hemlock woolly adelgid (HWA) are potential future threats that should be closely monitored. HWA is present in the northeastern United States and the current management of this disease should be closely monitored to act quickly should it arrive in New Brunswick. Oak wilt has been confirmed in southern Ontario but has been present in Michigan for some time. Management outcomes should be monitored for this threat as well.	Parks and Trees
Monitor and manage invasive tree species on public lands. Invading tree species such as European buckthorn are a threat to biodiversity in wooded areas. Biodiversity is important to the resilience of ecological communities during periods of change. These species can be hard to manage once they have become established, so early intervention is important. Community partners could be important to implementing this goal.	Parks and Trees

Table 14: Operational Excellence Recommendations

Operational Excellence	Ownership
Plant additional trees adjacent to trails and recreational areas. Shade is an important factor for the comfort of trail and recreation facility users in the summer months. This is particularly true for users that are more prone susceptible to heat such as children and the elderly. Including shade near trails and recreational areas is a good way to provide equitable inclusion for these populations. The use of deciduous trees provides shade in the summer but allows the sun to warm the area in the winter. Use of coniferous trees to screen wind from exposed areas should also be considered.	Parks and Trees
Reforest non-recreational open spaces. There are currently several areas that the City maintains through mowing, bush hogging, flail mowing etc. The reforestation of these areas through plating, seed dispersal, or a combination of both would increase the urban forest and partially offset removals in other areas for development. The planting could be part of a community or school event and partially funded through the savings in eliminating the periodic mowing. Consideration should be given to maintaining non-forest habitat types such as meadows to maintain biodiversity within the City.	Parks and Trees
Create a program for tree planting on private lands. Street tree planting in high priority planting areas will not sufficiently address canopy growth in the short term. This is due to the lag in time for trees to mature and the limited plantable areas in boulevards. The creation of a program may incentivise citizens to plant trees while allowing the City to provide strategic input on species, location, and post-planting care. Species diversity can be built in locations that are not as constrained as boulevards.	Parks and Trees
Increase the annual street tree planting rate to 750-1000/year. The current planting rate of 500 trees per year is providing sustainable canopy regeneration based on the number of removals that are occurring. Currently trees are imported from outside the province which has high shipping costs. The City greenhouse will eventually supplement this practice and allow for an increase in tree availability. Tree planting should increase to a minimum of between 750 and 1000 per year depending on availability. This will provide some buffer to compensate for small increases in mortality due to storm events or EAB. The City should plan to plant between 5,000 and 6,000 trees in plant newly developed streets over the upcoming growth period. Coordination with Planning and Development should be frequent to project annual demand.	Parks and Trees

Table 14: Operational Excellence Recommendations

Operational Excellence	Ownership
Plant climate adaptive species and increase the diversity at the species and genus levels. Maples make up an unsustainable proportion of the City's urban forest, with Norway maple being the most prevalent species. Planting of other species and genera should be a priority to build diversity and resilience. Maple planting should not be discontinued however as this genus has relatively few threatening pests and many species are projected to remain climate appropriate in the area. Additionally new neighbourhood developments should include an appropriate proportion of maple. Norway maple planting should be ceased in proximity to natural areas as they have shown the ability to invade native maple forests and outcompete some native species. Ash species planting should be ceased during the EAB infestation as any planted tree will require biennial injections to remain viable. The standard guideline for maximum species, genus, and family populations are 10%, 20%, and 30% of the total number of trees respectively. This is a long-term target – the short-term focus should be on planting higher proportions of non-maple species and particularly climate adaptive species.	Parks and Trees
Train all Parks and Trees staff to assist the Fredericton Fire Department with wildland firefighting support. The training of staff will allow Parks and Trees to effectively assist the Fredericton Fire Department in the containment of any wildfire within the City. Parks and Trees can be a benefit to the Fire Department as a temporary increase in skilled equipment operators and equipment. This additional capability may be important as the City has expanded the forested area that it is responsible for and wildfire risk is one of the concerns stemming from climate change.	Parks and Trees

4.2 Implementation

Implementation sequences have been developed to prioritize action on the recommendations (Table 15, Table 16, and Table 17). This sequence considers which recommendations need to be completed to begin subsequent recommendations. It also considers the availability of departmental resources, including resources of other departments with shared ownership of recommendations. It is anticipated that the sequence may change due to funding and partnership opportunities. The implementation sequence has been shown as short, medium, and long term with the estimated total timeframe of a 10 to 12-year period. Many of the recommendations should be considered continuations of existing practices that have been confirmed through technical review, or new ongoing practices that are key to sustainable urban forest management. All recommendations should be reassessed when the UFMS is updated.

The detailed implementation of the recommendations will be formalized annually via an implementation plan prepared by Parks and Trees to align with the budget approval cycle. The first implementation plan will be submitted in 2024 to appear in the 2025 City budget. Parks and Trees will present the proposed recommendations for implementation to the urban forest working group for interdepartmental coordination prior to finalizing the plan.

Table 15: Implementation Sequence – Urban Forest Planning

Urban Forest Planning Recommendations	Short Term	Medium Term	Long Term
Parks and Trees to support Planning and Development in reviewing and improving the tree planting and landscaping standards required by the City's Zoning By-law.			
Develop a policy to ensure Capital Planning considers the importance of green infrastructure and prioritizes tree protection rather than compensation for removal.			
Manage the urban forest to maximize climate adaptation and resilience.			
Develop a tree planting prioritization framework to work alongside the fundamentals of Capital Planning Policy and Climate Change Adaptation Plan.			
Establish appropriate urban forest canopy cover targets for City's Urban Growth Area based upon measurement of the tree canopy in relation to building footprint percentage.			
Develop a public forested areas management policy.			
Consider street tree planting requirements for new public streets.			
Enhance the urban forest along corridors such as trails and watercourses to increase forest connectivity.			
Select a site and plant a fruit forest.			

Table 16: Implementation Sequence - Outreach and Partnerships

Outreach and Partnerships Recommendations	Short Term	Medium Term	Long Term
Develop an interdepartmental urban forest working group.			
Re-establish the purpose of the Tree Commission to maximize its impact.			
Braid knowledge with Sitansisk.			
Pursue targeted stewardship initiatives, partnerships, and funding sources.			
Create and maintain a public education program.			

Table 17: Operational Excellence Recommendations

Operational Excellence Recommendations	Short Term	Medium Term	Long Term
Review the plantable area data in the field and develop a system for tracking the inventory of plantable area.			
Consider low impact development (LID) solutions to stormwater, where practical, to provide adequate water to boulevard trees.			
Continue to focus on proactive maintenance.			
Maintain the existing street tree inventory.			
Continue to monitor and manage urban forest pests and pathogens.			
Monitor and manage invasive tree species on public lands.			
Plant additional trees adjacent to trails and recreational areas.			
Reforest non-recreational open spaces.			
Create a program for tree planting on private lands.			
Increase the annual planting rate to 750-1000/year.			
Plant climate adaptive species and increase the diversity at the species and genus levels.			
Train all Parks and Trees staff to assist the Fredericton Fire Department with wildland firefighting support.			

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APPENDIX A:
Urban Forest Technical Report

URBAN FOREST TECHNICAL REPORT

City of Fredericton Urban Forest

May 26, 2023

Prepared for:
City of Fredericton

Prepared by:
Stantec Consulting Ltd.

Project Number:
161414297

The conclusions in the Report titled Urban Forest Technical Report are Stantec's professional opinion, as of the time of the Report, and concerning the scope described in the Report. The opinions in the document are based on conditions and information existing at the time the scope of work was conducted and do not take into account any subsequent changes. The Report relates solely to the specific project for which Stantec was retained and the stated purpose for which the Report was prepared. The Report is not to be used or relied on for any variation or extension of the project, or for any other project or purpose, and any unauthorized use or reliance is at the recipient's own risk.

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Acronyms / Abbreviations / Units

°C	Degrees Celsius
ALB	Asian longhorn beetle
AR	Assessment report (IPCC)
AR5	Assessment Report 5 (IPCC)
BBD	Beech bark disease
BCCA	Bias Correction/Constructed Analogues
BCCAQV2	Bias Correction/Constructed Analogues with Quantile delta mapping reordering
City	Cit of Fredericton
cm	Centimetres
CMIP	Coupled Model Intercomparison Projects
CMIP5	Coupled Model Intercomparison Projects Phase 5
CO	Carbon monoxide
DBH	Diameter at breast height
DED	Dutch elm disease
DEDMA	Dutch elm disease management area
EAB	Emerald ash borer
ECCC	Environment and Climate Change Canada
GCM	Global Climate Model
GHG	Greenhouse gasses
GIS	Geographic information system
ha	Hectare
HWA	Hemlock woolly adelgid
IPCC	Intergovernmental Panel on Climate Change
IV	Importance value
LiDAR	Light detection and ranging
m	Metres
mm	Millimetres
m^3/year	Cubic metres per year
NDVI	Normalized Difference Vegetation Index
NIR	Near infrared imagery
NO_2	Nitrogen dioxide
NRCan	Natural Resources Canada
O_3	Ozone
PCIC	Pacific Climate Impacts Consortium
PHZ	Plant Hardiness Zones

PM	Particulate matter
PM 10	Particulate matter 10 microns or less
PM 2.5	Particulate matter 2.5 microns or less
QDM	Quantile Delta Mapping
RCP 8.5	Representative Concentration Pathways 8.5
ROW	Right-of-way
SO_2	Sulphur dioxide
UNB	University of New Brunswick
VOC	Volatile organic compounds

1 Background

1.1 Purpose

The Urban Forest Technical Report has been prepared for the City of Fredericton (the City) and will be a key technical background document that will guide the development of an Urban Forest Management Strategy. The Report is a summary of the current state of urban forest management and the existing urban forest conditions. The report combines data from the existing urban forest, remote sensing, and ground-truthing, to address knowledge gaps and establish a baseline understanding of the urban forest to guide development of a Management Strategy. Understanding baseline urban forest conditions will aid management the resource for ecosystem services, climate resilience, carbon sequestration, aesthetics, and public health.

This Report has the following objectives:

- Qualitatively describe the urban forest according to canopy coverage, overall heath, species composition, and size and spatial distribution.
- Analyse gaps in existing datasets and close these gaps to establish a baseline for effective management.
- Assess current urban forest management practices.

1.2 Key Findings and Recommendations of Existing Studies

Fredericton's urban forest includes urban street trees, park trees, trees on private property, and trees in remnant woodlots throughout the City. As a living system, the urban forest depends on water cycles, climactic conditions, soil health, and human and animal activities including forest pests. To manage this resource, it is critical to quantify and understand the components of the urban forest. The City has worked with the University of New Brunswick (UNB) to quantify the urban forest, resulting in following studies produced by UNB:

- *Fredericton's Urban Street Tree Management Plan* Phase 1, 2015 (south side of St. John River).
- *Fredericton's Street Tree Management Plan* Phase 2, 2016 (north side of St. John River).
- *Two Steps Forward: An Urban Forest Management Plan for Fredericton's Parks*, 2018.
- *A Management Plan for the City of Fredericton's Odell Park and the Valley Trail System*, 2019.
- *Killarney Lake Management Plan*, 2020.

These reports provide thorough inventories of existing conditions and robust analysis within their respective scopes. This report uses the existing body of work to assess gaps and supplement with new forms of analysis when available. Key findings of the reports are included chronologically below for ease of reading; however, familiarity with the full reports is advised.

1.2.1 FREDERICTON'S URBAN STREET TREE MANAGEMENT PLAN PHASE 1

The Phase 1 inventory covered the urban area of Fredericton south of the St. John River. The dataset represents a "complete inventory of street trees located within 6 metres of roadside" (UNB 2015). Public elm trees greater than 6 m from roadside were also inventoried where possible. The most prevalent species observed in descending were Norway maple (*Acer platanoides*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), basswood (*Tilia americana*), red oak (*Quercus rubra*), white elm (*Ulmus americana*), silver maple (*Acer saccharinum*), white birch (*Betula papyrifera*), linden (*Tilia cordata*), and Japanese lilac (*Syringa reticulata*).

The dataset was audited and demonstrated to be robust before being used for a thorough analysis of management scenarios and quantification of environmental, social, and economic values. Climate change models and forest pest stressors were modelled to contribute to the following recommendations:

- Cessation of planting ash species due to probable future emerald ash borer (EAB) infestation.
- Continue annual planting to compensate for Hurricane Arthur impacts.
- Increase the composition of native street tree species for diversity and resiliency.
- Increase use of bur oak (*Quercus macrocarpa*), Freeman maple (*Acer x freemanii*), black oak (*Quercus velutina*), bitternut hickory (*Carya cordiformis*), shagbark hickory (*Carya ovata*), black walnut (*Juglans nigra*), sycamore (*Platanus occidentalis*), cucumber tree (*Magnolia acuminata*), tulip tree (*Liriodendron tulipifera*), basswood, eastern white pine (*Pinus strobus*), sugar maple, white elm, and red oak which were assessed as appropriate based on the climate modelling.
- Continue appropriate plantings per the "right tree – right location" philosophy, through careful species selection based on planting location. Considerations include salt tolerance, size at maturity where planting site is close to utilities, soil moisture, and required root zone volume.
- Implementation of ash tree treatment for EAB.
- Shift from reactive to proactive street tree management.
- Sustain long-term forest canopy to maintain environmental, economic, and social values through management of tree size and age composition.
- Develop integrated datasets including parks, trails, and residential trees through the use of LiDAR.

1.2.2 FREDERICTON'S STREET TREE MANAGEMENT PLAN PHASE 2

The Phase 2 inventory extended the Phase 1 study to the north side of the St. John River to complete the urban portion of the City. The dataset is a complete sample and was used for a thorough analysis of management scenarios and quantification of environmental, social, and economic values. The most prevalent genera observed, in descending order were maple, ash (*Fraxinus*), oak, linden, elm, and birch. When combined with the Phase 1 inventory the same order of prevalence exists. Limited remote sensing analysis was conducted including use of normalized difference vegetation index (NDVI) for planting site identification and heat island analysis. Climate change models and forest pest stressors were also modelled. Key findings include the following recommendations:

- Plant more introduced species suited to urban environments and projected climate.
- Temporary cessation of maple planting due to overrepresentation in the urban forest.
- Continue appropriate plantings per the “right tree – right location” philosophy.
- Update and maintain the inventory as management activities occur with each tree being revisited every 5-7 years.
- Focus pruning on young trees to develop good form and limit pruning mature trees to hazard management.
- Plant Dutch elm disease (DED) resistant elms to maintain their heritage in the City and manage existing elms through treatment.
- Manage EAB through systemic insecticide applied to ash trees.
- Survey residents to understand public opinion of street tree management in Fredericton.

1.2.3 TWO STEPS FORWARD: AN URBAN FOREST MANAGEMENT PLAN FOR FREDERICTON’S PARKS

The inventory of Fredericton’s parks included a complete inventory of six parks, a supplemental inventory for one park partially collected during the street tree inventory, and the inventory of selected species at Odell Park and Killarney Park. Species inventoried in Odell Park and Killarney Park included elm, ash, eastern white pine, and non-native ornamental species. Species diversity was higher in parks than in the street tree inventory. The dataset was used to analyse for 5- and 10-year management scenarios and quantification of environmental, social, and economic values. Additionally, climate change models and forest pest stressors were modelled. The report resulted in several recommendations:

- Follow a prescribed pruning regime.
- Forecast management practices to maintain 90% of park trees categorized as healthy.
- Maintain trees to have a maximum of 5% deadwood in the crown.
- Maintain trees to have a maximum of 5% of all trees categorized as hazardous.
- Diversify planted species for climate resiliency.
- Increase tree basal area within parks by 5% over 10 years.
- Increase the social, environmental, and economic value of the urban forest by 10% over the next 10 years.

- Decrease the proportion of non-native species within the urban forest by 5%.
- Limit tree species composition within the urban forest such that no species accounts for more than 10%, no genus accounts for more than 20%, and no family accounts for more than 30% of the total.

1.2.4 A MANAGEMENT PLAN FOR THE CITY OF FREDERICTON'S ODELL PARK AND THE VALLEY TRAIL SYSTEM

The forested area of Odell Park was inventoried by delineating stands and characterizing them using sample-based forestry metrics (such as basal area) compared with the individual tree urban forestry metrics collected in the previous three studies. Odell Park was found to have very large proportions of hemlock with a greater proportion of ash along Valley Trail. Improving trail safety through removal of hazardous trees and improvements to stand health were also areas of focus within the report.

Based on the forest inventory, the following recommendations were made:

- Increase trail accessibility and safety through the removal of hazard trees beginning in 2021. Decrease the number of hazardous trees by 25% by 2022.
- Follow regulations when applying management insecticides to prevent groundwater contamination per the *Wellhead Protection Act*.
- Continue with recommended public outreach initiatives based on management of Odell Park and EAB and hemlock woolly adelgid (HWA) management.
- Maintain large diameter trees along the margins of the trail systems.
- Increase sequestered carbon by 10% by 2029.
- Increase small diameter stems by 10% while maintaining or increasing species diversity by 2029.
- Reduce the number of invasive and non-native species by 15% by 2029.
- Increase the number of native climate change resilient trees by 10% by 2029.
- Limit additional dollars spent on EAB and HWA treatment to less than 20% increase through 2029.

1.2.5 KILLARNEY LAKE MANAGEMENT PLAN

The forested area of Killarney Lake Park was inventoried. Sample-based metrics were collected using variable area plots based on evenly distributed plot centres for 246 plots across the park. The most prevalent species observed, in descending order were balsam fir (*Abies balsamea*), red maple, white birch, aspen (*Populus tremuloides*), red spruce (*Picea rubra*), largetooth aspen (*P. grandidentata*), yellow birch (*Betula alleghaniensis*), and white spruce (*P. glauca*). The highest number of plots were assessed to be in stem exclusion, with understory reinitiation and stand initiation also being prevalent. Stand initiation is the first phase of forest development following a disturbance and the canopy has not yet closed. Stem exclusion defines the stage in forest development when the canopy has closed and very few new trees germinate and grow in the understory. Understory reinitiation follows stem exclusion when some gaps in the canopy and canopy height allow for understory development (Oliver 1981).

Three management scenarios were tested: 1) Passive management to allow forest regeneration with minimal interventions; 2) maximizing climate resiliency through multiple thinning interventions; and 3) thinning and spraying to reduce potential impacts of spruce budworm (*Choristoneura fumiferana*). Increased climate resiliency in scenario two was partially dependant on increasing the proportion of hardwoods in the stands.

Passive management was recommended as the forest is likely to progress to a more resilient state with a higher hardwood component within the scope of study. Active management to accelerate the transition to greater hardwood content was not cost effective and would be perceived poorly by the public.

1.3 Urban Planning

The urban forest and street trees are referred to in urban planning strategies and municipal plans for the City, Including *Imagine Fredericton: The Municipal Plan* (2020), *Fredericton Growth Strategy* (2017), *Fredericton Main Street Urban Design Plan* (2016), and *Fredericton City Centre Plan* (2015). References to trees within the two most recent urban planning documents are provided below. Most of the policies or references are focussed on protection and planting of street trees. However, there is one policy which requires the implementation of sustainable forest management practices.

Imagine Fredericton: The Municipal Plan (2020)

1.3 (8) iv. The City's tree canopy will increase, and there will be more tree-lined streets.

2.2.1 (21) To maintain the stability of residential neighbourhoods, while allowing for incremental change through sensitive new development and redevelopment, new development will respect and reinforce the existing pattern, scale, and character of the Established Neighbourhoods, by ensuring that:

> *iv. Healthy, mature trees are protected whenever possible.*

2.2.1 (28) Council shall seek to ensure that the design of Mixed-Use Nodes:

> *ix. Features a public realm with generous sidewalks lined with trees, pedestrian amenities, cycling parking, and high-quality landscaping.*

2.2.1 (32) New development is encouraged to transition towards a more pedestrian-oriented/ mixed-use design, where appropriate, by:

> *ii. Including street trees, sidewalks and lighting along public streets and main driveways.*

3.7.1 Urban Forest

> *(8) Prioritize street tree planting and landscaping in all development and other infrastructure projects including within public rights-of-way and on City-owned lands.*

(9) Encourage the use of drought-tolerant and/or flood-tolerant shrubs and trees in landscape design where appropriate and encourage the use of native species where appropriate.

(10) Implement sustainable forest management practices on City-owned lands and encourage such practices on privately owned land.

3.91 Complete Streets

(13) Streetscapes shall be designed to support walking and enhance the public realm. Emphasis should be given to the quality, character and function of the City's streets and strive to achieve a public realm that includes, but is not limited to, the following:

i. Landscaping, including trees on both sides, and planted medians where possible.

Fredericton Growth Strategy (2017)

4.3 Urban Core Growth Areas

[City Centre] Growth and physical change in the City Centre generally will be guided by the recently completed City Centre Plan, which provides direction regarding the appropriate form of new buildings and on improvements to the public realm that will help to attract more people and private investment. As new development adds more housing and commercial space, this can be done by:

- *Improving streetscapes with trees and pedestrian amenities.*

[South Core] As in the other areas of the Urban Core, development should contribute to a strong urban character and inviting pedestrian realm. To this end, buildings will be located close to the street, parking will be located at the rear of buildings or underground, and street trees will be required everywhere.

4.4 New Neighbourhoods

To ensure future development uses land and infrastructure efficiently, and supports the overall growth target for new residential neighbourhoods, growth in each community will average 35 units per net hectare. To further support the vision and goals for Fredericton, the Secondary Plans will reflect the following urban design principles for complete, walkable, sustainable communities:

- *Require sidewalks and street trees.*

4.5 Mixed Use Nodes

The public realm of a mixed-use node should feature generous sidewalks lined with trees, pedestrian amenities (benches and/or moveable chairs and tables, garbage/recycling bins), bicycle parking, and high-quality landscaping.

4.10 Areas of Stability and Minor Change

Maintaining Fredericton's stable, healthy residential neighbourhoods will be essential to sustaining growth, prosperity, and the city's high quality of life. Existing neighbourhoods will undergo minor change as older homes are improved or replaced, and modest forms of intensification may be permitted at the edges of neighbourhoods, along main roads, e.g., townhouse developments and low-rise apartment buildings. To make established neighbourhoods more attractive and complete, small-scale commercial amenities, such as convenience stores and personal services, may also be permitted on primary roads, particularly transit routes. All such changes, however, will respect and reinforce the existing pattern, scale, and character of the neighbourhood. More specifically, new development will:

- *Protect healthy, mature trees whenever feasible.*

1.4 Gap Analysis

The need for a gap analysis was determined through review of existing studies and discussions with City staff. Table 1 summarizes the results of the gap analysis and methods to address identified gaps.

Table 1: Summary of Gap Analysis

Identified Gap	Methods to Address	Limitations
Existing data sources do not quantify or assess private components of the urban forest and only some wooded areas.	NDVI analysis using NIR imagery and LiDAR analysis will be used to add a more comprehensive dataset	The NIR and the LiDAR data are not from the same year and are not current. Analysis of several datasets from different points in time is subject to issues of data disagreement. These disagreements require analyses to be conducted at a larger population level.
Climate change models used to forecast species suitability have used a variety of methods and assumptions.	The most recent climate change models are recommended as they have been updated since some reports have been published. The worst-case scenarios are recommended as they are most closely representing observed climate change to this point.	Climate models are large scale and based on specific periods of time. A species may be limited by current minimum temperatures (e.g., cold hardiness) in Fredericton based on the existing climate. Considering the long lifespan of tree species there may be a lag between suitability for planting, the decline of existing species, and the maturation of the planted species.
Species projected to adapt well to the regional climate have pest susceptibility constraints that may limit their contribution to the urban forest. Species climate adaptation does not necessarily translate to species suitability in urban environments.	The proposed and existing species analysed through climate models need to be filtered based on pest susceptibility and suitability for urban conditions.	Pest susceptibility is dynamic and, in some cases, impacted by existing stressors on the tree which can be compounding in stressful urban environments. Pest susceptibility is based on current understanding of pests and does not accurately predict the adaptation of the pest or the introduction of additional pests.

Table 1: Summary of Gap Analysis

Identified Gap	Methods to Address	Limitations
Available datasets vary in age. Street tree data is from 2014-2016, park data is from 2018, stand data is as current as 2020. Street tree data is maintained by the City as removals and plantings occur.	NDVI analysis using NIR imagery and LiDAR analysis will be used to add an additional dataset that is more comprehensive.	The aerial imagery (2012) and the LiDAR data (2015) are not from the same year and are not current. Analysis of several datasets from different points in time is subject to issues of data disagreement. These disagreements require any analysis to be conducted at a larger population level.
Forecasts for urban forest structure were forced to assume dates for EAB infestation based on proximity to the City. The City has now confirmed EAB presence as of 2021.	The EAB infestation can be modelled using street and park tree inventories with fewer timing assumptions. Replacement trees can be forecasted to model future population to maintain optimal population age structure.	EAB infestations are dynamic and depend on the distribution of ash as well as management interventions. Infestations can be modelled at a population level but inferences to specific trees or subpopulations are not advisable.

2 Urban Forest Cover Database Development

The development of a canopy cover database covering the entire City was identified as a need through the gap analysis and consultation with City staff. The following is an overview of the steps taken to develop the canopy cover database. The resulting GIS-based database provides an overview of the urban forest for the entire geographic area of Fredericton.

1. Existing point data were combined into one database and checked for quality. This included comparisons of the database provided by the City, planting records from the Park and Trees Division, and previous UNB studies (see section 2.1).

2. The City was divided into an urban and rural areas based on the spatial distribution of existing point data. These data points were collected in urban streets and some parkland. Point data was analysed differently, as a result delineation based on the data type is logical, in this from an operations standpoint and because Parks and Trees Division has different responsibilities in the urban and rural parts of the City.

3. Plot based field sampling focussed on areas where species composition and size distribution were not known and were publicly accessible. This program was based on the i-Tree Eco platform, with plots focussed in areas of the City where point data was not available, in this case the rural portion (see Section 3 for plot sample data collection methods).

4. Remote sensing was conducted to develop a City-wide model of the tree canopy which would fill identified gaps including private property and large tracts where field-based inventories are not feasible. LiDAR and NDVI methods were utilized as these are cost effective and repeatable techniques (see Section 2.2).

5. Administrative boundaries were included within the database to link tree data to policy and demographic variables for further analysis (see Section 2.3).

2.1 Public Tree Inventory

The public tree inventory is an existing point database which has been created by the City based on several data collection surveys. These surveys include the UNB inventories of 2015, 2016, and 2018 (see Section 1). The database does not project or track changes to tree condition, diameter at breast height (DBH), or canopy radius. Planting and removal activity is tracked by Parks and Trees and is current to 2023. As a result, tree location and species can be tracked. Variables that change with time such as vigour and size, however, are less accurate.

The 2023 database contains species, DBH, and health (categorised as good, average, poor, and dead). DBH is projectable as it will only remain constant or increase. Canopy width is correlated with DBH and can be projected. Health is not reliably projectable for individual trees but could be approximated using mortality rates at a population level.

Spatially, the public tree inventory is restricted to the urban portions of the City and only contains trees on public lands. Most of the data points focus on public rights-of-ways (ROWs) and as a result predominantly reflect street trees. There are fewer park trees and trees located along trails contained in the database (Figure 1).

Figure 1. Spatial extents of the public tree inventory (green dots represent individual trees)

2.2 Remote Sensing

LiDAR is remote sensing data that can be used to derive heights of objects above the ground. To accomplish this, a file is made containing a surface representing the ground, and a second file is created representing the heights of objects above the ground. The height of the ground is then subtracted from the hight of objects to give a measurement of their real height. Where there is bare ground, the height reads zero and wherever there is an object the height reads as greater than zero. These objects include buildings, hydro poles, and trees.

An image file with a near infrared band is required to isolate trees within the backdrop of other tall objects. This was done by selecting the colour green being reflected by the chlorophyll in tree leaves and removing everything else. The result was a spatial extent of the canopy which was filtered to show trees within the following height classes:

- 2-5 m
- 5-10 m
- >10 m

The spatial extents of this dataset included the entire City at the time of processing (2023) and additional lands that were to be added to the City in 2023. A portion of the new lands to be added to the City were not processed because the 2015 City NIR dataset did not include these areas (Figure 2). Methods are explained in further detail in Appendix C (see Appendix D for quick reference tables of canopy cover by administrative boundary).

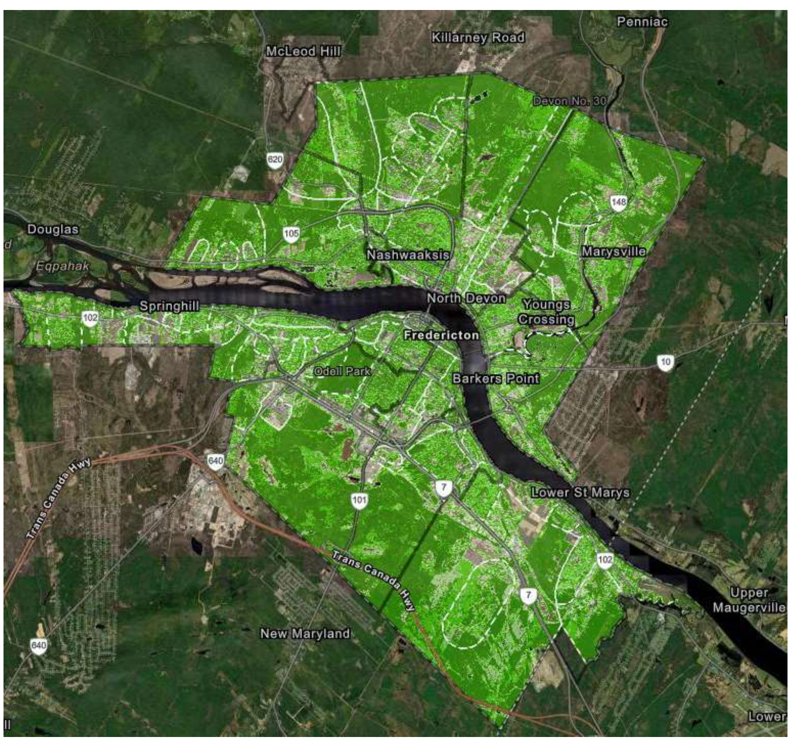


Figure 2. Spatial extents of the public tree inventory (green represent modelled canopy)

2.3 Administrative Boundaries

The addition of administrative boundaries into the database allows for analysis between datasets using the same geographic area. Several sets of administrative boundaries were imported into the database to analyse canopy cover in terms of demographics and land use policy. The following administrative boundaries were added to the database:

- **Zoning Type**: The two areas of the City determined by the spatial extents of the public tree inventory. This boundary contained two categories:
  - Urban
  - Rural

- **Zoning Detail:** The land use planning zoning designation used to guide development and types of land use within the City. This boundary contained the following categories and was provided by the City:
  - Agricultural
  - City Centre
  - Commercial
  - Comprehensive Development District
  - First Nations
  - Future Development
  - Industrial
  - Institutional
  - Mixed Use
  - Open Space
  - Park
  - Research and Advanced Technology Zone
  - Residential
  - Rural Residential - Chateau Heights
  - UNB Endowment Conservation
  - UNB Endowment Development

- Census Tract: Geographic areas defined by Statistics Canada within cities of more than 50,000 residents. Census tracts typically have populations of 2,500 to 8,000 and can be used to analyze an area in conjunction with the demographic datasets collected by the Census. This boundary contained each of the census tracts located in the City. This data was provided by the City.

- Ward: Wards are municipal government ridings represented by City Councillors elected by residents of the ward. Analysis by ward is relevant as councillors have a responsibility to the residents of their specific ward and political action on land use is often related to wards. The following ward data was provided by the City.
  - Bishop Drive/Odell (Ward 9)
  - Clements, Sunset (Ward 1)
  - East Downtown & Plat/UNB (Ward 11)
  - Main Street / North Devon (Ward 4)
  - Marysville (Ward 5)
  - McLeod, Brookside (Ward 2)
  - Nashwaaksis North (Ward 3)
  - Silverwood/Garden Creek (Ward 12)
  - Skyline Acres (Ward 8)
  - South Devon, Barker's Point, Lower St. Mary's (Ward 6)
  - Southwood Park, Lincoln (Ward 7)
  - West Downtown & Plat/Sunshine Gardens (Ward 10)

- Neighbourhoods: Geographic areas defined by landmarks or small-scale differences within the City as a whole. Residents often identify with specific neighbourhoods and are most directly involved with decisions at this scale. The following neighbourhoods were identified using data provided by the City.
  - Barkers Point
  - Brookside
  - Brookside Estates
  - Brookside Mini Home Park
  - College Hill
  - Colonial Heights
  - Cotton Mill Creek
  - Diamond Street
  - Doak Road
  - Douglas

- Downtown
- Dunn's Crossing
- Forest Hill
- Fredericton South
- Fulton Heights
- Garden Creek
- Garden Place
- Gilridge Estates
- Golf Club
- Grasse Circle
- Greenwood Minihome Park
- Hanwell North
- Heron Springs
- Highpoint Ridge
- Kelly's Court Minihome Park
- Knob Hill
- Knowledge Park
- Lian/Valcour
- Lincoln
- Lincoln Heights
- Main Street
- Marysville
- McKnight
- McLeod Hill
- Monteith/Talisman
- Montgomery/Prospect East
- Nashwaaksis
- Nethervue Minihome Park
- Devon
- Northbrook Heights
- Plat
- Poet's Hill
- Prospect
- Rail Side
- Regiment Creek
- Royal Road
- Saint Mary's First Nation
- Saint Thomas University
- Sandyville

2.4 Discussion

Canopy cover for the City of Fredericton was 63.4% for canopy heights greater than 2 m. Urban and rural areas had canopy cover of 44.2% and 69.6%, respectively (Table 2 and Table 3). Canopy cover in Fredericton is relatively high for urban areas and compared with other Canadian cities (Table 4). This is partially attributable to the amount of forested area that has been retained in the urban portion of the City. Canopy cover in Fredericton is higher than other municipalities with comparable population or area, with Fort McMurray (pre-fire) and Halifax being comparable, and is similar to the most ambitious long-range canopy targets for many cities in Canada (Table 4). A mixture of climates is represented by these cities; however, the Ontario and Quebec cities are from the St. Lawrence Lowlands ecoregion which shares many tree species with the Maritime Lowlands ecoregion where Fredericton is located. Many of the southern Ontario cities have lost substantial canopy cover to EAB, however they have also lost large amounts of canopy to development prior to formalizing urban forest management.

Table 2: Total Canopy Cover – City of Fredericton

Canopy Height Range	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Total	4.6	11.6	47.1	36.6

Table 3: Canopy Cover Urban/Rural Split – City of Fredericton

Canopy Height Range	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Urban	3.5	8.8	32	55.8
Rural	5	12.6	52.1	30.4

Table 4: Canadian Cities Urban Forest Comparison – Canopy Cover and Targets

City (Province)	Canopy Cover (year)	Canopy Cover Target (year)
Cambridge (ON)[1]	27% (2015)	30% (2034)
Charlottetown (PEI)[2]	21% (2020)	N/A
Fort McMurray (AB)[3]	41% (2015), 25% (2016)*	25% (2025)
Guelph (ON)[4]	29% (2015)	40%
Halifax (NS)[5]	43% (2013)	(Targets per community)
Hamilton (ON)[6]	21% (2018)	30%
Kelowna (BC)[3]	16% (2013)	20%
London (ON)[7]	24% (2015)	34% (2065)
Mississauga (ON)[8]	19% (2014)	N/A
Montreal (QC)[3]	20% (2012)	25% (2025)

Table 4: Canadian Cities Urban Forest Comparison – Canopy Cover and Targets

City (Province)	Canopy Cover (year)	Canopy Cover Target (year)
Oakville (ON)[9]	28% (2015)	40% (2057)
Ottawa (ON)[10]	25% (2021)	40%
Toronto (ON)[11]	27% (2013)	40% (2050)
Vancouver (BC)[12]	18% (2018)	22% (2050)
Winnipeg (MB)[13]	17% (2018)	24% (2065)
*Decline due to large forest fire Sources: [1] Urban Forest Innovations Inc., Beacon Environmental Ltd. 2015; [2] City of Charlottetown 2020; [3] Rosen 2019, [4] City of Guelph 2019; [5] Halifax Regional Municipality 2013; [6] City of Hamilton 2020; [7] B.A. Blackwell & Associates Ltd. 2014.; [8] City of Mississauga 2014; [9] Town of Oakville 2016; [10] City of Ottawa n.d.; [11] City of Toronto 2018;[12] City of Vancouver 2018; [13] City of Winnipeg 2022		

Retention of forested areas within Fredericton is encouraging as these areas preserve natural heritage and create resiliency in ways that street trees cannot. However, they can make a city appear to have a higher canopy cover than what individual neighbourhoods experience by inflating the overall canopy coverage values in the city. As a result, it is important to view canopy coverage data at multiple scales to determine if this is the case in Fredericton. In an ideal scenario canopy cover within each neighbourhood would be approximately equal to the overall urban canopy cover. In practice this is difficult to achieve because land use practices are different between commercial, industrial, and residential areas. Also, new developments tend to result in tree removal with replanted trees tending to be smaller than trees in older neighbourhoods. Overall, Fredericton outperforms the typical other Canadian cities in every case, but canopy cover appears to be inflated by undeveloped treed land zoned as commercial or industrial within the City. As a result, canopy coverage in the City may be unrealistic to maintain considering future development (Table 5).

Table 5: Great Lakes St. Lawrence Lowlands Ecoregion Cities Urban Forest Comparison – Canopy Cover Per Land Use

Land Use Type	Average Canopy Cover	Fredericton Canopy Cover
Commercial	7.8 %	22.3%
Industrial	7.8%	51.5%
Low Density Residential	28.3%	50.9%
Medium/High Density Residential	21.1%	
Parks/Open Space	54.8%	69.6%
Institutional	16.2%	26.8%
Sources: City of Hamilton 2020; Town of Oakville 2016; B.A. Blackwell & Associates Ltd. 2014; City of Mississauga 2014; City of Toronto 2018.		

Fredericton's canopy coverage by ward, census tract, and neighbourhood were measured to evaluate the distribution of canopy coverage. The mean, median, and population standard deviation were calculated for each of these administrative areas. An overall set of the same measurements was calculated from the combined dataset (Table 6). The mean and median are close to one another in every case which indicates there are as many areas of high canopy coverage areas as low canopy coverage. The least symmetrical dataset is canopy cover by ward due to much lower cover in some wards. The standard deviation is moderately high for each dataset indicating moderately high variance in canopy cover between wards, neighbourhoods, and census tracts. For context the City of Charlottetown has published canopy cover by ward and that data is summarised by 22.8% mean, 20.3% median, and 5.8 population standard deviation. This distribution is more equitable than Fredericton's because the range of cover is smaller – however the absolute canopy cover is much lower with a maximum coverage of 33.1%.

Table 6: Canopy cover summary statistics by ward, neighbourhood, and census tract

Statistic	Ward	Neighbourhood	Census Tract	Overall
Mean	57.5	47.9	54.9	51.0
Median	63.8	45.8	54.2	51.0
Population Standard Deviation	13.6	19.1	20.7	19.2

Canopy cover targets should be determined based on available budget for planting efforts as well as the plantable space. If planting programs are focused on street trees, then the plantable space is determined by the available boulevard space. Once this space has been utilized, the canopy the City controls is maximized, and the priority shifts to succession planning so that as the largest trees decline the next age group is able to replace them with the least reduction in canopy cover and urban tree benefits. Use of NDVI imagery in conjunction with the canopy cover model is an effective method to determine the amount of plantable space. This is done by isolating the vegetation covered areas less than 1 m in height as these are typically turf or meadow areas. Non-plantable turfgrass areas (such as sports fields) are then subtracted to provide plantable area.

Fredericton has a high canopy coverage when considered at each scale examined from neighbourhood to urban and rural areas. This is also true for canopy coverage in terms of land use type. However, many areas within the City have lower canopy coverage and could benefit from future consideration.

2.5 Data Limitations

2.5.1 SPATIAL LIMITATIONS

The compiled dataset has canopy cover data for the entire 2022 City boundary and almost the entire 2023 proposed boundary. The public tree inventory covered the public ROWs within the urban portions of the City, while the plot sample survey covered the rural portion. As a result, areas within the urban boundary can only be directly compared to areas within the rural boundary using remote sensing data. Inferences can be made from the plot sample results or the public inventory, but this should be done carefully and with the understanding that they are different data types.

2.5.2 TEMPORAL LIMITATIONS

The database draws on several datasets collected at different times. Timespans within the database range from points data inventory and LiDAR collected in 2015 to plot samples from late 2022, resulting in discrepancies between datasets and existing conditions. The following are examples of such discrepancies:

- Street trees were inventoried in 2016 by UNB. For each tree, species, DBH, and health category were assessed. Where Parks and Trees have not removed a tree, the data point would exist in the same location and the species would not have changed. The DBH and health category are unchanged since the inventory date but may have changed since the inventory point. This may result in a discrepancy between the physical condition and the data.
- Trees planted after the 2015 would not appear in the 2015 LiDAR derive canopy model. For example, a tree planted in 2017 and inventoried by UNB in 2018 would appear in the inventory but would not appear in the 2015 LiDAR derived canopy model. Trees that were removed after 2015 but before 2018 would have the opposite impact on the inventory.

These challenges occur in almost every study where more than one dataset is compiled because it is often not feasible to synchronize the timing. Even LiDAR imagery and aerial photos from the same year are unlikely to be taken on the same day and are analysed sometime later. Therefore, the same issues exist and are magnified by the overall age of data and the different inventory dates.

2.5.3 DATA QUALITY LIMITATIONS

The point data inventories completed by UNB were subjected to quality assurance reviews before publication and are reported to be accurate enough for the purposes of this study. The point data has been maintained by qualified members of Parks and Trees as well as City GIS staff. Plot samples were collected by experienced field staff and guided by well-established sample methods and are useful if they are not extended past their intended use and the relative standard error of 20% is accounted for.

The LiDAR data used were of high enough resolution for the purposes of the report. The computation of LiDAR data to the raster image assigns a pixel to be the height that was measured so that resolution of the final image is based on the resolution of the input. The raster image is therefore not appropriate to be viewed at every level of magnification or zoom. As a guideline – if the canopy raster appears organic in shape, then the scale is likely appropriate for review. If the raster appears pixilated and jagged, then the level of zoom is likely too great.

The most effective means of screening out tall objects that are not trees from the canopy model is using the colour green in the near infrared imagery. This technique is most effective when the foliage is at peak chlorophyll. The imagery owned by the City was taken during partial leaf-off conditions which meant that the smallest filter range would remove trees form the canopy model. A larger range of values was therefore necessary, and this resulted in some non-canopy objects being included within the canopy model. The overall impact to the data is small assuming appropriate levels of magnification and analysis.

3 Urban Forest Canopy Status

The urban and rural divisions of the City that were discussed in Section 2 of this report were carried through to the canopy status analysis. This split was decided upon due to the spatial distribution of the tree inventory which included data points for individual trees. This data was collected in boulevards and City rights-of-way (ROW) areas within the urbanized portion of the City. A comprehensive street tree inventory is the most detailed data set typically used in urban forestry applications but is the most labour intensive to collect. For this reason, a detailed inventory of the entire City is not feasible.

The two main gaps identified in the gap analysis were an understanding of the trees on private land and trees in the wooded portions of the City. The spatial component (height, location, and spread of canopy) of these gaps were addressed in Section 2 through LiDAR methods. To address species composition and stem size of the gap areas a field study was undertaken. Plot sampling was selected due to its labour efficiency and established methods of analysis provided in the i-Tree Eco suite. This section will address the methods of analysis and results of the following tree classifications:

Rural Trees: All trees beyond the boundary of the urban area.

Urban Private Trees: All trees within the urban boundary growing on private land.

Urban Public Trees: All street, park, and trail corridor trees within the stratified urban boundary.

3.1 Rural Trees

The i-Tree Eco random sampling methods were selected to assess the health and structure of rural trees. Random sampling offers a relatively easy means to accurately assess urban forest structures and subsequently estimate its ecosystem services and values (Nowak et al. 2008a). Seventy (70) circular plots with a radius of 11.3 m were randomly established within rural areas using GIS. Data for these plots was collected using i-Tree ECO plot sample data collection protocol. Refer to i-Tree documentation for protocol details.

A relative standard error of less than 20% is expected with 70 plots (Nowak et al. 2009b). An increased number of plots within the strata would decrease the standard error (increase the precision of the data), however the field survey was time-constrained by leaf drop in October 2022.

Detailed vegetation information was recorded for each plot in accordance with i-Tree Eco data collection protocol. This protocol can be accessed for detailed review online through the program documentation. The following is an overview of the recorded plot data:

- Percent tree cover.
- Percent shrub cover.
- Percent plantable space.
- Land use as observed in the field.

- Percent of plot within each observed land use.
- Percent ground cover of each groundcover type:
  - 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 trunk diameter at breast height (1.4m) (DBH) of at least 3 cm, the following data were recorded:

- Species.
- Status (planted, naturally in-seeded, or unknown).
- Land use in which the tree is growing.
- Number of stems.
- DBH for each stem up to a maximum of 6 stems.
- Tree height.
- Height to top of live crown, if different from total height.
- Height to base of live crown.
- Crown width (average of two perpendicular measurements).
- Percent canopy missing.
- Tree condition (based on percent of branch dieback in crown):
  - Excellent (< 1 dieback)
  - Good (1-10)
  - Fair (11-25)
  - Poor (26-50)
  - Critical (51-75)
  - Dying (76-99)
  - Dead (100-no leaves)
- Percent of area under tree canopy occupied by impervious ground surface.
- Percent of area under tree canopy occupied by shrub mass.
- Crown light exposure (number of the tree's sides out of a total of 5 that are exposed to direct sunlight).

3.1.1 RURAL TREES DATA ANALYSIS

Data from the 70 field plots were analysed using the i-Tree Eco v6 model developed by the U.S. Forest Service, Northern Research Station 2022. This is an industry standard urban forest modelling program. The i-Tree Eco model used standardized field, air pollution-concentration, and meteorological data for Fredericton to quantify urban forest structure and function. Detailed analysis methods and metrics are available in the program documentation and supporting research online (USDA, n.d.). The analysis utilized the following model components:

- Urban Forest Structure:
  - Quantifies urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf, and tree biomass) based on field data.
- Biogenic Emissions:
  - Quantifies 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
  - O_3 and carbon monoxide (CO) formation based on VOC emissions.
- Carbon Storage and Annual Sequestration”
  - Calculates total stored carbon, and gross and net carbon sequestered annually by the urban forest based on field data.

3.1.1.1 Tree Characteristics

The rural forest of Fredericton has an estimated 4,616,000 trees with a density of 348 trees/ha (Table 7). The three most common species are balsam fir (41.8 percent), red maple (11.4 percent) and red spruce (8.9%), with 89% of all trees native to North America.

In rural Fredericton, the most dominant species by leaf area are red maple, silver maple, and balsam fir (Table 7). Importance values (IV) are calculated as the sum of percent population and percent leaf area. High importance values do not mean these species should necessarily be encouraged in the future; rather these species currently dominate the urban forest structure. The IV score is a good indicator of what each species is contributing in terms of the key metrics and ecosystem services considered in the model. A detailed analysis output is available in the technical appendices. Some of the key metrics include (all values in CAD):

- Number of trees: 4,616,000.
- Most common species of trees: Balsam fir, Red Maple, Red spruce.
- Percentage of trees less than 15.2 cm diameter: 57.0%.
- Carbon Storage: 525 thousand metric tons ($60.4 million).
- Carbon Sequestration: 14.04 thousand metric tons ($1.6 million/year).

- Oxygen Production: 15.4 thousand metric tons/year.
- Avoided Runoff: 48.8 thousand cubic meters/year ($113 thousand/year).
- Replacement value: $2.6 billion.

Table 7. Most important species in rural Fredericton

Common Name	Percent Population	Percent Leaf Area	IV
Balsam fir	41.8	9.2	51
Red maple	11.4	22.2	33.6
Silver maple	2.5	13.4	15.9
Red spruce	8.9	5.8	14.8
Eastern hemlock	3.4	4.8	8.1

(Source: Stantec modelling)

3.1.1.2 Carbon Storage and Sequestration

Trees can help mitigate climate change by sequestering atmospheric carbon from carbon dioxide in tissue and by reducing energy use in buildings, and consequently reducing carbon dioxide emissions from fossil-fuel based power sources (Abdollahi et al 2000). Carbon storage is the total amount of carbon contained in the tree while sequestration refers to the process of turning atmospheric carbon into tree tissue. The amount of carbon annually sequestered increases with the size and health of the trees (Nowak et al. 2006).

Gross sequestration of carbon by trees in Fredericton is approximately 14,040 metric tons of carbon per year with an approximate value of $1.6 million calculated with the default valuation in i-Tree ($114.87/ton). Net carbon sequestration in the urban forest is approximately 5,600 metric tons. When trees die and decay much of the stored carbon is released back into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance can contribute to carbon emissions (Nowak et al 2002c). When a tree dies, using the wood in long-term wood products, to heat buildings, or to produce energy will help reduce carbon emissions from wood decomposition or from fossil-fuel offsetting.

Trees in rural Fredericton are estimated to store 525,000 metric tons of carbon ($60.4 million). Of the species sampled, silver maple stores the most carbon (approximately 21.3% of the total carbon stored) and red maple sequesters the most (approximately 26.6% of all sequestered carbon).

3.1.1.3 Oxygen Production

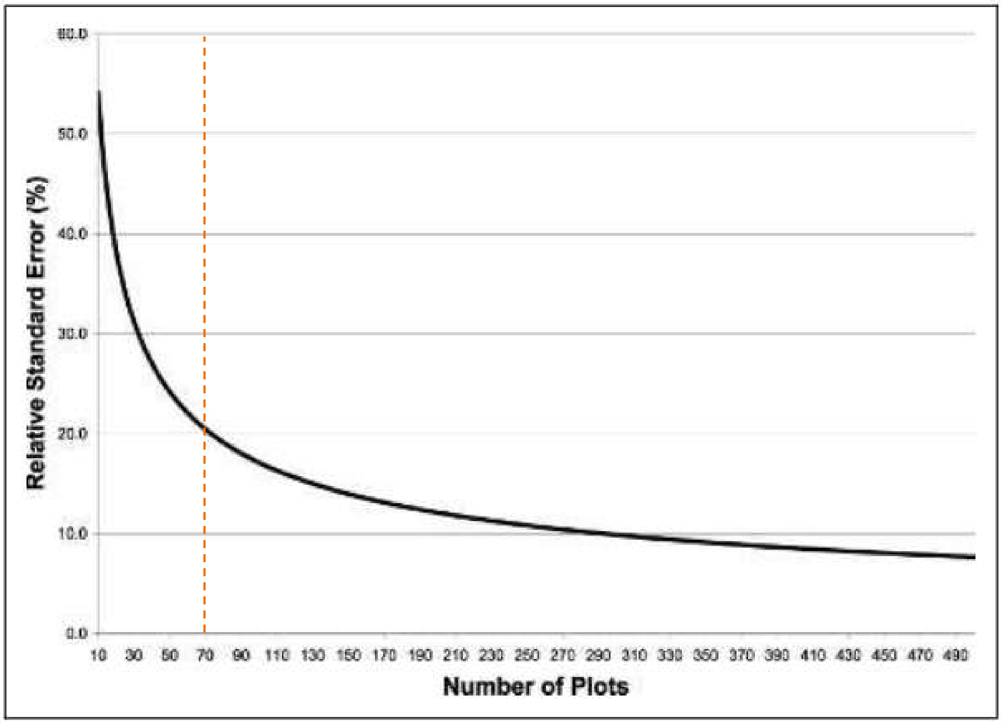
Oxygen production is one of the most cited benefits of urban trees. The net annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass. Trees in Rural Fredericton are estimated to produce 15,140 metric tons of oxygen per year (Table 8). However, this benefit is very small because of the large and relatively stable amount of oxygen in the atmosphere and extensive production by aquatic systems. If all fossil fuel reserves, all tree, and all organic matter in soils were burned, atmospheric oxygen would only drop a few percent (Broecker 1970).

Table 8. The top 10 oxygen production species

Species	Oxygen (Metric ton)	Net Carbon Sequestration (Metric ton/year)	Carbon Storage (Metric ton)	Number of Trees	Leaf Area (hectare)
Red maple	9.7	3,436.92	86,662.60	525,459	5,941.57
Silver maple	3.04	1,140.75	112,169.10	1,117,185	3,578.29
Quaking aspen	0.92	343.83	9,990.20	272,720	406.71
Weeping Willow	0.85	318.45	17,879.10	5,580	811.69
Northern red oak	0.75	282.23	16,628.50	13,481	1,377.6
Freeman maple	0.69	257.92	14,108.50	33,481	845.12
Norway maple	0.57	212.55	5,093.00	39,979	504.24
Black locust	0.54	202.82	3,690.50	55,802	611.95
Sugar maple	0.46	170.86	13,151.10	31,927	620.90
American beech	0.39	147.92	13,260.70	50,222	1,477.01
Subtotal	**17.91**	**6,514.25**	**292,633.30**	**2,145,836**	**16,175.08**

3.1.2 RURAL TREES DATA LIMITATIONS

The accuracy of a plot sample survey depends on how well the sampled portion of the City represents the City as a whole. Accuracy of random sample protocols increase as sample size increases. The sample size for this study was restricted based on available field time with leaf fall occurring in October. Greater accuracy could be achieved, however the data quality – some collected data depends on accurate foliage assessment – would have declined. The main objective of the plot sample study was to gain an understanding of rural species composition to synchronize with the LiDAR-assessed canopy cover. This objective was achievable without higher sample densities required to get detailed results. Rapid decrease in Relative standard error decreases rapidly as plot numbers increase until between 50 and 90 plots where the relative standard error decrease more slowly (Figure 3). The opportunity to develop some estimates of ecosystem services through use of i-Tree was an additional benefit. Any further analysis of the data produced through plot sampling beyond the intended use should consider these limitations.



(Source: Nowak et al. 2008b)

Figure 3. Relationship Between Relative Standard Error and Number of Trees Sampled.

3.2 Urban Trees

An assessment of vegetation structure, function, and value of Fredericton urban areas was completed using existing tree inventory data. Data from 19,288 trees located on public ROWs within the urban portion of Fredericton were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station. i-Tree ECO's forecasting module was also used to model the growth of urban public trees 30 years into the future. The following two modelling scenarios were completed:

- Scenario 1: Existing annual planting efforts.
- Scenario 2: Planting and management efforts that maintain current canopy cover.

The urban forest of Fredericton has 19,288 trees and the prevalent common genus is maple (*Acer*). The three most common species are Norway maple (18.5%), red maple (12.5%), and sugar maple (12%).

Urban forests are composed of a mix of native species and additional exotic tree species which can increase tree diversity. Increased tree diversity can reduce the likelihood of occurrence or severity of insect or disease outbreaks, but it can also pose a risk to native plants if some of the exotic species are invasive plants capable of outcompeting and displacing native species. Invasive plant species are often characterized by their vigour, ability to adapt, reproductive capacity, and general lack of natural predators. These abilities can enable non-native plants to displace native plants and make them a threat to natural areas. In Fredericton, approximately 59% of urban trees are species native to North America, with 22% of non-native trees originating in Europe and Asia.

In urban Fredericton, the most dominant species by leaf area are Norway maple, American basswood, and sugar maple (Table 9). Importance values (IV) are calculated as the sum of percent population and percent leaf area. High importance values do not mean that these trees should necessarily be encouraged in the future; rather these species currently dominate the urban forest structure. The IV score is a good indicator of the contribution of each species in terms of the species' role in the urban forest and ecosystem services (see Appendix F for a detailed analysis of the model output). Some of the key metrics include:

Number of trees: 19,288.

Tree Cover: 63.99 hectares.

Most common species of trees: Norway maple, Red maple, Sugar maple.

Percentage of trees less than 15.2 cm diameter: 37%.

Carbon Storage: 9.336 thousand metric tons ($1.07 million).

Pollution Removal: 1.88 metric tons ($8.01/thousand/year).

Carbon Sequestration: 124.4 metric tons ($20.8 thousand/year).

Oxygen Production: 331 metric tons/year.

Avoided Runoff: 10.9 thousand cubic meters/year ($37 thousand/year).

Replacement values: $35 million.

Table 9. Most Important Urban Tree Species in Fredericton

Common Name	Percent Population	Percent Leaf Area	IV
Norway maple	18.5	20.5	39
Sugar maple	11.8	10.5	22.3
Red maple	12.4	9.5	21.9
Littleleaf linden	7.9	13.5	21.4
Green ash	8.3	10.6	18.9
Northern red oak	7.8	8.1	16
White ash	3.6	5	8.6
Silver maple	1.8	6.0	7.8
White elm	2.9	2.6	5.5
Eastern white pine	1	2.2	3.2
Subtotal	**76**	**78.5**	**164.6**
Total (including all other species)	**100**	**100**	**200**

3.2.1 CARBON STORAGE AND SEQUESTRATION

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

The amount of carbon sequestered annually increases with tree size and health. Gross sequestration of trees in the urban forest of Fredericton is approximately 124.4 metric tons of carbon per year with an associated value of $14,300 (Appendix F). Street and Park Trees in Fredericton are estimated to store 7,010 metric tons of carbon ($806,000). Of the species sampled, Norway maple stores and sequesters the most carbon (approximately 25.1% of the total carbon stored and 30.4% of all sequestered carbon.)

3.2.2 OXYGEN PRODUCTION

Oxygen production is one of the most cited benefits of urban trees. The net annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass. Trees in rural Fredericton are estimated to produce 4,019 metric tons of oxygen per year (Table 10). However, this tree benefit is relatively insignificant because of the large and relatively stable amount of oxygen in the atmosphere and extensive production by aquatic systems.

Table 10. The top 5 oxygen production species

Species	Oxygen (metric ton)	Gross Carbon Sequestration (metric ton/year)	Number of Trees	Leaf Area (hectare)
Norway maple	100.95	37.86	3,561	96.90
Red maple	45.02	16.88	2,400	44.87
Northern red oak	34.83	13.06	1,531	63.87
Sugar maple	26.49	9.93	1,511	38.49
Green ash	20.86	7.82	2,278	49.69
Subtotal	**228.15**	**85.55**	**11,281**	**293.82**

3.2.3 RUNOFF MITIGATION

Surface runoff can be a cause for concern in many urban areas as it can contribute to pollution of streams, wetlands, rivers, lakes, and oceans. During precipitation events, some portion of the precipitation is intercepted by vegetation (trees and shrubs) while the other portion reaches the ground directly. The portion of precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff (Hirabayashi 2012). In urban areas, the large extent of impervious surfaces increases the amount of surface runoff. Urban trees and shrubs, however, are beneficial in reducing surface runoff. Trees and shrubs intercept precipitation, while their root systems promote infiltration and storage in the soil.

Avoided runoff is estimated based on local weather from the Fredericton Airport weather station. In Fredericton, the total annual precipitation in 2018 was 107.9 centimeters. The i-Tree methods for calculation estimate rainfall interception based on the cubic metres of water intercepted by square metre of canopy multiplied by the canopy cover. The trees and shrubs of Fredericton help to reduce runoff by an estimated 10, 800 m^3/year with a value of $24,000.

3.2.4 AIR POLLUTION MITIGATION

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damage to sensitive flora and fauna, ecosystem processes, and reduced visibility. Urban forests can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power sources (Nowak & Heisler 2010). Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation (Nowak and Dwyer 2000).

Pollution removal by trees in Fredericton was estimated using field data and recent available pollution and weather data (2010). Pollution removal was greatest for ozone (O_3). It is estimated that trees in Fredericton remove 1.88 metric tons of O_3, carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter less than 2.5 microns (PM2.5), particulate matter less than 10 microns and greater than 2.5 microns (PM10), and sulphur dioxide (SO_2) per year with a value of $8, 010.

3.3 Forecasting the Urban Forest

The urban street tree inventory was modelled via the i-Tree Forecast module using the baseline City target planting scenario of 500 trees planted annually. Two scenarios have been modelled for leaf area after a 30-year period. In both scenarios the City is faced with an extreme weather event in year 12, beech bark disease (starting year 1), EAB (starting year 1), DED (continuing year 1), and HWA (starting year 5). Both models consider the current size, health, and species for each tree in the inventory. The following differences occurred between each scenario:

1. A low mortality scenario where pests and diseases are proactively mitigated, and proactive pruning continues. This scenario represents an extension of current management practices to meet additional pest and disease challenges.

2. An average mortality scenario where pests and diseases are reactively mitigated and reactive pruning is used. This scenario represents less effort being expended on pruning and maintaining treatment for DED but not controlling other pests to a significant degree.

In scenario 1, proactive pruning lessens damage during extreme weather events from a 25% mortality rate (assumed for scenario 2) to a 10% rate. Proactive pest and disease management also reduces annual mortality.

Extreme weather events and pest and disease outbreaks are likely to occur within the modelled period. DED is currently controlled in Fredericton, EAB has been confirmed since 2021, BBD is present in New Brunswick, and HWA is present in southern Nova Scotia. Extreme weather events are not as predictable, but it is reasonable to expect at least one event in a 30-year period.

In both scenarios there is decline over the 30-year period, however leaf area is 1.9 times greater in 2053 for scenario 1 compared to scenario 2 (Table 11). The number of trees with a DBH less than 8 cm is similar by 2053, but the number of trees in the larger size classes is substantially higher in scenario 1. Larger trees have more leaf area than small trees which accounts for some of the difference in the two scenarios. The total number of trees is also larger by 2032 in scenario 1 than scenario 2 because mortality has been reduced while planting the same number of trees.

The decline in leaf area for both scenarios highlight a planting deficiency if the target is to maintain or grow the leaf area of the urban forest. The magnitude of the deficiency is difficult to estimate because the potential range of storm damage is wide, and the timing is also unknown. Substituting approximately 900 trees planted per year into the low mortality scenario nets leaf area growth at 30 years with no major storm event. With 1000 trees planted per year in the low mortality scenario the 2053 leaf area is projected at 446 ha. Extrapolating this result the City would likely need to plant 1500 – 2000 trees to maintain leaf area in the low mortality scenario. Leaf area will fluctuate based on mortality and planting and should not be expected to follow a linear increase.

Table 11 shows the results of the models. DBH models of the two scenarios in year 30 are found in Figure 4 and 5. The model advances existing and planted trees through successive size brackets to account for annual growth. There is the possibility of underestimation due to the time elapsed between the initial measurement and the start of the model – in this case 8 years. The effect of this in both 30-year models would likely be a larger number of 8-15 cm DBH trees.

Table 11. Forecast model results for leaf area

Scenario	2023 Leaf Area	2053 Leaf Area
Low Mortality (Scenario 1)	472.8 ha	429.0 ha
Average Mortality (Scenario 2)		229.5 ha

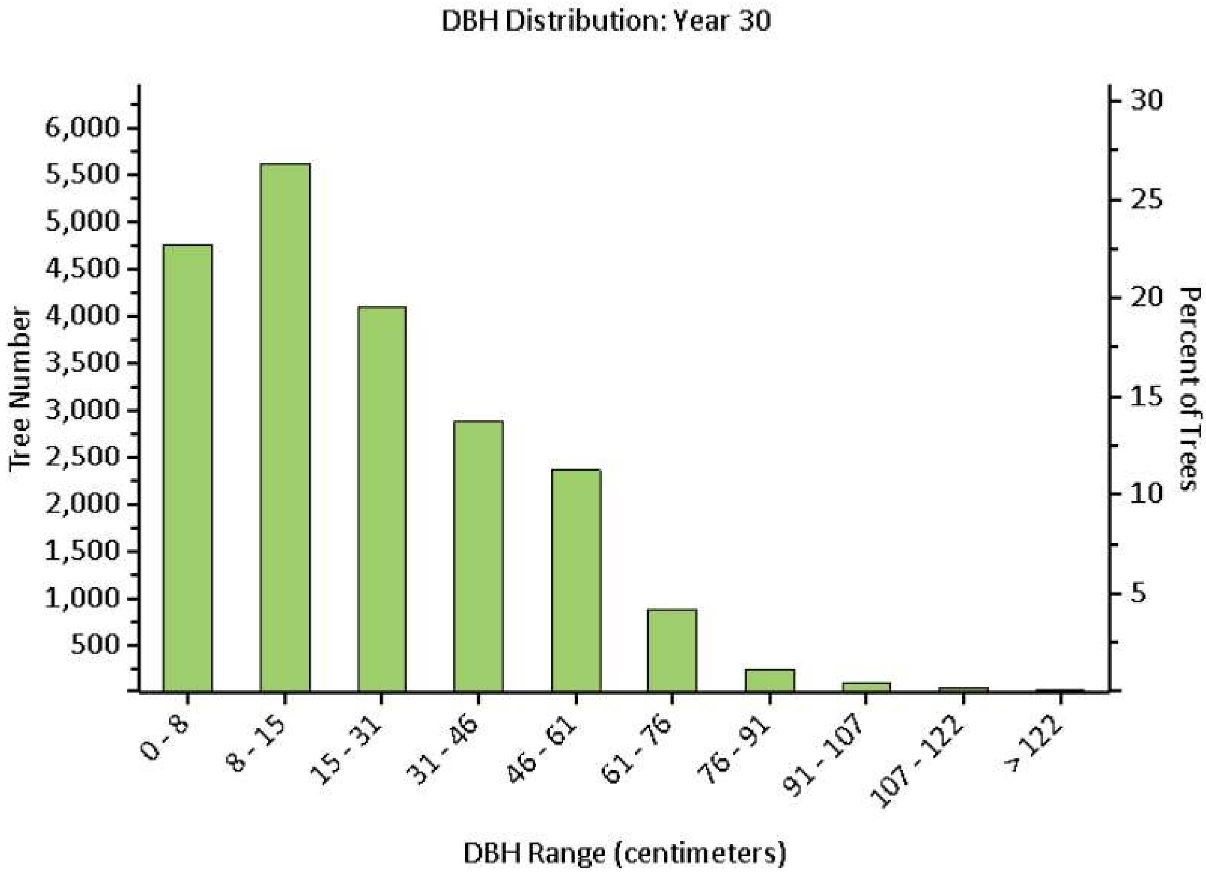


Figure 4. Forecast model results for DBH distribution in the low mortality scenario.

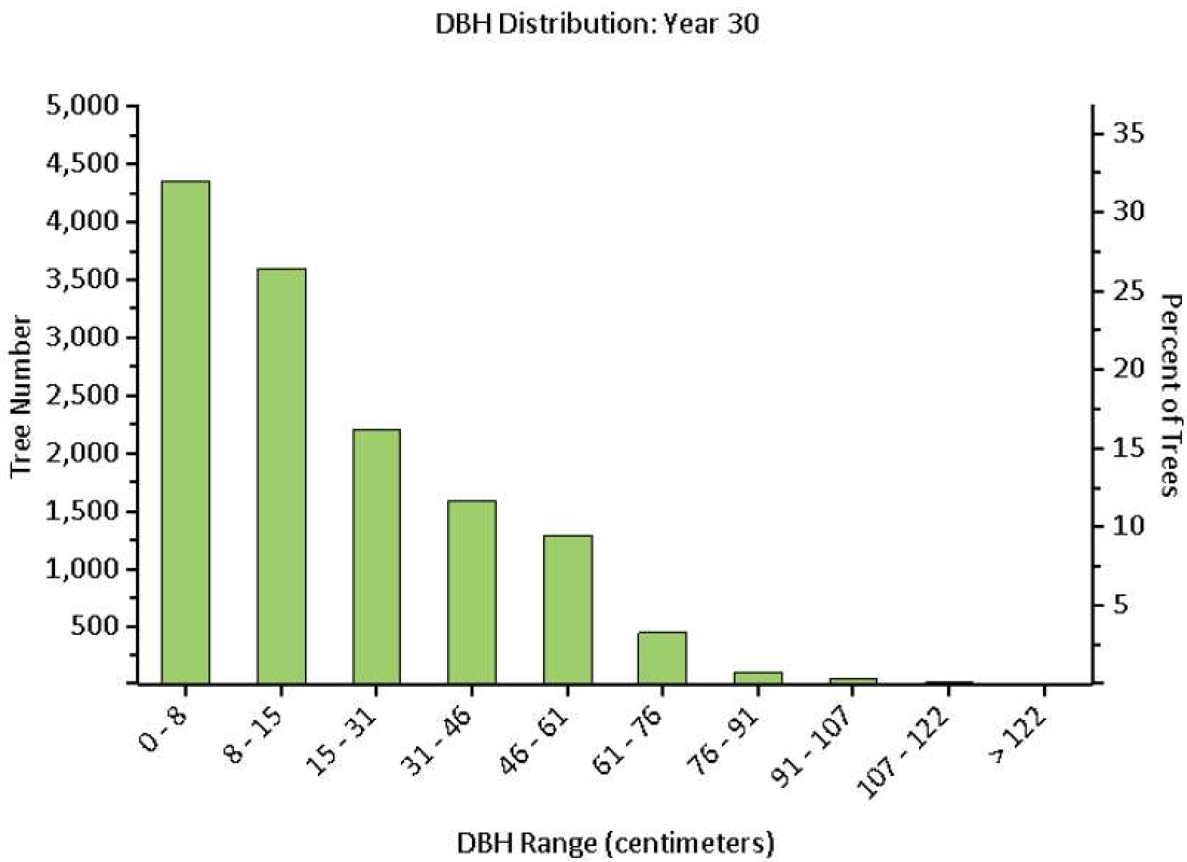


Figure 5. Forecast model results for DBH distribution in the average mortality scenario.

The results of the models illustrate the difference that a proactive approach could have assuming the pruning and pest control efforts bear out the modelled impacts. It also demonstrates the approach required to manage an urban forest which transitions to a stable population rather than an increasing one. A plantable space analysis will be required to confirm the remaining space for urban forest expansion in Fredericton. In a stable population the aim of planting is to maintain the population size by replanting to mitigate the mortality rate while simultaneously maintaining the existing trees with the goal of minimizing mortality. The result is a more stable leaf area and more stable ecosystem services as a result.

3.4 Discussion

Estimations of ecological benefits are calculated based on the size, condition and species of tree and are backed by a large scientific body of work (Nowak & Dwyer 2000). These benefits are an important driver of the need to effectively manage an urban forest. In this case effective management refers to the long-term retention or growth of benefits despite changes to the urban forest through pest outbreaks, development pressure, storm events, and natural mortality. An understanding of species composition, size distribution, and condition are important factors in planning for effective management.

Species diversity contributes to resiliency to climate change, native and introduced pests, and development pressures impact individual species in different ways (Kendal et al 2014). Species diversity can hedge against these changes and contributes to ecosystem function. This is a relevant metric because the percent of the population demonstrates the vulnerability of the urban forest, and the percent leaf area shows the magnitude of the impact a species has. A more diverse population tends to be more resilient to pests that target specific species or genera because a smaller number will be susceptible.

Table 12. Most important species in rural and urban Fredericton

Common Name	Rural IV	Urban IV
Balsam fir	51	-
Red maple	34	22
Silver maple	16	8
Red spruce	15	-
Eastern hemlock	8	-
Norway maple	-	39
Sugar maple	-	22
Littleleaf linden	-	21
Green ash	-	19
Other species	76	69
Total	**200**	**200**

The rural portion of the City's forest is not actively managed by Parks and Trees and is largely private lands and forest tracts (with the exception of management in Killarney Park). Within the urban portion maples comprise 91 IV. The relative importance of red and silver maples is less in the urban portion than the rural portion, however a large contribution from Norway maple and sugar maple increases the maple genus proportion. Linden (*Tilia*) and green ash (*Fraxinus*) are the other two genera represented in the top five species by urban importance. The top three urban genera contribute 131.3 IV out of a total 200 IV (66%), representing low diversity in terms of ecological services.

Size distribution is an important consideration because size contributes to benefits per tree (larger trees generally have more leaf area and store more carbon) but also reflects tree age. All trees have a natural mortality rate and lifespan which means that replacement is important for maintaining levels of ecological benefits. Richards (1983) proposed the commonly accepted size distribution based on DBH measurement. This distribution has been modified for municipal environments and modelled to achieve continuous canopy coverage. This ideal is based on an expanding population which is prevalent in most municipalities with canopy targets above their existing canopy cover measurement. This may not be the case in Fredericton as the City has a comparatively high canopy coverage measurement. A plantable area inventory will be needed to confirm as management differs between an expanding population and a stable one (Morgenroth et al. 2020).

Fredericton's urban forest has a high proportion of trees in the 30.6 cm to 61 cm DBH range (Figure 6). Trees this size have a large contribution to ecological benefits of an urban forest. Fredericton's size distribution lags the ideal in the 0-15.2 cm, 15.3-30.5 cm, and 61.1< cm categories but is not heavily focussed in any single category. A forest of this size composition is expected to outperform a forest with ideal composition due to the high proportion of mature trees which have higher leaf areas per tree. This higher leaf area corresponds with higher ecological services per tree. However, an increased focus on tree renewal will be required in the medium term as mortality in this cohort increases with age.

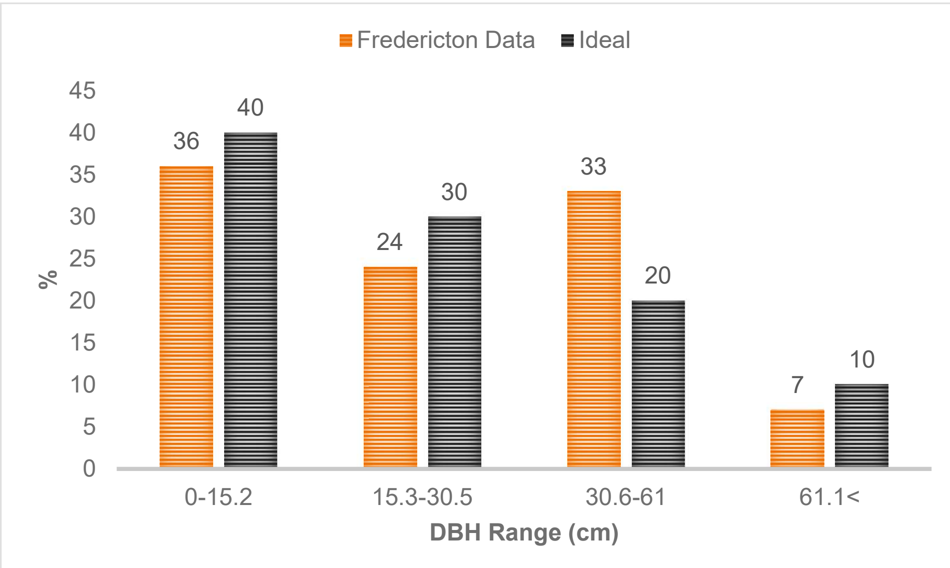


Figure 6: Fredericton Urban Tree Size Versus Ideal Population by Size

Urban forest tree health is an important consideration as ecosystem services are a function of leaf area and vigour is important for leaf area. Additionally, a healthy tree is more resilient to environmental or biological stresses such as drought or pest infestation. A high percentage of trees (98%) in Fredericton are of average to excellent condition, suggesting that tree species selection has been very effective based on the conditions and that proactive maintenance has had a positive effect.

4 Urban Forest Management Review

Urban forest management can encompass a wide range of actions including tree removal, planting, pruning, pest management, development of bylaws or policies, and planning activities. At one end of the spectrum is wholly reactive management where trees are felled or cleaned up when they fail but no other actions are taken. At the other end would be a management plan that includes pest management, proactive pruning cycles, and in-depth planning exercises. An understanding of baseline management planning is important to guide the development of an urban forest management plan. For this purpose, a summary of the current urban forest management system has been included along with a brief comparison to some other municipalities.

4.1 Field Staff

The Parks and Trees division had four crews consisting of seven full time staff (including ISA Certified Arborists, foresters, forest technologists, and horticulture technicians) and 7 summer students in the field for 2022. One crew was operating in their fourth year of a seven-year pruning cycle of city owned ROW and park trees. This cycle is planned from a street and urban park inventory which covers the urban portion of the City. The second crew was responsible for completing tree removals with a bucket truck. All street and park tree pruning, planting, and removal is completed by City staff except for clearing of hydro lines which is completed by the distributor, NB Power. The third crew was responsible for watering plantings from the previous season using gator bags. The final crew was an Integrated Pest Management (IPM) team consisting of three to four UNB forestry summer students. This crew was responsible for EAB treatment, monitoring EAB populations, and DED treatment. For 2023 a second bucket truck crew will be added focusing on park and trail tree care.

Compared to other municipalities, Fredericton is more proactive in management style and contracts out less work. In many municipalities large-scale removals and some street tree pruning are often performed by contractors. Fredericton's ability to handle urban forest management work without external contractors is likely dependant on the continuing proactive management of the forest. The pruning cycle allows for more consistent work, helping to avoid labour requirement peaks following storm events, which are typically required to be filled by external contracts in many municipalities.

4.2 Pest Management

EAB was detected in Fredericton in February 2021. Since its detection the City has adopted a proactive management approach, which includes selecting trees as candidates for TreeAzin® injection. Tree selection is based on percentage of dieback with trees with less than 1/3 canopy dieback selected for injection. This is a very proactive approach which some municipalities have used. This approach maximizes ash retention and lengthens the period of mortality rather than experiencing a mortality peak approximately 5 to 10 years into an infestation.

Ash trees that are not suitable for injection are scheduled for proactive removal by City crews and replanting with alternative species. Injection treatments are biennial, and the City has set a goal of injecting 650 trees annually, which would result in a total of 1300 protected trees. 634 trees were treated in 2022 and approximately 500 trees were treated in 2021. No outside contractors have been used in the study and field work regarding EAB management.

Fredericton's EAB approach is proactive compared with many municipalities. Having a proactive maintenance and operations program in place as well as an IPM program are beneficial to EAB management, and Fredericton has likely benefited from observing the EAB responses in Ontario and the United States.

EAB mortality rates typically spike over a two-to-three-year period due to delayed detection and the number of ash trees in the urban forest. The ash genus is a large component of the Fredericton urban forest but is not as high as some municipalities in Ontario. Contracting out tree removal was a necessity for these municipalities due to the high volume of dead hazardous ash trees that required immediate removal.

Elm trees have a special history and cultural significance in Fredericton. The Parks and Trees division is responsible for the identification and treatment of white elm trees (*Ulmus americana*) on City property within the Dutch elm disease management area, which includes the neighbourhoods of the Downtown Core and Devon. The City uses DutchTrig® which is an annual injection. The injections are partnered with a monitoring program which identifies trees infected with DED and determines which require removal. This is also a proactive approach compared with many municipalities though depending on location many cities lost their elm canopy prior to the advent of injections. In these cases, cities have been trialling several cultivars of elm which are resistant to DED. These trials have had successes, but the trees have yet to reach maturity.

4.3 Tree Planting

City crews plant approximately 500 trees annually with planting occurring in spring. Trees are maintained through three seasons by a watering crew. The objective of this program is to plant a tree in front of every residential property or business if site conditions are conducive. Tree species are selected based on the site constraints with small stature trees planted where overhead wire conflicts exist. Where possible, trees are planted in advance of removing unretainable ash trees to proactively offset canopy loss.

The cost of each tree planting was $500 in 2022 for 40 mm calliper containerized stock. This figure reflects tree purchase, planting, and watering for the first year. Trees are sourced from a single Ontario nursery due to the lack of tree nurseries within New Brunswick capable of supplying the quantity required by the City. The need to source tree stock from Ontario is a disadvantage to Fredericton and eastern Cities as wire basket stock is a bulky item to transport and nursery stock can be negatively impacted by transport depending on truck type and environmental exposure. Trees not up to quality standard for planting, as determined by the City division, are separated from the delivery stock and heeled-in within the City yard. These trees are maintained by City staff until they are approved for planting.

One solution to the supply issue would be for the City to consider a multiyear contract with a grower to guarantee quantities purchased and increased quality of stock. This type of relationship exists between nurseries with many contract-growing certain species and sizes to a particular specification for other nurseries. This would allow the City to secure a reliable source of stock and also determine the species compositions a year in advance. Several types of stock could be explored through this type of arrangement such as fibre container stock and large liner stock which are more economical to ship but require more maintenance to attain the size of a 40 mm calliper tree.

Parks and Trees has broken ground on an exciting new zero-carbon greenhouse project. When complete, the greenhouse will support the City's street and park tree planting program, providing better planting stock of native tree species grown from locally sourced seeds. This will reduce the carbon footprint of transporting nursery trees from greenhouses out of province. By using seeds collected from local sources and growing them in a City-owned greenhouse located in Fredericton, the trees will already be optimized to the local climate when planted in ROWs and will not be at risk of transporting non-native pests or diseases to the City from out of province.

The greenhouse will be 30'x 96' and equipped with automatic roll up sides, a sprinkler system, and an automatic ventilation system. To align with the Climate Change Adaptation Plan's target of reducing corporate emissions by 30% by 2030 and 80% by 2050, the greenhouse will be heated using an earth battery heat retention system. This system consists of a series of pipes in sand layered underneath the building. As the greenhouse warms during the day, some of this heat will be captured and stored underground in the pipes, warming the sand around it, then released back into the greenhouse as the building cools at night. By storing and using the heat naturally produced in the building during the daytime, we will be drastically reducing total energy loss and consumption for this new structure.

This project is being supported by funding from the 2 Billion Trees Program's Capacity Building Grant. Trees are known to capture and store carbon from the atmosphere, cool urban centers, support biodiversity, and enhance human well-being. This program is a part of the federal government's commitment to the 2030 Paris Agreement and aims to support the planting of trees to reduce greenhouse gas emissions, helping Canada reach net zero by 2050.

The completion of this project will allow the City to have access to trees as needed, scale up our planting program, and address any future decline in the urban canopy due to invasive pests such as the EAB. A municipally owned greenhouse allows the City of Fredericton to ensure the resilience of the urban canopy, and using locally sourced seeds will ensure that these native trees have a greater ability to adapt to a changing climate.

4.4 Policy and Management

The City of Fredericton Parks and Trees division manages the urban forest within the City and reports to Council. This includes the rural and urban portions of the City, though the majority of maintenance and planning efforts have been directed at the urban portion. The Division has adopted a proactive management position and completes its operations through internally employed staff.

The Fredericton Tree Commission is an advisory body which reports to Council. The Commission is appointed by resolution of Council per By-Law No.L-7. The membership includes one City Councillor, one City Forester, one Forest Technician, and eight council appointed members. The Tree Commission's role is to provide advice and recommendations to City Council, City staff and the Planning Advisory Committee regarding issues related to the urban forest.

One such policy would be By-Law No. L-18 A By-Law for the Management of Trees Within the City of Fredericton. Enacted January 13, 2020, the bylaw defines the authority of the City over publicly owned trees and some limited authority over privately owned trees. This is the key policy providing protections to the trees of the urban forest.

In many small municipalities trees fall under the jurisdiction of public works or an equivalent department. If there is a policy regarding trees this can be administered through public works or a planning department. In many large municipalities trees are under the jurisdiction of a dedicated urban forestry department or are a part of the parks department. In this regard, Fredericton has a structure that is typical of its size and regional importance. The Commission is a unique addition, however, and a dedicated commission to Council to report on tree matters highlights the importance of trees in the City.

By-Law L-18 is structured in a similar fashion to many By-Laws protecting publicly owned trees. The prohibitions, exemptions, and authority given to the City are all in agreement with what would be expected of a City of Fredericton's size. Some smaller municipalities do not have by-laws protecting trees. The next step above this would be municipalities who protect trees on public property or who have by-laws prohibiting planting of trees on public land unless so authorized.

The next level of tree protection would be a by-law providing prohibitions and exemptions of trees located on private property and a policy defining the expectations of tree retention through development. These are common in larger cities with set canopy targets and strong development pressures. These by-laws vary in detail regarding the minimum protected size of tree, protections of certain species, and number of trees but all generally require some type of permit for a landowner to remove trees. Two by-laws with two standards for tree permits are common in many cities with urban centres and large rural areas. In some cases, the by-law requirements are only applied to the urban portion of a city.

Administration of tree protection bylaws and permit processes can have an important impact on the workload of urban forestry departments. Varying levels of dedicated staff are required depending on the volumes of permits submitted with some departments understaffed. This can lead to frustrated applicants and workplace morale issues. These issues are important considerations for any bylaw changes.

4.4.1 URBAN PLANNING

The specific urban planning policies from the *Fredericton Growth Strategy* and *Imagine Fredericton: The Municipal Plan* are referenced in Section 1.2 of this report. The policies can be summarized as below.

- Policies requiring or encouraging street tree planting in development areas and existing neighbourhoods. This is the most frequent area of policy related to trees in the documents.
- Policies encouraging retention of mature, healthy trees.
- Policies encouraging the sustainable management of all trees in the urban forest and growth of the urban forest.

Specific targets noted in the policies include an increase in street trees and an increase in tree canopy. This is likely feasible when strictly considering numbers of street trees. There is likely adequate plantable space to increase the number of street trees without development and the street cross sections proposed in the *Growth Strategy* include plantable space. These cross sections would be most beneficial in the urban centre where canopy cover is low.

It is unlikely that the target of increasing the urban forest canopy is possible when considering the entire canopy and not the quantity of street trees. Table 5: Great Lakes St. Lawrence Lowlands Ecoregion Cities Urban Forest Comparison – Canopy Cover Per Land Use compares the average canopy cover for various land uses in several cities to those of Fredericton. Setting aside parkland, Fredericton has 1.7 to 6.6 times more percent canopy cover per land use type, due to Fredericton having a lower density of development, or many parcels zoned for development that have yet to be developed.

The *Growth Strategy* identifies 200 ha of undeveloped land within the urban area and an additional 400 to 525 ha in the rural area required to accommodate the 2041 population projections. A further 45.2 ha are projected to accommodate employment growth in the following land uses: retail and commercial service employment (18.9 ha), institutional employment (12.8 ha), industrial employment (11.0 ha), and commercial office employment (2.5 ha). Currently there is a total canopy cover greater than 2 m in height of 81.7% (per 2015 LiDAR) in areas zoned as Future Development. It would be expected that post development this figure would shrink to 20-30% considering the canopy cover in development areas reported by comparator cities. Even accounting for more street tree planting this amount of reduction is not typically feasible to offset.

4.5 Natural Areas

Most of the Parks and Trees planning, maintenance, and planting efforts are expended on urban street trees and maintained turfgrass areas of parks. Trees are cleared from official trails as required by hazard level or to clear trails. Management of these areas would therefore be considered more reactive in comparison to the rest of Fredericton operations. This is similar to many municipalities with split urban and rural areas. This arrangement is generally successful except where natural areas have extremely high-use trails or where there are large tree mortality events. EAB has been problematic in many municipalities with high ash proportion woodlots. Contracts for removal have been frequently required to deal with woodlot removals where municipal capacity is overwhelmed in streets and parks. This is an area where the City should develop a consistent framework that meets public expectations. Particular attention is needed in Odell Park, Killarney Park, and other multi-use trail areas.

4.6 Discussion

The overall style of management in Parks and Trees is proactive. This includes proactive maintenance of trees to maintain health and structure, integrated pest management to retain trees, and replanting efforts. This approach has been successful in managing an excellent urban forest. The woodlots, trails, and rural areas have received less management attention but remain in good condition. A significant contribution has been made by private landowners to the urban forest to support high canopy coverage throughout the City.

There are some important pest vulnerabilities that will be covered in Section 5, however the City has been a leader in DED management for years and is well positioned to effectively manage EAB through experience gained in pest management. Hemlock woolly adelgid and beech bark disease will impact the urban forest, particularly in natural areas. However, staff are knowledgeable in management for invasive pests.

The City's population is expected to increase substantially within the medium term, and this will present a challenge for management of the urban forest. Development impacts canopy cover in cities because some amount of tree removals is usually required for development or redevelopment of properties. This is offset in some municipalities through replanting requirements and compensation. However, the loss of canopy cover is not offset in terms of ecological benefits in the short term as trees mature slowly. Therefore, retention of trees, wherever feasible is a priority. The existing policy framework has worked under the current development pressure; however, it will need to be reconsidered to work under a population growth scenario. The most effective course of action will need to be formulated with input from the departments responsible for planning and engineering, City stakeholders, elected representatives, and the public.

5 Invasive Forest Pest Vulnerability

The vulnerability of an urban forest is impacted by the ability of pests to proliferate, the presence of pest vectors, and the presence of host species. There are many native pest species as well as several invasive species which are present and invasive species that have the capability to expand their range into Fredericton. Interactions between these species and their hosts are likely to change along with climate and management activities. Known native and invasive pests were analysed for their potential impact and the potential changes in impact due to climate change. Risks to the urban forest categorized as high, medium, and low with mitigation recommendations. Appendix B contains a matrix with all the considered species and a brief account of methods.

5.1 Dutch Elm Disease

Dutch elm disease (DED) is a fungus native to Eurasia which impacts elms (genus *Ulmus*). The vector of spread is predominantly through boring beetles but can also spread through grafts and contaminated cutting tools. The fungus impacts the function of the vascular tissue and leads to foliage desiccation or what is often called flagging. An infection is typically fatal though mortality is not 100% even where DED has been present for many decades. DED has been present in New Brunswick since at least the 1960s (identified in 1961) and the City currently inoculates mature street trees in the Fredericton City Centre to protect against DED (Magasi et al. 1993). Where DED has been introduced it has severe impacts to naturally occurring trees as well as urban environments as elms were popular street trees. DED resistant cultivars and hybrid species have been introduced to the nursery market (Pinchot et al., 2017). Many have demonstrated sufficient resistance to be utilized as street trees. The planting of elms not from a resistant strain is not recommended as there is a high probability of mortality.

5.2 Emerald Ash Borer

Emerald ash borer (EAB) is a small, iridescent green wood boring beetle native to Asia. Ash species (genus *Fraxinus*) are the only observed host in North America despite the species not being a strict specialist in Asia (NRCan, 2021). The boring larvae cause mechanical damage to the vascular tissues of an infested tree eventually resulting in mortality. Symptoms of infestation include "D" shaped exit holes, thinning crown, and loose bark. EAB has caused severe mortality in ash species within Ontario, where it was first discovered in Canada. It has recently been detected in New Brunswick. Significant mortality typically occurs within a few years of initial detection in white (*Fraxinus americana*), black (*F. nigra*), and green ash (*F. pennsylvanica*). Blue ash (*Fraxinus quadrangulata*) may have some resistance.

There is a systemic insecticide available which can be injected into ash trees to provide protection against infestation (azadirachtin sold as TreeAzin®). A commonly recommended mitigation strategy is to inject mature ash street trees. At the present time no planting of ash trees is recommended apart from potential trial planting of blue ash.

Mitigation of EAB is potentially affected by ash yellows. Ash yellows is a chronic disease which affects the growth rate of infected ash species. Ash yellows are not confirmed to be present in New Brunswick and it is not clear if it will spread in the wake of EAB. For many trees it will be a moot point with EAB causing significant mortality, however it may present an issue for inoculated ash.

5.3 Hemlock Woolly Adelgid

Hemlock woolly adelgid (HWA) are aphid-like insects native to Asia. Their host species in North America is the eastern hemlock. They feed on the contents of cells in the needles of hemlock trees and eventually cause mortality (Fewster et al., 2021). HWA has been progressing north from Virginia in the United States and is currently believed to be climate constrained. The current northern limits of the HWA distribution include parts of Maine, and Nova Scotia. The impacts of HWA through the southern Appalachian Mountains have been severe. HWA has not been observed in New Brunswick but the potential to arrive has been assessed at high based on the projected changes in climate. Mitigation strategies can include pesticide application coupled with stand improvement; however, the present recommended strategy is to avoid investment into hemlock within the urban forest. HWA has the potential to severely impact Odell Park due to the prevalence of mature hemlocks there.

The mitigation of HWA is affected by hemlock looper which is a significant defoliator of hemlock and is present in New Brunswick. Eastern hemlock is a host of this species however mortality can also be caused in balsam fir, and this has been observed as a significant problem in New Brunswick and Nova Scotia. It is unclear how this will be affected by the potential spread of HWA into New Brunswick. Balsam fir is very common in the rural parts of Fredericton and its further use in the urban forest should be limited.

5.4 Beech Bark Disease

Beech bark disease (BBD) is a European fungus which causes a canker. The vector of spread is a beech scale. Symptoms include canker progressing from bark discolouration to severe trunk deformation, and eventual mortality (Sajan, 2001). This fungus is currently present in New Brunswick and presents a severe threat to the native beech population there. Presently there are few mitigation options besides the avoidance of investment of beech in the urban forest. Beech surviving with limited or no observable BBD damage in stands with BBD presence should be retained as potentially resistant stock.

5.5 Butternut Canker

Butternut canker is an invasive fungus of unknown origins. Butternut is the only known host of this species. Symptoms include elongated vertical cankers on the stem and branches. These cankers periodically exude black fluid and can appear as sooty. There is no known treatment for this fungus though the mortality rate is not 100%. The impacts of the canker on the butternut species have been severe throughout the Ontario portion of their range with butternut being listed federally as an Endangered Species and listed as Critically Imperilled (S1) in New Brunswick. Butternut canker has been present in New Brunswick since at least 1997 (Harrison & Hurley, 1998). Investment in butternut within the urban forest is not recommended at this time.

5.6 Asian Long-horned Beetle

Asian long-horned beetles (ALB) are an invasive beetle with predominantly maple, birch, poplar, and willow hosts. The boring larvae cause mechanical damage to the vascular tissues of an infested tree casing eventual mortality. Symptoms include large, round, exit holes and general signs of decline. ALB has the potential to cause severe damage to the Fredericton urban forest with its preferred host species accounting for more than half of Fredericton's urban forest. However, ALB has not been confirmed within New Brunswick and previous introductions in Ontario have been contained. The current assessment of ALB is that the likelihood of introduction in Fredericton is low because it does not have known wide distributions within North America and has not been observed outside Ontario within Canada (CFIA, 2020).

5.7 Discussion

Several forest pests and diseases are likely to impact Fredericton in the near to medium term in addition to the existing challenges currently being managed. EAB is the most significant emerging threat as ash trees have a high importance value within the urban forest and rural areas. City staff have been proactively monitoring for the arrival of EAB and are familiar with the management principles having already begun treatment of suitable trees. The potential complication of ash yellows could be significant but there is little previous experience to draw on with that situation. The impacts of EAB are likely to be very significant in areas that are not managed as it is not feasible to treat these trees.

HWA, BBD, and butternut canker are likely to have an impact on the woodlots and rural portions of the City. It may be possible to mitigate some of the impacts within urban woodlots through management, however there is likely to be increased mortality.

6 Biodiversity Review

6.1 Existing Urban Forest Diversity

Existing species in the urban canopy were reviewed for prevalence to understand the representation at species, genus, and family levels. The data used to complete this exercise were the street tree point data provided by the City. The prevalence of species, genus, and family were reviewed with the industry best practice guideline of 10% species, 20% genus, and 30% family. Three species of maple (Norway, red, and sugar) had prevalence proportions greater than 10%. No other species exceeded 10%. Maples (*Acer*) account for 49% of diversity at the genus level – no other genus exceeded 20%. *Sapindaceae* (the family which includes maples) accounts for 49% of family diversity – no other family exceeded 30%.

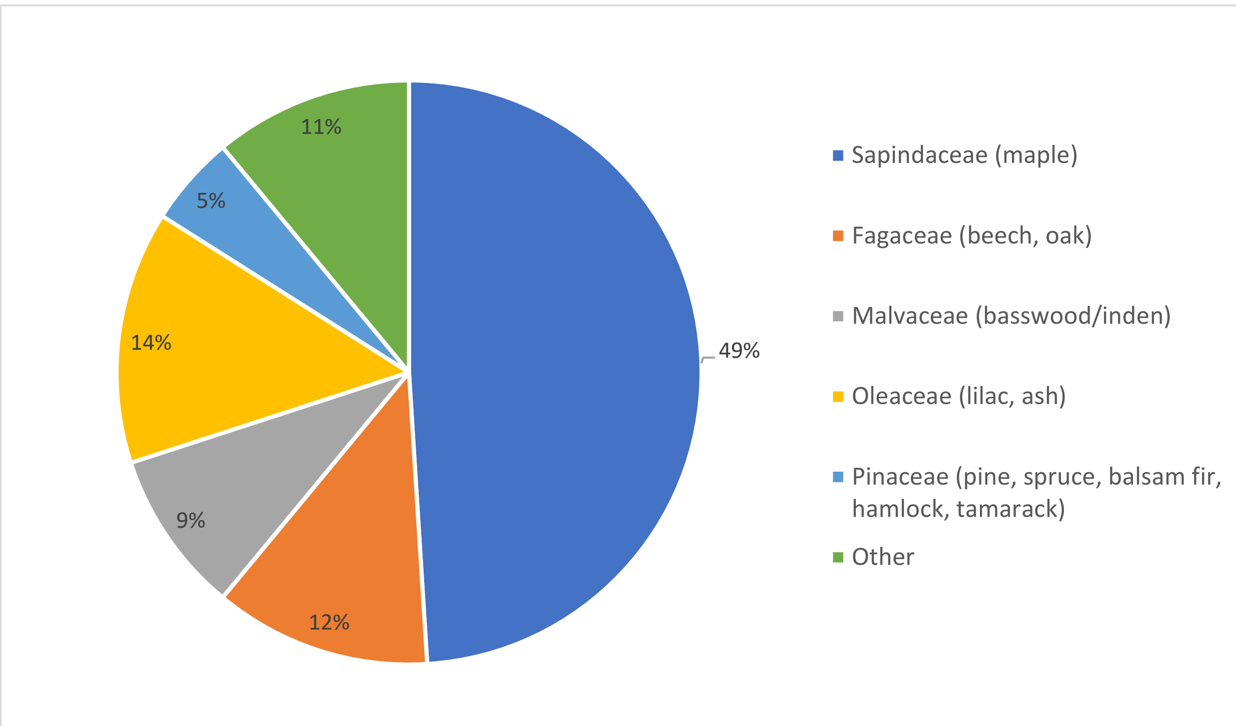


Figure 7. Urban Tree Diversity by Family

6.2 Planted Species Suitability

A hierarchical analysis was used to assess the suitability of trees for the Fredericton urban forest. The three highest order criteria were: suitability for urban conditions, projected climate suitability, and external limitations. Species that have been suggested in previous reports, species planted recently by the City, and species that are commonly used landscape trees in other similar regions were tested against these criteria. Table 13 provides detailed information on these three criteria and lower tier sub-criteria.

Table 13: Evaluation Criteria

Criteria	Considerations
Suitability for urban conditions defines the suitability of a tree for thriving within the constraints of an urban environment. This criterion has three categories: urban, park, and natural. These categories correspond to the three basic scenarios the City will plant trees in. Urban includes areas of significant constraint such as boulevards, planters, areas where sight triangles are important, and areas with significant potential for soil compaction. Park includes maintained parkland where constraints of the urban environment are found to some extent but are not quite as limiting. Natural includes areas with very few urban constraints such as woodlots or thickets.	• Aerial pollution tolerant • Heat island tolerant • Soil compaction tolerant • Drought tolerant • Salt tolerant • Suitability for planting boulevards with sightline concerns
Projected climate suitability defines the suitability of a species to the projected climate of a given time. Plant hardiness depends partially on the minimum temperatures of a region and with a warming climate species will have different potential ranges depending on this hardiness factor. This may include species that are not present in an area because the climate can change at a different rate than the migration speed of a species.	• Cold hardiness suitable for current minimum temperatures • Projected range covers Fredericton. • Present to a significant degree within the Fredericton urban forest in the available data
External limitations define constraints that are not related to the growing conditions of a tree.	• Species is exotic and has documented invasive potential. • Species has significant forest pest constraints. • Species currently constitutes a high proportion of the Fredericton urban forest. • Species has wood strength concerns

6.2.1 SUITABILITY FOR URBAN CONDITIONS METHODS

The considerations listed in Table 13 were evaluated for each species based on consultation with resource materials, corroborated with multiple street tree planting lists from municipalities within the Great Lakes Lowlands and Manitoulin-Lake Simcoe Ecozones (Mixedwood Plains Ecoregion), and reviewed by professionals with experience in this area. These resources are based on continuous refinement for use in the urban setting, have reasonably similar plant hardiness zones per Natural Resource Canada, and have experienced DED, EAB, and spongy moth infestations. These species were then reviewed for climate suitability based on the projected climate of Fredericton and external limitations.

6.2.2 PROJECTED CLIMATE SUITABILITY

The projected climate of Fredericton was modelled using scenarios adopted by the IPCC for AR5 that are based on various future greenhouse gas concentration trajectories. The highest Representative Concentration Pathways (RCP) 8.5 was used for the mode because current global GHG concentrations are closer to following the RCP 8.5 pathway, despite global agreements/targets for GHG emissions reductions. The following Table 14 shows the model outputs relating to plant hardiness for two time periods.

Table 14: Summary of Project Change in Climate Variables Associated with Tree Habitat Suitability

Climate Variable	Baseline (1981-2010)	Near Future (2050s)	Far Future (2080s)
Annual Mean Temperature (°C)	5.6	8.5	10.6
Minimum Temperature of Coldest Month (°C)	-15.0	-10.7	-7.8
Maximum Temperature of Hottest Month (°C)	25.5	28.6	30.9
Annual Precipitation (mm)	1070	1155	1204
Precipitation of Warmest Quarter (mm)	256	262	270
Precipitation of Coldest Quarter (mm)	263	298	316

(Source: Natural Resources Canada, 2022)

Natural Resources Canada has utilized projected climate data to develop potential plant species distribution maps for the future. These maps are based on the climate parameters of know ranges of each species. These models were used to assess the suitability of existing tree species in Fredericton, as well as the suitability of trees from warmer ecosystems. Refer to Technical Appendix for detailed methods and results relating to climate projections. Figure 8 provides an example of shifting climate suitability for Norway maple which currently has the highest importance value in Fredericton's urban forest.

(Source: NRCan Composite AR5 ANUCLIM model)

Figure 8. Climate suitability for Norway maple: 2011-2040, 2041-2070, 2071-2100

6.2.3 EXTERNAL LIMITATIONS

The sub-criteria listed in Table 13 were evaluated for each species via resource consultation, corroboration, and professional experience similar to the suitability for urban conditions. The compiled urban forest database including street trees and park trees inventoried in Fredericton were reviewed in conjunction with the conclusions from the reports the data was published in. This process identified species, genera, and families that account for a large proportion of the urban forest. The industry best practice threshold of 10% for species, 20% for genus, and 30% for family was used to define a large proportion. Wood strength concern ratings of high, medium, and low were assigned to trees based on professional experience and the observed frequency of failure in published sources. Pest vulnerability was also considered an external limitation – refer to Section 5 of this report for a discussion on this topic.

6.2.4 RECOMMENDED PLANTING SPECIES

The recommended list of planted species was determined after considering the constraints and individual characteristics of many species. Recommended species have been categorized into the following categories: increase, maintain, decrease, and trial. These categories are based on the overall diversity within the urban forest and are only valid while the current species proportions remain valid. For example, it is recommended that the proportion of maple in the urban forest decrease over time. In practice this will mean planting higher proportions of other species. It is not recommended to cease maple planting however, as this would create a gap in the overall maple population. A species recommended to increase in proportion is one that should account for a larger proportion of the planted species to gradually increase its prevalence in the urban forest. Species recommended to be maintained are species such as red oak which currently account for about 8.2% of trees in urban forest. This is close to the recommended 10% threshold and red oak planting should be carried out to maintain this proportion of the urban forest as this is a highly suitable species.

Species recommended for trial use are those which models may not support use but professional judgment and experience in the interpretation of the models suggests that it may be suitable for limited use. These species may be good performers in the urban environment and provide additional diversity. Trial use would include the planting of a low number of individuals from these species in locations suited to their characteristics and monitoring their success. If species prove successful, their use can be cautiously expanded.

There are caveats to the general interpretations. For example, several ash species are listed under decrease – no planting of ash is recommended due to the presence of EAB. Some species that are recommended to be maintained may not have an inventoried population – in these cases planting is recommended at a moderate level in comparison to other species. Some species that are included under decrease may not be locally prevalent and in this case the decrease category should be interpreted as avoid. It should also be noted that some of the species under the decrease category may not be under near-term threat by climate change but recently planted trees may be affected in the future given the long-life expectancy of many tree species. Trees in very confined urban settings with low life expectancies may not be affected by this timeframe.

Ultimately these species would be assigned proportions of a total planted number. This number would be based on modelling to maintain the urban forest, the available budget allocated to planting, and the available space for planting. The following Table 15 contains the recommended species by category. Both urban and natural/rural species have been included. Refer to Appendix E for further details on classifications. Trees with an asterisk and bold font are considered suitable for some street tree applications. Consideration of site-specific moisture soil moisture, sun exposure, and growing space is required to decide on the appropriate species from this list.

Table 15: Recommended Planting Species

Increase	Maintain	Decrease	Trial
Betula lenta Carpinus caroliniana Carya cordiformis Carya glabra Carya lacinioda Carya ovata **Catalpa speciosa*** **Celtis occidentalis*** **Cladrastis kentuckea*** **Ginko biloba*** **Gleditsia triacanthos*** **Gymnocladus dioicus*** **Juglans nigra*** Juniperus virginiana Larix decidua **Ostrya virginiana*** Picea abies Picea pungens Pinus nigra Pinus resinosa Pinus rigida Pinus strobus Pinus sylvestris Pinus virginiana **Platanus occidentalis*** **Populus balsamifera*** Prunus serotina **Quercus alba*** **Quercus coccinea*** **Quercus macrocarpa*** **Quercus velutina*** Sassafras albidum Ulmus rubra	**Amelanchier canadensis*** Betula cordifolia Larix laricina Populus tremuloides Prunus pensylvanica **Prunus virginiana*** **Quercus pallustris*** **Quercus rubra*** Rhus typhina Salix nigra **Sorbus americana*** **Syringa reticulata*** Thuja occidentalis **Tilia americana*** Tsuga canadensis	Abies balsamea Acer negundo Acer nigrum Acer pensylvanicum **Acer platanoides*** **Acer rubrum*** **Acer saccharinum*** **Acer saccharum*** Acer spicatum **Aesculus glabra*** Betula alleghaniensis Betula papyrifera Betula populifolia Cercis canadensis Fagus grandifolia **Fraxinus americana*** **Fraxinus nigra*** **Fraxinus pennsylvanica*** Juglans cinerea Larix occidentalis **Liquidambar styraciflua*** Picea engelmannii Picea glauca Picea mariana Picea rubens Pinus banksiana Pinus contorta Pinus echinate Pinus elliotti Pinus ponderosa Pinus serotina Populus grandidentata Pseudotsuga mensziesii **Quercus bicolor*** **Quercus ellipsoidalis*** **Tilia cordata***	Carya illinoinensis Castanea dentata (canker resistant) Chamaecyparis thyoides Cornus florida **Nyssa sylvatica*** **Plantanus x acerifolia*** **Ulmus americana* (DED resistant cultivars)**

Asterisk and bold font denoted street tree species.

6.3 Discussion

The importance values presented in Section 3 had maples, lindens, and ash as the three most important genera in the existing urban forest. This is reflected in the biodiversity assessment where maples are again the most prominent genera and Norway maple the most numerous street tree. Approximately half of the City's street trees belong to the *Sapindaceae* family – a significant limitation for biodiversity. There are a significant number of tree species represented in the urban forest (110) however diversity should be assessed in terms of prevalence and not just presence. Ideally prevalence and a metric such as importance value can be reviewed in tandem.

Boulevards can be a difficult environment to grow large canopy trees owing to unnatural drainage conditions, confined rooting zones, frequent disturbance, and unfavourable microclimates. Add onto this the fact that some species are not suited to these spaces because of sightline concerns (a conifer issue), and somewhat horizontal growing tendencies (such as willows) and the list can be restrictive. Pest outbreaks have reduced the list even further in recent years. For these reasons it may not be possible to meet all diversity requirements in boulevards. Where this is the case, planting in parkland and more suitable conditions needs to utilize the extended planting palate to the extent possible.

7 Conclusion and Discussion for Urban Forest Management Plan

This report developed an understanding of the existing urban forest condition and the state of urban forest management in Fredericton, NB. The findings of this report will inform the development of an urban forest management plan with input from stakeholders. As a result, this report has not made any management recommendations. However, some brief discussion points are presented here as closing thoughts for initiating a management plan. The intent is to present some of the most important findings to guide the initial stages of the management plan development.

The state of the urban forest in Fredericton is overall healthy. Canopy cover measured via LiDAR is greater than most peer Canadian Cities. The distribution of age classes appears to be sustainable, and the spatial distribution of canopy coverage is relatively equitable when reviewed over several scales. There are neighbourhoods with low canopy coverage that would benefit from additional planting efforts (Technical Appendix). A plantable area analysis via NDVI would be very beneficial to assessing how much population growth could be accommodated before a stable population management scenario would be required.

Management of the urban forest is proactive in terms of maintenance, pest management, and replanting efforts. This approach will be beneficial in the near term as the City is likely to face some additional pest challenges including EAB, BBD, and HWA. Fredericton has been a leader for many years in DED management and is well positioned to meet the first challenges of EAB. The impacts of EAB will be seen in both the urban and rural environments as ash are common street and natural woodland trees in New Brunswick. BBD and HWA impacts will be more focused on natural areas as beech and hemlock are not common urban species. Mature hemlock are prevalent in Odell Park and HWA has the potential to significantly impact these trees.

Urban forest biodiversity is good in terms of species presence but low when assessed for species prevalence. There is an overreliance on maple species beyond what is estimated in the rural area. Climate models suggest that maples will continue to grow well for the near term in the City, however this could be a significant vulnerability. No significant threat to maples has been identified for Fredericton in the near term, however any significant mortality event impacting maple trees would have a very negative impact on the urban forest. Building resilience through diversity will be important.

Climate change is projected to make Fredericton warmer and increase annual precipitation. Conditions will become less suitable for several native species but more suitable for some more southern species. The net change will likely increase the number of appropriate street tree species. The impacts to the forested areas are not fully understood but species migration should be monitored to prevent stand decline in City woodlots. There is also a heightened likelihood of severe weather events that cause damage to Fredericton's trees. Current pruning practices are likely to mitigate some of these impacts on street trees, however, impacts to rural forests may increase.

The largest identified risk to the Fredericton urban forest is the planned City population growth. Maintaining high canopy coverage in the City is important to Fredericton's status as a liveable City. Trees are an important cultural feature in Fredericton and will be an important source of resiliency in supporting population growth. Smart, collaborative management with planning and engineering City departments will be critical.

The *Growth Strategy* projects 200 ha of growth within the existing urban area and 400-525 ha of growth beyond the current urban area for residential use. An additional 45.2 ha of growth are projected for a mixture of other land uses to support the residents. Currently the urban area of Fredericton has a canopy cover of approximately 44%. With a decline to approximately 25% in the 245.2 ha of projected growth, there would be an approximate loss of 46.6 ha of canopy. Repeating this for the rural area currently at 63% canopy coverage, the canopy loss would be approximately 152-200 ha. Large, mature trees have a much higher leaf area than smaller trees and removal of large trees should be avoided as a potential mitigation strategy. Development tree losses will be predominantly focussed on areas of private property where the canopy was quantified by LiDAR. The number of street and park trees actively managed by Parks and Trees will actually expand due to the expansion of street networks. As a result, continued tracking from both point inventory and remote sensing will be important to assess changes as development progresses.

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TECHNICAL APPENDICIES

Appendix A Climate Projection

Projected Climate Suitability Methods

A changing climate will influence species distribution and shift suitable climate zones for forests. One way to measure tree habitat suitability is by using the plant hardiness classification system. The plant hardiness approach incorporates one or more climate variables to describe a set of plants that can tolerate those conditions (McKenney et al. 2014; USDA 1960).

While there are different approaches to estimating plant hardiness zones, most of these approaches have concluded that the following climate variables are the most relevant when classifying plant hardiness (McKenney et al. 2011):

- **Annual mean temperature:** the average temperature measured throughout the whole year.
- **Minimum temperature of the coldest month:** the average of the daily low temperatures for the month with the lowest average daily temperature.
- **Maximum temperature of the warmest month:** the average of the daily high temperatures for the month with the highest average daily temperature.
- **Annual precipitation:** the average amount of precipitation occurring each year.
- **Precipitation of the warmest season:** The average amount of precipitation occurring in the season with the highest average daily temperature.
- **Precipitation of the coldest season:** The average amount of precipitation occurring in the season with the lowest average daily temperature.

Natural Resources Canada has developed a plant hardiness zone classification system ranging from 0a to 9a, with lower zones corresponding to areas of colder temperatures and/or drier conditions. Historical changes in plant hardiness zones between the 1950s and 1990s is shown in Figure 9 (McKenney et al. 2014). In some regions, plant hardiness zones have changed by 3 or more, while in the Fredericton region, plant hardiness zones have shifted by one over the last 50 years.

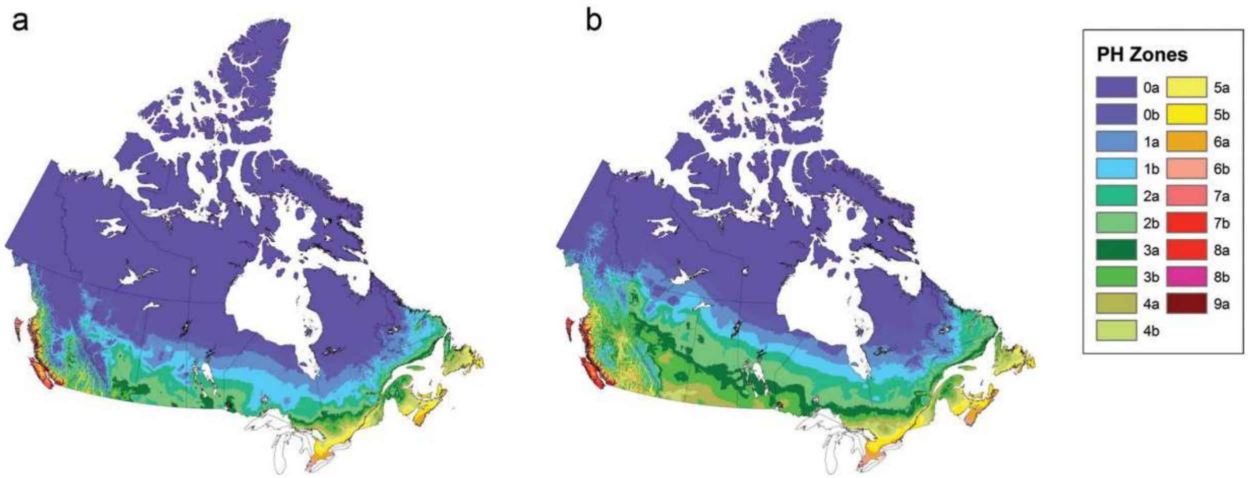

Figure 9. Plant Hardiness (PH) Zones between the (a) 1950s and (b) 1990s (Reproduced from McKenney et al. 2014)

CLIMATE DATA SOURCES

Historical Climate Data

Historical daily climate data is available from Environment and Climate Change Canada (ECCC) at their ambient monitoring station at the Fredericton International Airport (Station IDs: 8101500 and 8101505) from 1955 to the present. ECCC also produces Climate Normals data, which are summaries of many climate variables for locations with sufficient data. Current Climate Normals data from ECCC for Fredericton (Station ID: 8101500) are representative of the 1981-2010 timeframe and were also used to characterize existing climate in Fredericton.

Climate Projection Data

Climate models are the primary tools used to develop three-dimensional climate projections to help understand future climate change. Climate models allow investigations into the possible future changes in climate variables, such as air temperature, precipitation, and sea level rise. The outputs of these models are called projections, which refer to a range of plausible climate conditions into the future that will vary with the assumptions about the future economic, social, technological, and environmental conditions that will drive greenhouse gas emissions globally. Climate models simulate how Earth’s climate may respond to increasing greenhouse gas (GHG) concentrations while representing the physical processes and interactions between the atmosphere, ocean, cryosphere (snow and ice), and land surfaces. As such, climate models are complex tools to provide guidance on plausible future climates based on the most up-to-date science.

Climate models are regularly reviewed, refined, and updated, and new data sources for climate change projections are continuously being developed. Most climate change assessments include modelling projections from the Coupled Model Intercomparison Projects (CMIP), which is a coordinated planning, comparison, and assessment of Global Climate Models (GCMs) developed by groups all over the world. These CMIPs also typically form the basis for climate projections for the UN-supported Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (ARs). For example, CMIP Phase 5 (CMIP5) formed the basis for the IPCC AR5 published in 2013. These GCMs take months of intense computational effort to run and process.

In addition to the physics of the GCMs, global progress towards meeting GHG emissions targets is also a large source of uncertainty in future climate projections. There are four Representative Concentration Pathways (RCP) scenarios (van Vuuren et al., 2011) adopted by the IPCC for AR5 that are based on various future greenhouse gas concentration trajectories. This study will focus on the high emissions greenhouse gas concentrations scenario, RCP 8.5. Current global GHG concentrations are closer to following the RCP 8.5 pathway, despite global agreements/targets for GHG emissions reductions.

While global climate modelling provides insight into future climate on a global scale, the spatial resolution of the GCMs can make it challenging to interpret climate projections more regionally. For example, the resolution of GCMs may not accurately resolve coastlines, may miss elevation extremes in regions of complex topography, or may obscure regions of varied land use or land cover. Regional Climate Models (RCMs) and other statistical methods have been developed to refine the output from the global climate models to help resolve some of these smaller-scale features to help provide more accurate climate projection data. These refinements are also called downscaling, since it involves refining climate projections from a large scale – on the order of up to several hundred kilometres – down to scales on the order of 10’s of kilometres.

Climate projections of future precipitation and temperature in this assessment were based on statistical downscaling of Canada-wide climate projection data from the Pacific Climate Impacts Consortium (PCIC). Downscaled scenarios for CMIP5 were constructed from 27 GCMs and 3 RCPs. This data set is now referred to as Canadian Downscaled Climate Scenarios – Univariate (CMIP5), or CanDCS-U5 for short. Statistical downscaling was achieved using the BCCAQv2 downscaling method (Bias Correction/Constructed Analogues with Quantile delta mapping reordering). BCCAQv2 is a hybrid method developed at PCIC that combines results from Bias Corrected Constructed Analogs (BCCA; Maurer et al. 2010) and Quantile Delta Mapping (QDM; Cannon et al. 2015). BCCA uses spatial aggregation from a linear combination of historical analogues for daily large-scale fields. QDM applies a form of quantile mapping where relative changes in GCM quantiles are preserved to avoid inflationary effects that can occur with standard quantile mapping. BCCAQv2 is an updated version of BCCAQ (version 1), which employed standard quantile mapping.

Climate projection data was collected for two 30-year time periods to represent two future climatologies for Fredericton:

- Near future, represented by the 30-year period around 2050 (i.e., 2036-2065).
- Far future, represented by the 30-year period around 2080 (i.e., 2066-2095).

CLIMATE PROJECTION RESULTS

Temperature

A summary of the historical monthly, seasonal, and annual mean temperature is provided in Table 16, along with average minimum and maximum temperatures for each month. The warmest month in Fredericton is July while the coldest month is January.

Table 16: Summary of Baseline (1981-2010) Temperature in Fredericton

Month	Season	Daily Average Temperature (°C)	Daily Maximum Temperature (°C)	Daily Minimum Temperature (°C)
January	Winter	-9.4	-3.8	-15.0
February		-7.9	-2.0	-13.7
March	Spring	-2.4	3.0	-7.8
April		4.5	10.0	-1.0
May		11.1	17.6	4.6
June	Summer	16.2	22.7	9.7
July		19.3	25.5	13.0
August		18.4	24.8	12.1
September	Fall	13.6	20.0	7.1
October		7.5	13.2	1.6
November		1.5	6.0	-3.0
December	Winter	-5.7	-0.7	-10.7
Annual Average		5.6	11.4	-0.2

Climate projections for average, minimum, and maximum temperature are shown in Tables 17 through 19, respectively. The warmest and coldest months are projected to continue to be July and January, respectively. High temperatures in July are projected to increase by more than 5 °C by the 2080s, while the low temperatures in January are projected to increase by more than 8 °C by the 2080s.

Table 17: Projected Change in Average Daily Temperature in Fredericton

Month	Season	Average Daily Temperature (°C)		
		Baseline (1981-2010)	Near Future (2050s)	Far Future (2080s)
January	Winter	-9.4	-5.7	-3.1
February		-7.9	-4.5	-2.0
March	Spring	-2.4	0.5	2.2
April		4.5	7.0	8.8
May		11.1	13.6	15.5
June	Summer	16.2	18.8	20.8
July		19.3	22.2	24.5

Table 17: Projected Change in Average Daily Temperature in Fredericton

Month	Season	Average Daily Temperature (°C)		
		Baseline (1981-2010)	Near Future (2050s)	Far Future (2080s)
August		18.4	21.3	23.8
September	Fall	13.6	16.6	18.9
October		7.5	10.3	12.2
November		1.5	4.1	6.1
December	Winter	-5.7	-2.4	-0.1

Table 18: Projected Change in Average Daily High Temperature in Fredericton

Month	Season	Average Daily High Temperature (°C)		
		Baseline (1981-2010)	Near Future (2050s)	Far Future (2080s)
January	Winter	-3.8	-0.7	1.4
February		-2.0	0.8	2.9
March	Spring	3.0	5.7	7.3
April		10.0	12.6	14.5
May		17.6	20.1	22.1
June	Summer	22.7	25.3	27.4
July		25.5	28.6	30.9
August		24.8	27.9	30.5
September	Fall	20.0	23.1	25.5
October		13.2	16.0	18.1
November		6.0	8.6	10.7
December	Winter	-0.7	2.2	4.3

Table 19: Projected Change in Average Daily Low Temperature in Fredericton

Month	Season	Average Daily Low Temperature (°C)		
		Baseline (1981-2010)	Near Future (2050s)	Far Future (2080s)
January	Winter	-15.0	-10.7	-7.8
February		-13.7	-9.8	-7.0
March	Spring	-7.8	-4.7	-2.7
April		-1.0	1.4	3.2
May		4.6	7.0	8.8
June	Summer	9.7	12.3	14.2
July		13.0	15.7	17.9
August		12.1	14.9	17.2
September	Fall	7.1	10.1	12.3
October		1.6	4.3	6.2
November		-3.0	-0.4	1.6
December	Winter	-10.7	-7.0	-4.5

PRECIPITATION

A summary of the historical monthly and annual seasonal average precipitation is provided in Tables 20 and 21, respectively. Average precipitation is currently highest in the Fall, with November having the most precipitation.

Table 20: Historical Average Monthly Precipitation in Fredericton

Month	Season	Precipitation (mm)
January	Winter	95.3
February		73.1
March	Spring	93.2
April		85.9
May		96.2
June	Summer	82.4
July		88.3
August		85.6
September	Fall	87.5
October		89.1
November		106.3
December	Winter	94.9
Annual Total		1078

Table 21: Historical Average Seasonal Precipitation in Fredericton

Season	Precipitation (mm)
Winter	263
Spring	275
Summer	256
Fall	283

Climate projections for average annual and seasonal precipitation are provided in Tables 22 and 23, respectively. While fall currently experiences the most precipitation in Fredericton, climate projections suggest that most precipitation will occur in the Winter in the future.

Table 22: Projected Change in Average Monthly Precipitation in Fredericton

Month	Precipitation (mm)		
	Baseline (1981-2010)	Near Future (2050s)	Far Future (2080s)
January	95.3	104.7	108.8
February	73.1	82.0	90.4
March	93.2	105	115
April	85.9	92.8	102.5
May	96.2	105	104
June	82.4	85.2	90.1
July	88.3	90.1	92.5
August	85.6	86.2	87.6
September	87.5	87.8	88.5
October	89.1	89.3	91.5
November	106	115	117
December	94.9	112	117
Annual Total	1078	1155	1204

Table 23: Projected Change in Average Seasonal Precipitation in Fredericton

Season	Precipitation (mm)		
	Baseline (1981-2010)	Near Future (2050s)	Far Future (2080s)
Winter	263	298	316
Spring	275	303	321
Summer	256	262	270
Fall	283	292	297

SUMMARY OF CLIMATE PROJECTIONS

A summary of the climate projections for variables associated with plant habitat suitability are provided in Table 24.

Table 24: Summary of Project Change in Climate Variables Associated with Tree Habitat Suitability

Climate Variable	Baseline (1981-2010)	Near Future (2050s)	Far Future (2080s)
Annual Mean Temperature (°C)	5.6	8.5	10.6
Minimum Temperature of Coldest Month (°C)	-15.0	-10.7	-7.8
Maximum Temperature of Hottest Month (°C)	25.5	28.6	30.9
Annual Precipitation (mm)	1070	1155	1204
Precipitation of Warmest Quarter (mm)	256	262	270
Precipitation of Coldest Quarter (mm)	263	298	316

Climate Change and Plant Hardiness

Climate projection modelling results have been produced that review the potential changes in plant hardiness zones and habitat suitability in Canada (McKenney et al. 2014). The change in habitat range for a variety of tree species were projected using two methods that correlate presence/absence data of the species with mapping of climate data, soil conditions, and hydrology (NRCan 2022):

- ANUCLIM, which has been used extensively for research and governments globally for natural resources investigation and management, environmental monitoring and modelling, plant, and crop growth condition evaluation, and, in particular, bioclimatic analysis and distribution mapping of species, across study areas at various spatial scales (Xu and Hutchinson 2013). ANUCLIM works by summarizing the climate at known occurrence locations for a given species.
- Maxent, where species distributions are modelled using machine learning techniques to correlate known species locations (also knowns as presence-only data) and potential locations where species may be based on biogeoclimatic factors.

The climate projections of tree habitat are classified into three categories:

- Core Range, where the species is likely present.
- Entire Range, where the species is possible to be present.
- Absence / Out of Range, where the species is unlikely to be present.

The climate projections of tree habitat were reviewed to provide additional analysis of climate change impacts to tree species found in the City of Fredericton.

A recent summary of forest climate resiliency was completed for the Fundy Biosphere that included consideration of climate change projection data and changes in insect disturbance, disease, animal browsing, and other physical events (also known as abiotic events) (Phillips 2015). An overall resiliency score, ranging from Proliferate to Disappear, was calculated for each tree species identified in the Fundy Biosphere to help guide conservation efforts. A summary of the resiliency score calculation is provided in Table 25. These resiliency scores were also reviewed to help characterize climate change impacts to tree species in the City of Fredericton.

Table 25: Summary of Resiliency Categories used in Fundy Biosphere Study (Phillips 2015)

Resiliency Category	
Proliferate	Species more likely to succeed and/or expand presence.
Prosper	
Persevere	
Decline	
Disappear	Species at-risk to additional stress or reduced presence

A summary of the major tree species present in Fredericton are provided in Table 26 and includes tree species currently found in rural or in urban settings in Fredericton. Some species are abundant in both rural and urban settings, such as the Norway maple, red maple, and Northern red oak. Norway maple is the most abundant urban tree species, while Quaking aspen was found to be the most abundant species in rural areas. The species counts were taken from plot samples conducted by Stantec and UNB data from street and park inventories.

Table 26: Summary of the Most Abundant Tree Species in Fredericton in Urban or Rural Areas

Species	Common Name	Urban		Rural	
		Number of Trees	Percent of Population	Number of Trees	Percent of Population
Abies balsamea	Balsam fir	36	<0.1%	33376	9.3%
Acer platanoides	Norway maple	3522	19.9%	12560	3.5%
Acer rubrum	Red maple	2329	13.1%	20952	5.8%
Acer saccharinum	Silver maple	370	2.1%	2026	0.6%
Acer saccharum	Sugar maple	2228	12.6%	4508	1.2%
Betula papyrifera	Paper birch	209	1.2%	15068	4.2%
Betula populifolia	Gray birch	39	<0.1%	8534	2.4%
Fraxinus americana	White ash	654	3.7%	675	0.2%
Fraxinus pennsylvanica	Green ash	1482	8.4%	96	0.0%
Larix laricina	Tamarack	35	<0.1%	20612	5.7%
Malus baccata	Siberian crabapple	N/A	N/A	8148	2.3%
Picea glauca	White spruce	171	1.0%	44575	12.4%
Pinus banksiana	Jack pine	16	<0.1%	24445	6.8%

Table 26: Summary of the Most Abundant Tree Species in Fredericton in Urban or Rural Areas

Species	Common Name	Urban		Rural	
		Number of Trees	Percent of Population	Number of Trees	Percent of Population
Populus tremuloides	Quaking aspen	48	<0.1%	91755	25.4%
Quercus macrocarpa	Bur oak	326	1.8%	N/A	N/A
Quercus rubra	Northern red oak	1447	8.2%	8148	2.3%
Tilia cordata	Littleleaf linden	1537	8.7%	N/A	N/A
Ulmus americana	American elm	727	4.1%	4508	1.2%

Projections of changes to habitat suitability are shown in Table 27, along with the resiliency scores developed by the Fundy Biosphere study. Some species were not included in the Fundy Biosphere study (e.g., Norway maple) and some species did not have species-specific climate projection data available (e.g., Littleleaf linden). Many of the abundant urban tree species, such as red maple, Sugar maple and Green ash, are expected to be resilient to future climate and succeed into the far future. However, this is not the case for all abundant urban species – for example, the range of the Norway maple is expected to shift well north of Fredericton by the end of the century. Several of the rural forest species are also expected to decline or become located in unfavourable climates or experience climate stress in the near future, including Quaking aspen, White spruce, and Balsam fir.

Table 27: Summary of Climate Suitability Projections for Most Abundant Tree Species in City of Fredericton

Species	Common Name	Fundy Biosphere Resiliency Rating	Projection of Climate Suitability		
			Current	Near Future (2050s)	Far Future (2080s)
Abies balsamea	Balsam fir	Decline	Core	Range	Out of Range
Acer platanoides	Norway maple	--	Core	Range	Out of Range
Acer rubrum	Red maple	Proliferate	Core	Core	Core
Acer saccharinum	Silver maple	Decline	Range	Range	Range
Acer saccharum	Sugar maple	Prosper	Core	Core	Range
Betula papyrifera	Paper birch	Decline	Core	Range	Out of Range
Betula populifolia	Gray birch	Decline	Core	Range	Out of Range
Fraxinus americana	White ash	Prosper	Range	Core	Core
Fraxinus pennsylvanica	Green ash	--	Range	Core	Core
Larix laricina	Tamarack	Persevere	Core	Out of Range	Out of Range
Malus baccata	Siberian crabapple	--	--	--	--
Picea glauca	White spruce	Decline	Core	Out of Range	Out of Range
Pinus banksiana	Jack pine	Decline	Range	Range	Out of Range
Populus tremuloides	Quaking aspen	Decline	Core	Range	Out of Range
Quercus macrocarpa	Bur oak	Persevere	Range	Range	Range
Quercus rubra	Northern red oak	Prosper	Core	Range	Range
Tilia cordata	Littleleaf linden	--	--	--	--
Ulmus americana	American elm	Prosper	Range	Core	Range

-- Indicates a species not included in the dataset
Core = areas with projected climatic values between 5th and 95th percentiles of climatic range
Range = areas with projected climatic values between the minimum and maximum climatic range

Appendix B Forest Pest Assessment

Species	Scientific Name	Lifeform	Tree species	Risk	Recorded Presence In NB	Prevalence	Native or Invasive	Potential to Arrive	Likelihood to Increase with Climate Change	Recommendation
Eastern tent caterpillar	*Malacosoma americanum*	*Insect*	Poplars; Willows	Low	Yes	Wide	Native	N/A	Unknown	Limit maples and poplars
Dutch elm disease	*Ophiostoma novo-ulmi*	*Fungus*	Elms	High	Yes	Wide	Invasive	N/A	Unknown	Avoid - unless resistant variety
balsam fir woolly adelgid	*Adelges picea*	*Insect*	Firs	Low	Yes	Wide	Invasive	N/A	Yes	Limit Firs
Hemlock woolly adelgid	*Adelges tsugae*	*Insect*	Easter hemlock	High	No	Wide	Invasive	High	Yes	Avoid hemlock
Spruce bark beetle	*Dendroctonus rufipennis*	*Insect*	Spruces	Low	Yes	Wide	Native	N/A	Yes	Avoid spruce monocultures
Beech bark disease	*Neonectria spp.*	*Fungus*	Beech	High	Yes	Wide	Invasive	N/A	Unknown	Avoid beech
Sudden oak death	*Phytophtora ramorum*	*Fungus*	Oaks	High	No	Low	Invasive	Low	Yes	None
Butternut canker	*Ophiognomonia claviginenti-juglandacearum*	*Fungus*	Butternut	High	Yes	Wide	Invasive	N/A	Unknown	Avoid butternuts
Emerald ash borer	*Agrilus planipennis*	*Insect*	Ashes	High	Yes	Wide	Invasive	N/A	Yes	Avoid ashes
White pine blister rust	*Cronartium ribicola*	*Fungus*	White pines	Mod	Yes	Wide	Invasive	N/A	Unknown	Explore resistant pines
Spruce budworm	*Choristoneura fumiferana*	*Insect*	Firs, spruces	Mod	Yes	Wide	Native	N/A	Unknown	Limit spruces and firs
Spongy moth	*Lymantria dispar dispar*	*Insect*	Oak, birch, poplars	Mod	Yes	Wide	Invasive	N/A	Yes	None
Asian longhorn beetle	*Anonplophora glabripennis*	*Insect*	Hardwoods	High	No	Low	Invasive	Low	Yes	None
Larch sawfly	*Pristiphora erichsonii*	*Insect*	Larches	Low	Yes	Wide	Invasive	N/A	Unknown	None
Jackpine budworm	*Choristoneura pinus*	*Insect*	Jackpine	Low	Yes	Wide	Native	N/A	Unknown	None
Pine weevil	*Pissodes strobi*	*Insect*	White pine	Mod	Yes	Wide	Native	N/A	Unknown	None
Ash Yellows	*Phytoplasma fraxini*	Bacteria	Ashes	High	No	Wide	Invasive	High	Unknown	None
Brown longhorn beetle	*Tetropium fuscum*	Insect	Spruces	Low	No	Low	Invasive	Low	Unknown	None
Hemlock looper	*Lambdina fiscellaria*	Insect	Balsam fir	High	Yes	Wide	Native	N/A	Unknown	Limit hemlocks and firs
Southern pine beetle	*Dendroctonus frontalis*	Insect	Pines	Mod	No	Wide	Native	Moderate	Yes	None
winter moth	*Arpenteuse tardive*	Insect	Oaks, many species	Mod	Yes	Wide	Native	N/A	Yes	None
eastern larch beetle	*Dendroctonus simplex*	Insect	Larch	Low	Yes	Wide	Native	N/A	Yes	None
Engraver beetles	*Ips spp.*	Insect	Pines	Low	No	Wide	Native	Moderate	Yes	None
Bronze birch borer	*Agrilus planipennis*	Insect	Birch	Mod	Yes	Wide	Native	N/A	Yes	Avoid non-native birches
Larch casebearer	*Coleophora laricella*	Insect	Larch	Low	Yes	Wide	Native	N/A	Yes	None
Red oak borer	*Enaphalodes rufulus*	Insect	Oaks	Low	No	Wide	Native	Low	Yes	None
Pine engraver	*Ips pini*	Insect	Pines	Low	No	Wide	Native	Moderate	Yes	None
Balsam fir sawfly	*Neodiprion abietis*	Insect	Firs	Low	Yes	Wide	Native	N/A	Unknown	Limit balsam first monocultures
Sirococcus shoot blight	*Sirococcus conigenus*	Fungus	Pines, Spruces	Low	Yes	Wide	Native	N/A	Unknown	None
Balsam gall midge	*Paradiplosis tumifex*	Insect	Firs	Low	Yes	Wide	Native	N/A	Unknown	None

Appendix C Canopy Model

Methods

The urban forest canopy was extracted from a canopy height model with a 2-m ground resolution, derived from LiDAR data collected by the City of Fredericton in 2015. To extract the forest canopy from the continuous canopy height model, Esri’s Remap Raster Function was used to reassign individual canopy height pixels into canopy height classes. The following canopy height classes were extracted:

- 2-5 meters
- 5-10 meters
- >10 meters

Vegetation below 2 meters in height was considered not to contribute significantly to the urban forest canopy and was omitted.

The extracted canopy class raster was smoothed using Esri's Spatial Analyst extension tools, including Majority Filter (parameters used were: 8 neighbours, replacement threshold of half) and Boundary Clean (Figure 10). It was then exported to a feature layer and integrated with Fredericton administrative boundaries of interest using Esri’s Union geoprocessing tool. Administrative boundaries were obtained from the Fredericton Open Data Portal and included:

- Zoning (2013)
- Census tracts (2016)
- Wards (2016)
- Neighbourhoods (2020)

In addition, areas already included in the City of Fredericton's existing tree inventory were identified. This was accomplished by buffering all inventoried tree point locations to produce an approximate known tree inventory canopy extent. The following buffer radii bins were used to approximate tree canopy, based on tree diameter at breast height (DBH):

Diameter at Breast Height (cm)	Canopy Radius (m)
<15	2
16 – 30	4
31 – 60	6
61 – 80	8
>81	10

The existing tree inventory buffer was integrated into the canopy height class feature layer with the administrative boundaries.

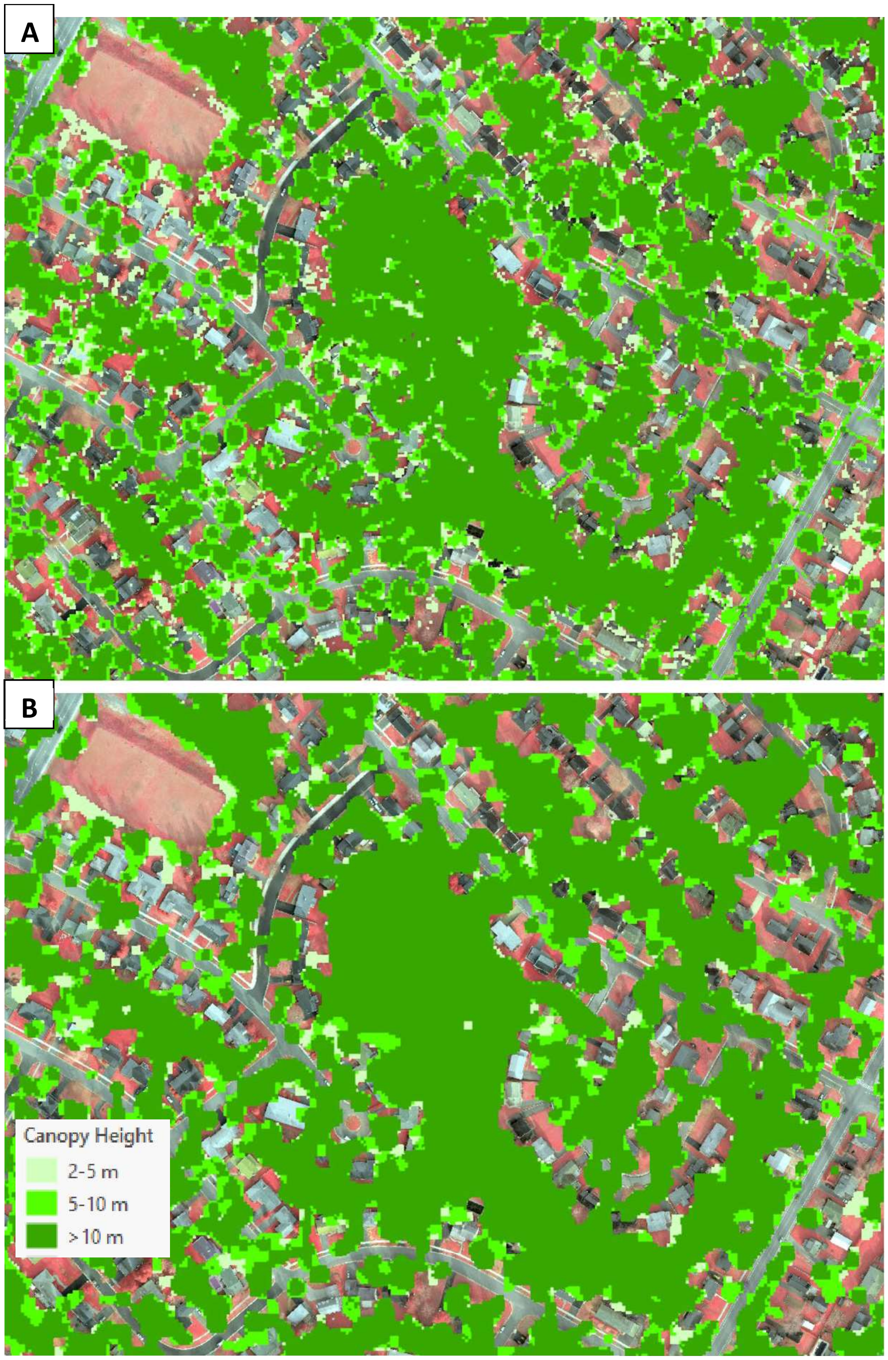

Figure 10. A) Canopy height classes extracted from LiDAR canopy model. B) Canopy height classes after smoothing using Majority Filter and Boundary Clean.

Data Limitations and Recommendations for Future Update

CANOPY HEALTH

The 2015 canopy cover layer was developed using only LiDAR-derived canopy height data. As a result, the layer represents only canopy extent and does not include any measure of canopy health. Colour infrared aerial imagery was collected by the city of Fredericton in 2012, which included visible (red, green) and near-infrared (NIR) bands, allowing for the calculation of a Normalized Difference vegetation Index (NDVI).

NDVI measures the greenness and density of vegetation as captured in satellite or aerial imagery. It is calculated as the difference between the visible red and near-infrared spectral bands using the following equation:

NDVI = (NIR – Red)/ (NIR + Red)

This equation produces an index ranging from -1 to +1, with values greater than 0.2 representing vegetation. Higher values indicate healthier and denser vegetation.

However, the 2012 imagery was captured at a time when deciduous trees were without leaves; as a result, NDVI had to be omitted from the analysis, as it would have resulted in deciduous trees being classified as unhealthy, or even being omitted entirely. Figure 11 shows that the canopy height model detects all tree cover, while NDVI calculated from leaf-off imagery results in deciduous trees being assigned non-vegetated values.

To incorporate a measure of canopy health in future work, future aerial imagery collection should both include a near infrared (NIR) band and should be collected during the summer months, when deciduous trees are in leaf. This would allow for a canopy health assessment based on calculated NDVI values.

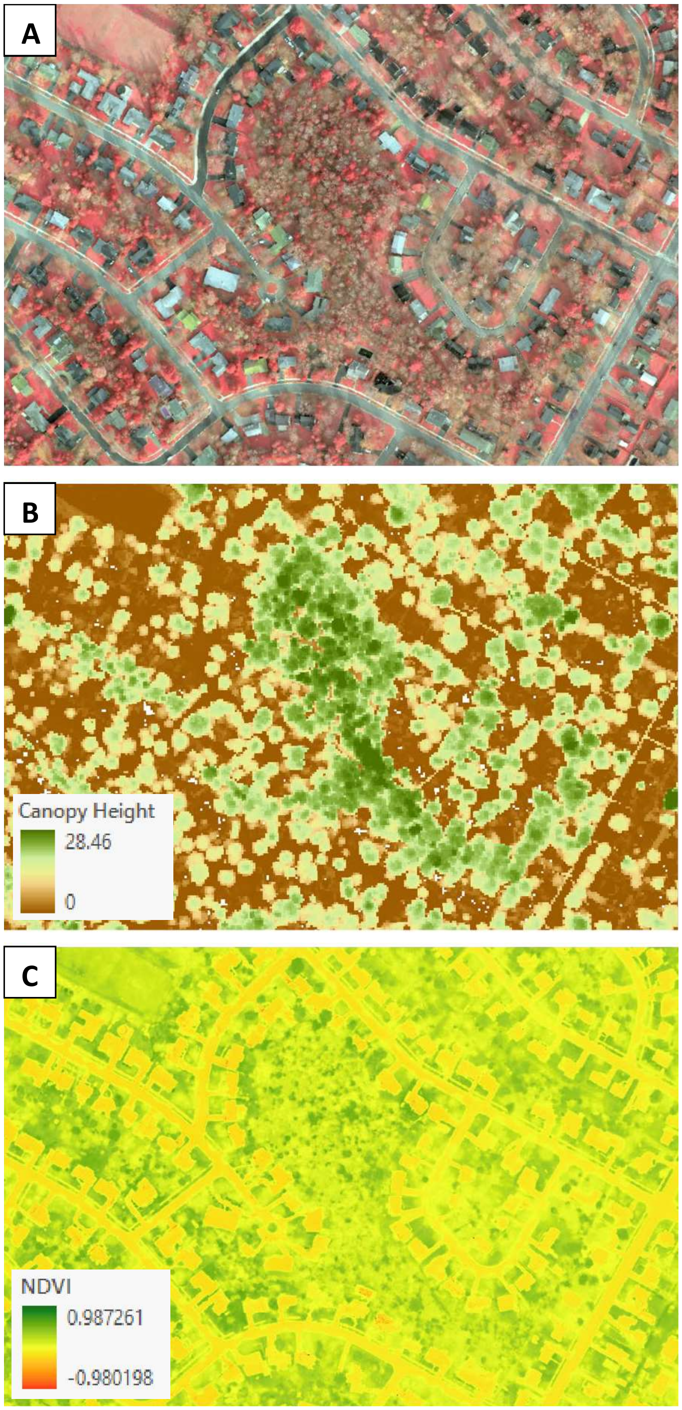

Figure 11: A) Colour infrared imagery (2012); B) LiDAR canopy height model (2015); C) NDVI derived from 2012 CIR, showing that the canopy height model captures the full canopy extent, while leaf-off deciduous trees are missed by the NDVI layer.

DATASET QUALITY

The 2015 urban forest canopy layer includes a small proportion of the total area that is associated with telephone poles and wires, and high fences. While these features can be easily identified as non-vegetated and removed using an NDVI layer, it was not possible to use NDVI in this analysis due to the low NDVI values associated with leaf-off deciduous trees captured in the 2012 aerial imagery. Using NDVI as a mask would have resulted in the removal of a large amount of the deciduous canopy.

Figure 12 demonstrates that most wires, fences, and posts are removed through the majority filtering process; however, a few larger features, such as taller telephone poles, may remain.

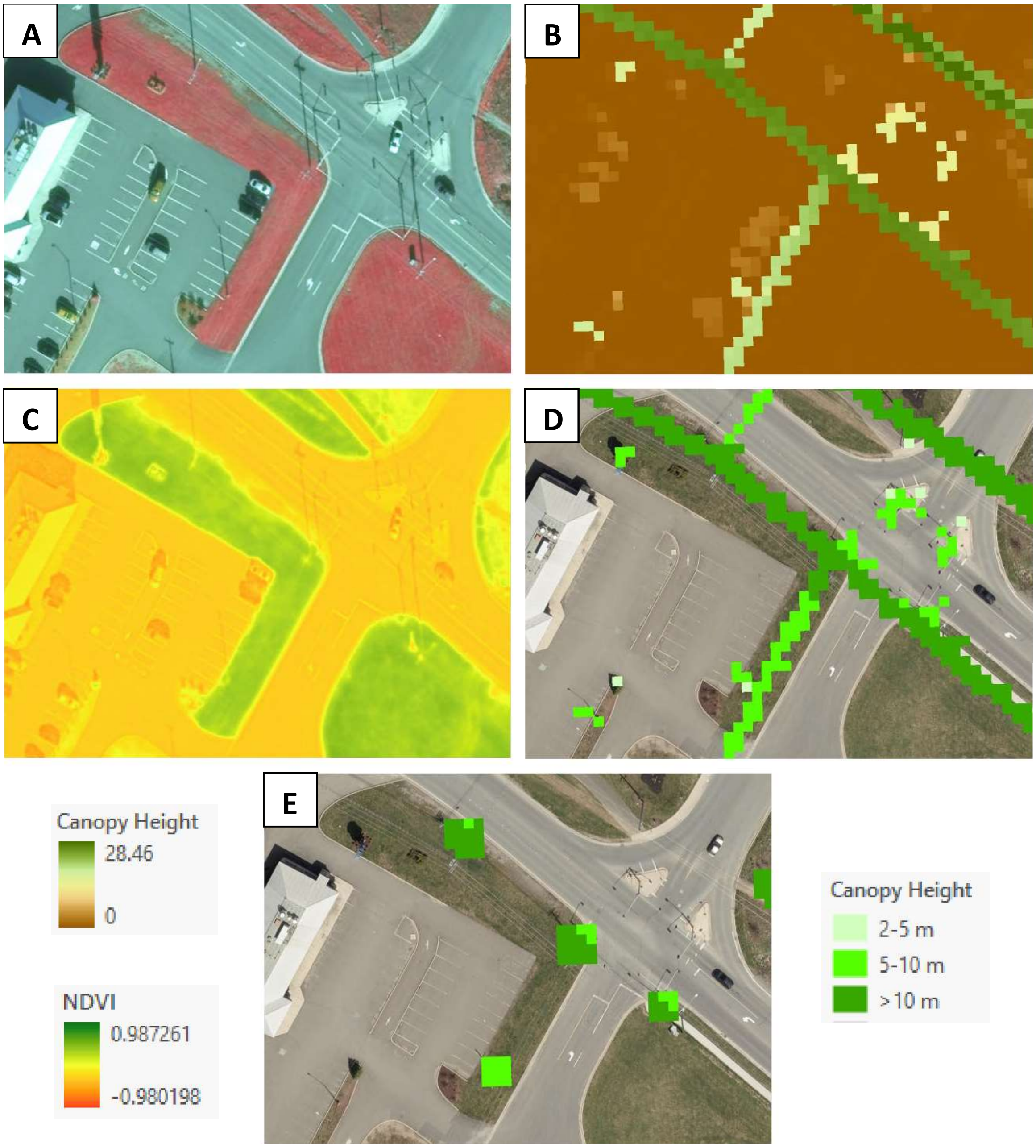

Figure 12: Detection and removal of telephone poles and wires from the urban forest canopy layer. A) colour infrared imagery; B) canopy height model; C) NDVI; B) raw urban forest canopy layer; E) urban forest canopy layer after majority filtering.

Appendix D Canopy Cover Quick Reference

Table 28: Total Canopy Cover

	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Total	4.6	11.6	47.1	36.6

Table 29: Canopy Cover Urban/Rural Split

City Portion	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Urban	3.5	8.8	32	55.8
Rural	5	12.6	52.1	30.4

Table 30: Canopy Cover by Land Use

	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Agricultural	1.6	4.5	39.4	54.6
City Centre	1.5	4	12.3	82.2
Commercial	3.3	4.9	14.1	77.7
Comprehensive Development District	2.5	4.8	55.2	37.5
First Nations	3.3	11.9	56.9	27.9
Future Development	7.2	16.3	58.2	18.3
Industrial	6.3	9.1	36.1	48.4
Institutional	2	5.9	18.9	73.2
Mixed Use	3.3	4.7	20.9	71.1
Open Space	4.9	14.1	50.4	30.7
Park	2.2	9.1	58.9	29.8
Research and Advanced Technology Zone	2.4	6.1	67.4	24.1
Residential	3.7	9.9	37.3	49.2
Rural Residential - Chateau Heights	No Data	No Data	No Data	No Data
UNB Endowment Conservation	6.6	18.5	61.6	13.3
UNB Endowment Development	1.6	10.9	78.3	9.2

Table 31: Canopy Cover by Census Tract

	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
1	1.8	4.6	10.7	82.9
2	2.3	6	35.3	56.4
3	2.3	6.7	29.1	62
4	1.6	6.1	46.5	45.9
5	2.3	6.2	24.6	66.9
6	3.9	8.8	37.7	49.6
7	8.5	16.8	50.6	24.1
8	3.9	12	45.3	38.8
9	3.6	9.4	48.9	38.1
10	2.9	9.6	25.7	61.9
11	3.2	6.9	22.2	67.6
12	3.3	11	22.7	63.1
13	4.3	13.5	57.5	24.8
14	4.2	10.5	57.4	27.9
15	5.4	8.5	45.3	40.9
16	6.3	6.4	23.4	63.9
17	3.1	12.2	57.3	27.5
22*	0.2	10.9	81	7.9
23	1.6	21.8	68.5	8.1
*Partially beyond the Fredericton boundary				

Table 32: Canopy Cover by Ward

	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Bishop Drive/Odell	3.5	13.5	51	31.9
Clements, Sunset	3.7	9.8	51.2	35.2
East Downtown & Plat/UNB	2.2	6	25.6	66.2
Main Street / North Devon	3.8	14.5	44.5	37.2
Marysville	4.1	10.9	57.4	27.5
McLeod, Brookside	4.8	10.8	58.3	26.2
Nashwaaksis North	3.1	11.4	26.1	59.4
Silverwood/Garden Creek	3.5	8.5	40.6	47.4
Skyline Acres	3.4	10.4	55.8	30.5
South Devon, Barker's Point, Lower St. Mary's	4.4	7.8	38.7	49.1
Southwood Park, Lincoln	8	15.1	41.7	35.3
West Downtown & Plat/Sunshine Gardens	2.1	6.3	28.1	63.5

Table 33: Canopy Cover by Neighbourhood

	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Barkers Point	5.4	8.5	45.3	40.8
Brookside	3.4	14.5	66.8	15.3
Brookside Estates	2.7	6.5	31.6	59.1
Brookside Mini Home Park	1.6	5.5	52.6	40.2
College Hill	2.7	11.3	40.2	45.9
Colonial Heights	4.2	13.5	32.6	49.7
Cotton Mill Creek	0.9	3.5	58.1	37.4
Diamond Street	4	11.1	17.8	67.1
Doak Road	14.2	29.1	33.9	22.8
Douglas	3.5	10.3	61.5	24.7
Downtown	2.1	4.4	13.7	79.7

Table 33: Canopy Cover by Neighbourhood

	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Dun's Crossing	3.6	8.5	33.7	54.3
Forest Hill	2.6	7.1	41.3	49
Fredericton South	5.9	14.4	54.5	25.2
Fulton Heights	3	11.7	25.8	59.5
Garden Creek	8.1	6.8	43.8	41.2
Garden Place	3.6	8.7	32.4	55.3
Gilridge Estates	4.7	14.7	10.2	70.4
Golf Club	1.7	6.3	36.7	55.2
Grasse Circle	3.5	8.1	19.9	68.4
Greenwood Minihome Park	3.7	12.2	13	71.1
Hanwell North	2.4	8.5	45.6	43.5
Heron Springs	7.3	8.2	40	44.5
Highpoint Ridge	2.6	9.6	52.9	34.9
Kelly's Court Minihome Park	1.8	9	28.8	60.4
Knob Hill	9.2	10.3	48.4	32
Knowledge Park	2.3	9.7	26.8	61.2
Lian/Valcore	2	4.2	7.8	86
Lincoln	3.9	6.9	23.7	65.5
Lincoln Heights	4.5	9.9	31.5	54.1
Main Street	2.6	9.6	22.4	65.4
Marysville	4.1	11.4	58	26.5
McKnight	2.1	9.2	25.3	63.4
McLeod Hill	10.1	17.8	57.3	14.8
Monteith/Talisman	2.9	7.3	28.7	61.1
Montgomery/Prospect East	2.9	4.6	12.9	79.6
Nashwaaksis	3.3	7.9	50.7	38.2
Nethervue Minihome Park	1.5	5.2	7.3	85.9
North Devon	4.6	6.6	28.6	60.2
Northbrook Heights	1.5	4.5	51.5	42.4

Table 33: Canopy Cover by Neighbourhood

	2-5 m (%)	5-10 m (%)	>10 m (%)	No Canopy (%)
Plat	2.1	6.7	27.3	63.9
Poet's Hill	3.2	7.5	22.6	66.7
Prospect	0.9	3.7	5.5	89.9
Rail Side	5.3	4.6	43	47.1
Regiment Creek	2.5	6.3	15.1	76.1
Royal Road	2.8	21.8	57.1	18.4
Saint Mary's First Nation	3.4	12.7	53.9	29.9
Saint Thomas University	2.3	8.4	19.6	69.7
Sandyville	2.4	9.9	49.7	38.1

Appendix E Tree Species Suitability Matrix

	Species	Common Name	1970 - 2000	2011-2040	2041-2070	Percent of Urban Trees	Recommendation	Reason
Acadian Species	*Abies balsamea*	Balsam fir	Proliferate	Decline	Decline	<0.1%	Decrease	Climate
	Acer pennsylvanicum	Striped maple	Proliferate	Prosper	Persevere	<0.1%	Decrease	Overrepresented
	Acer rubrum	Red maple	Proliferate	Proliferate	Proliferate	13.1%	Decrease	Overrepresented
	Acer saccharinum	Silver maple	Persevere	Persevere	Decline	2.1%	Decrease	Overrepresented
	Acer saccharum	Sugar maple	Proliferate	Prosper	Prosper	12.6%	Decrease	Overrepresented
	Acer spicatum	Mountain maple	Persevere	Persevere	Persevere	<0.1%	Decrease	Overrepresented
	Amelanchier canadensis	Serviceberry	Proliferate	Prosper	Persevere	<0.1%	Maintain	Diversity
	Betula alleghaniensis	Yellow birch	Proliferate	Persevere	Decline	<0.1%	Decrease	Climate
	Betula cordifolia	Mountain paper birch	Prosper	Proliferate	Prosper	<0.1%	Maintain	Diversity
	Betula papyrifera	Paper birch	Proliferate	Decline	Decline	1.2%	Decrease	Climate
	Betula populifolia	Grey birch	Prosper	Persevere	Decline	<0.1%	Decrease	Climate
	Fagus grandifolia	Beech	Proliferate	Proliferate	Proliferate	<0.1%	Decrease	Disease
	Fraxinus americana	White ash	Persevere	Proliferate	Prosper	3.7%	Decrease	Disease
	Fraxinus nigra	Black ash	Persevere	Persevere	Decline	<0.1%	Decrease	Disease
	Juglans cinerea	Butternut	Persevere	Prosper	Prosper	<0.1%	Decrease	Disease
	Larix laricina	Tamarack	Proliferate	Persevere	Persevere	<0.1%	Maintain	Diversity
	Ostrya virginiana	Ironwood	Prosper	Proliferate	Proliferate	<0.1%	Increase	Diversity
	Picea glauca	White spruce	Proliferate	Decline	Decline	1.0%	Decrease	Climate
	Picea mariana	Black spruce	Proliferate	Decline	Decline	<0.1%	Decrease	Climate
	Picea rubens	Red spruce	Proliferate	Prosper	Decline	<0.1%	Decrease	Climate
	Pinus banksiana	Jack pine	Persevere	Persevere	Decline	<0.1%	Decrease	Climate
	Pinus resinosa	Red pine	Proliferate	Prosper	Persevere	<0.1%	Increase	Diversity
	Pinus strobus	White pine	Proliferate	Prosper	Prosper	1.1%	Increase	Diversity

	Species	Common Name	1970 - 2000	2011-2040	2041-2070	Percent of Urban Trees	Recommendation	Reason
	Populus balsamifera	Balsam poplar	Prosper	Persevere	Persevere	<0.1%	Increase	Diversity
	Populus grandidentata	Bigtooth aspen	Persevere	Decline	Decline	<0.1%	Decrease	Climate
	Populus tremuloides	Trembling aspen	Prosper	Persevere	Persevere	<0.1%	Maintain	Diversity
	Prunus pennsylvanica	Pin cherry	Prosper	Persevere	Persevere	<0.1%	Maintain	Diversity
	Prunus serotina	Black cherry	Persevere	Proliferate	Proliferate	<0.1%	Increase	Diversity
	Prunus virginiana	Choke cherry	Prosper	Persevere	Persevere	<0.1%	Maintain	Diversity
	Quercus macrocarpa	Bur oak	Persevere	Persevere	Persevere	1.8%	Increase	Diversity
	Quercus rubra	Red oak	Prosper	Prosper	Prosper	8.2%	Maintain	Diversity
	Rhus typhina	Staghorn sumac	Persevere	Persevere	Persevere	<0.1%	Maintain	Diversity
	Salix nigra	Black willow	Persevere	Persevere	Persevere	<0.1%	Maintain	Diversity
	Sorbus americana	Mountain ash	Proliferate	Persevere	Persevere	<0.1%	Maintain	Diversity
	Thuja occidentalis	Eastern white cedar	Persevere	Persevere	Persevere	<0.1%	Maintain	Diversity
	Tilia americana	Basswood	Prosper	Persevere	Persevere	<0.1%	Maintain	Diversity
	Tsuga canadensis	Hemlock	Proliferate	Prosper	Prosper	<0.1%	Maintain	Diversity
	Ulmus americana	White elm	Prosper	Prosper	Prosper	4.1%	Trial	Diversity
Temperate Species	*Acer nigrum*	Black maple	Decline	Decline	Decline	<0.1%	Avoid	Climate
	Betula lenta	Cherry birch	Persevere	Prosper	Persevere	<0.1%	Increase	Diversity
	Carpinus caroliniana	Musclewood	Persevere	Proliferate	Proliferate	<0.1%	Increase	Diversity/climate
	Carya cordiformis	Bitternut hickory	Persevere	Prosper	Prosper	<0.1%	Increase	Diversity/climate
	Carya ovata	Shagbark hickory	Persevere	Persevere	Prosper	<0.1%	Increase	Diversity/climate
	Castanea dentata	Chestnut	Persevere	Prosper	Prosper	<0.1%	Trial	Diversity
	Chamaecyparis thyoides	Atlantic cedar	Persevere	Prosper	Proliferate	<0.1%	Trial	Diversity

	Species	Common Name	1970 - 2000	2011-2040	2041-2070	Percent of Urban Trees	Recommendation	Reason
	Cornus florida	Flowering dogwood	Persevere	Persevere	Persevere	<0.1%	Trial	Diversity
	Juniperus virginiana	Eastern red cedar	Persevere	Prosper	Prosper	<0.1%	Increase	Diversity
	Nyssa sylvatica	Black gum	Disappear	Persevere	Persevere	<0.1%	Trial	Diversity
	Pinus rigida	Pitch pine	Persevere	Proliferate	Proliferate	<0.1%	Increase	Diversity/climate
	Platanus occidentalis	Sycamore	Decline	Persevere	Prosper	<0.1%	Increase	Diversity/climate
	Quercus alba	White oak	Decline	Prosper	Proliferate	<0.1%	Increase	Diversity/climate
	Quercus bicolor	Swamp white oak	Persevere	Decline	Decline	<0.1%	Avoid	Climate
	Quercus coccinea	Scarlet oak	Disappear	Persevere	Prosper	<0.1%	Increase	Diversity/climate
	Quercus velutina	Black oak	Persevere	Prosper	Proliferate	<0.1%	Increase	Diversity/climate
	Sassafras albidum	Sassafras	Disappear	Persevere	Proliferate	<0.1%	Increase	Diversity/climate
	Ulmus rubra	Slippery elm	Persevere	Prosper	Prosper	<0.1%	Increase	Diversity/climate
Additional Urban Tolerant Species	*Acer negundo*	Manitoba maple	Core	Core	Core	1.0%	Avoid	Overrepresented
	Acer platanoides	Norway maple	Core	Null	Null	19.9%	Avoid	Overrepresented
	Aesclus glabra	Buckeye	Null	Null	Range	<0.1%	Avoid	Climate
	Betula lenta	Cherry birch	Range	Core	Core	<0.1%	Increase	Diversity/climate
	Carya glabra	Pignut hickory	Range	Range	Core	<0.1%	Increase	Diversity/climate
	Carya illinoinensis	Pecan	Null	Range	Range	<0.1%	Trial	Diversity/climate
	Carya lacinioda	Shellbark hickory	Null	Range	Core	<0.1%	Increase	Diversity/climate
	Catalpa speciosa	Catalpa	Null	Range	Range	<0.1%	Increase	Diversity
	Celtis occidentalis	Hackberry	Null	Range	Range	<0.1%	Increase	Diversity
	Cercis canadensis	Redbud	Null	Null	Range	<0.1%	Avoid	Climate
	Cladrastis kentuckea	Yellowwood	Null	Range	Core	<0.1%	Increase	Diversity/climate
	Fraxinus pennsylvanica	Green ash	Core	Core	Core	8.4%	Avoid	Disease

	Species	Common Name	1970 - 2000	2011-2040	2041-2070	Percent of Urban Trees	Recommendation	Reason
	Ginkgo biloba	Ginkgo	Unranked	Unranked	Unranked	<0.1%	Increase	Diversity/climate
	Gleditsia triacanthos	Honey locust	Null	Range	Core	1.6%	Increase	Diversity/climate
	Gymnocladus dioicus	Kentucky coffeetree	Null	Null	Null	<0.1%	Increase	Climate
	Juglans nigra	Black walnut	Range	Range	Core	<0.1%	Increase	Diversity/climate
	Larix decidua	Larch	Core	Core	Core	<0.1%	Increase	Diversity/climate
	Larix laricina	Tamarack	Core	Core	Null	<0.1%	Avoid	Climate
	Larix occidentalis	Western larch	Null	Null	Null	<0.1%	Avoid	Climate
	Liquidambar styraciflua	Sweet gum	Null	Null	Core	<0.1%	Avoid	Climate
	Picea abies	Norway spruce	Core	Core	Range	<0.1%	Increase	Diversity/climate
	Picea engelmannii	Englemann spruce	Range	Null	Null	<0.1%	Avoid	
	Picea pungens	Colorado spruce	Range	Range	Range	<0.1%	Increase	Diversity/climate
	Pinus contorta	Lodgepole pine	Range	Range	Null	<0.1%	Avoid	
	Pinus echinata	Shortleaf pine	Null	Null	Range	<0.1%	Avoid	Climate
	Pinus elliotti	Slash pine	Null	Null	Null	<0.1%	Avoid	-
	Pinus nigra	Austrian pine	Core	Core	Core	<0.1%	Increase	Diversity/climate
	Pinus ponderosa	Ponderosa pine	Range	Null	Null	<0.1%	Avoid	-
	Pinus rigida	Pitch pine	Range	Core	Core	<0.1%	Increase	Diversity/climate
	Pinus serotina	Pond pine	Null	Null	Null	<0.1%	Avoid	-
	Pinus sylvestris	Scots pine	Core	Core	Range	<0.1%	Increase	Diversity/climate
	Pinus virginiana	Virginia pine	Null	Range	Core	<0.1%	Increase	Diversity/climate
	Plantanus x acerifolia	London plantree	Unranked	Unranked	Unranked	<0.1%	Trial	-
	Platanus occidentalis	Sycamore	Null	Range	Core	<0.1%	Increase	Diversity/climate

	Species	Common Name	1970 - 2000	2011-2040	2041-2070	Percent of Urban Trees	Recommendation	Reason
	Pseudotsuga mensziesii	Douglas fir	Range	Range	Null	<0.1%	Avoid	-
	Quercus ellipsoidalis	Hill oak	Null	Null	Null	<0.1%	Avoid	
	Quercus pallustris	Pin oak	Null	Null	Core	<0.1%	Avoid	Climate
	Syringa reticulata	Japanese lilac	Unranked	Unranked	Unranked	1.5%	Maintain	Diversity
	Tilia cordata	Linden	Unranked	Unranked	Unranked	8.7%	Avoid	Climate

Sources:
NRCan RCP 8.5 ANUCLIM models
(Phillips 2015)

Appendix F Urban Species Ecosystem Services

Species	Trees	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Replacement Value
	Number	(metric ton)[1]	($)[1]	(metric ton/year)[1]	($/year)[1]	(m^3/year)[2]	($/year)[2]	(metric ton/year)[3]	($/year)[3]	($)[4]
Silver fir	4	0.22	24.77	0.00	0.38	0.31	0.72	0.00	0.23	4781.79
Balsam fir	36	3.92	450.73	0.06	7.40	8.10	18.83	0.00	5.99	31715.58
White fir	10	2.09	240.47	0.03	3.17	5.69	13.23	0.00	4.21	19209.13
Grand fir	2	0.06	6.60	0.00	0.34	0.14	0.34	0.00	0.11	188.67
Maple spp	1	0.05	6.25	0.00	0.33	0.23	0.53	0.00	0.17	108.45
Hedge maple	4	1.15	131.90	0.01	0.77	2.46	5.73	0.00	1.82	5500.42
Acacia dempsteri	306	23.21	2666.08	0.26	30.02	111.69	259.66	0.02	82.57	227448.82
Ironwood	16	2.09	239.82	0.02	2.62	7.51	17.46	0.00	5.55	17784.28
Freeman maple	9	8.02	921.32	0.11	12.38	12.32	28.65	0.00	9.11	31853.34
Amur maple	19	0.18	20.34	0.02	2.16	1.03	2.40	0.00	0.76	1317.01
Paperbark maple	1	0.00	0.45	0.00	0.05	0.03	0.07	0.00	0.02	62.43
Boxelder	177	80.34	9228.56	1.65	189.78	122.19	284.05	0.02	90.33	224886.92
Japanese maple	5	0.65	74.91	0.01	0.89	1.10	2.56	0.00	0.81	4334.12
Norway maple	3561	1757.23	201852.55	37.86	4348.51	2220.72	5162.53	0.39	1641.72	7968561.59
Red maple	2400	657.49	75525.80	16.88	1939.14	1028.33	2390.58	0.18	760.22	3196864.95
Silver maple	355	543.39	62419.25	5.51	632.41	650.50	1512.23	0.11	480.90	1668720.55
Sugar maple	2278	742.90	85336.99	9.77	1122.85	1138.74	2647.24	0.20	841.84	3595436.56

Species	Trees	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Replacement Value
	Number	(metric ton)[1]	($)[1]	(metric ton/year)[1]	($/year)[1]	(m^3/year)[2]	($/year)[2]	(metric ton/year)[3]	($/year)[3]	($)[4]
Mountain maple	1	0.76	87.12	0.00	0.12	1.41	3.29	0.00	1.04	3244.69
Ohio buckeye	1	0.04	4.34	0.00	0.34	0.22	0.51	0.00	0.16	95.18
Horse chestnut	22	7.98	916.18	0.14	15.83	11.52	26.77	0.00	8.51	29423.11
Downy serviceberry	100	1.33	153.16	0.07	8.56	2.70	6.27	0.00	1.99	9609.93
Birch spp	1	0.27	30.89	0.01	0.88	0.73	1.70	0.00	0.54	1213.51
Yellow birch	19	9.48	1088.71	0.10	11.73	12.30	28.60	0.00	9.10	39100.33
River birch	1	0.02	2.72	0.00	0.27	0.14	0.32	0.00	0.10	65.51
Paper birch	1	0.00	0.33	0.00	0.08	0.04	0.10	0.00	0.03	58.31
European white birch	2	0.22	25.69	0.01	1.17	0.86	2.01	0.00	0.64	1298.98
Asian white birch	208	58.72	6744.79	1.78	204.19	128.13	297.88	0.02	94.73	250553.13
Gray birch	39	3.48	399.29	0.15	16.78	10.77	25.03	0.00	7.96	16951.05
Northern catalpa	2	0.06	6.33	0.00	0.43	0.24	0.55	0.00	0.18	295.78
European hackberry	175	2.05	235.71	0.11	12.12	23.03	53.55	0.00	17.03	49028.20
Katsura tree	10	0.04	4.34	0.00	0.46	0.64	1.49	0.00	0.48	827.47
European filbert	1	0.00	0.19	0.00	0.03	0.01	0.03	0.00	0.01	75.40
Hawthorn spp	101	2.37	272.60	0.11	13.19	4.52	10.51	0.00	3.34	13978.06
Mountain Ash	37	4.36	501.20	0.13	15.44	9.41	21.87	0.00	6.95	17878.56

Species	Trees	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Replacement Value
	Number	(metric ton)[1]	($)[1]	(metric ton/year)[1]	($/year)[1]	(m^3/year)[2]	($/year)[2]	(metric ton/year)[3]	($/year)[3]	($)[4]
American beech	8	2.64	302.97	0.04	4.93	9.41	21.87	0.00	6.95	13929.70
European beech	66	0.33	37.66	0.04	4.39	2.65	6.17	0.00	1.96	5507.43
White ash	689	289.21	33221.52	5.44	624.86	544.21	1265.14	0.09	402.32	1361728.27
Green ash	1597	339.65	39015.36	7.82	898.60	1149.59	2672.47	0.20	849.86	2647077.08
Ginkgo	21	0.04	4.49	0.00	0.39	0.56	1.30	0.00	0.41	1710.46
Honeylocust	322	21.40	2458.58	0.77	88.56	37.98	88.29	0.01	28.08	127891.88
Kentucky Coffee tree	3	0.01	1.16	0.00	0.17	0.10	0.23	0.00	0.07	229.22
Te	24	2.81	322.33	0.06	6.39	3.58	8.33	0.00	2.65	12207.38
Butternut	1	0.09	10.35	0.00	0.49	0.40	0.94	0.00	0.30	608.55
Junipero	2	0.14	15.60	0.00	0.45	0.27	0.62	0.00	0.20	508.03
Black walnut	15	2.14	246.38	0.06	7.02	3.65	8.48	0.00	2.70	10287.36
Larch spp	7	3.64	418.43	0.05	6.06	6.28	14.60	0.00	4.64	29135.41
Japanese larch	5	0.73	83.94	0.02	2.61	2.27	5.28	0.00	1.68	6769.83
Tamarack	30	8.62	989.92	0.20	23.41	17.91	41.63	0.00	13.24	66058.26
Dawson crabapple	2	0.02	2.54	0.00	0.27	0.07	0.16	0.00	0.05	104.56
Saucer magnolia	1	0.00	0.24	0.00	0.06	0.02	0.05	0.00	0.02	69.37
European crabapple	109	0.38	43.89	0.07	7.68	2.13	4.96	0.00	1.58	5698.45
Dawn redwood	4	0.29	32.76	0.01	1.00	1.19	2.76	0.00	0.88	4024.82

Species	Trees	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Replacement Value
	Number	(metric ton)[1]	($)[1]	(metric ton/year)[1]	($/year)[1]	(m^3/year)[2]	($/year)[2]	(metric ton/year)[3]	($/year)[3]	($)[4]
White mulberry	1	0.02	2.03	0.00	0.19	0.06	0.14	0.00	0.04	62.33
Yellow cedar	1	0.02	2.14	0.00	0.20	0.05	0.11	0.00	0.04	77.62
Amur corktree	23	0.28	32.49	0.02	2.03	1.09	2.53	0.00	0.80	2891.69
Norway spruce	19	11.73	1347.93	0.11	12.48	25.66	59.66	0.00	18.97	70188.55
Jack pine	17	1.46	167.67	0.05	6.12	4.71	10.95	0.00	3.48	9426.61
White spruce	171	31.31	3596.99	0.42	48.77	85.58	198.94	0.01	63.26	233029.01
Black spruce	13	0.49	56.77	0.01	1.63	1.04	2.42	0.00	0.77	3007.07
Austrian pine	70	13.39	1537.56	0.27	31.07	31.31	72.79	0.01	23.15	125746.93
Blue spruce	140	26.60	3055.48	0.41	46.61	61.89	143.87	0.01	45.75	193479.55
Red pine	92	24.20	2779.57	0.62	70.71	51.65	120.07	0.01	38.18	169233.09
Red spruce	23	3.71	426.62	0.08	9.45	8.59	19.97	0.00	6.35	28728.54
Eastern white pine	193	137.48	15792.19	1.71	196.75	242.22	563.08	0.04	179.06	1237735.84
Scots pine	16	2.32	266.12	0.06	6.80	7.06	16.41	0.00	5.22	18900.88
London planetree	64	0.13	14.63	0.02	2.49	1.49	3.46	0.00	1.10	4375.38
Cottonwood spp	5	9.62	1105.20	0.09	10.10	7.60	17.68	0.00	5.62	22877.17
White poplar	36	23.35	2682.76	0.26	30.18	22.27	51.76	0.00	16.46	56495.75
Carolina poplar	1	0.48	55.16	0.01	1.39	1.19	2.77	0.00	0.88	1698.94

Species	Trees	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Replacement Value
	Number	(metric ton)[1]	($)[1]	(metric ton/year)[1]	($/year)[1]	(m^3/year)[2]	($/year)[2]	(metric ton/year)[3]	($/year)[3]	($)[4]
Bigtooth aspen	9	4.41	506.03	0.10	11.14	7.87	18.30	0.00	5.82	14139.27
Lombardy poplar	14	4.57	525.15	0.09	10.76	11.10	25.79	0.00	8.20	15949.58
Quaking aspen	48	7.16	822.09	0.24	27.36	8.24	19.15	0.00	6.09	28543.70
Cherry plum	1	0.01	0.79	0.00	0.11	0.03	0.07	0.00	0.02	48.11
Canada plum	3	0.04	4.59	0.00	0.48	0.11	0.24	0.00	0.08	144.34
Pin cherry	19	0.66	76.29	0.03	3.59	1.72	3.99	0.00	1.27	3011.65
Black cherry	2	0.33	37.89	0.02	1.73	0.89	2.07	0.00	0.66	1266.55
Common chokecherry	2	0.02	2.36	0.00	0.39	0.07	0.17	0.00	0.05	96.52
Schmitt's Cherry	45	2.67	306.16	0.10	11.86	3.98	9.25	0.00	2.94	7552.48
Douglas fir	3	0.53	60.43	0.01	1.12	1.93	4.49	0.00	1.43	7253.46
Callery pear	13	0.04	4.19	0.01	0.79	0.34	0.78	0.00	0.25	875.68
Common pear	49	0.18	20.54	0.04	4.74	0.98	2.28	0.00	0.72	3300.64
Ornamental pear	79	0.28	32.13	0.05	5.41	1.85	4.30	0.00	1.37	5329.75
Oak spp	2	0.02	2.06	0.00	0.25	0.05	0.11	0.00	0.03	160.41
Sawtooth oak	29	0.37	42.55	0.05	6.13	1.00	2.33	0.00	0.74	2325.98
White oak	1	0.06	6.37	0.00	0.23	0.21	0.49	0.00	0.16	327.08
Swamp white oak	177	2.27	260.72	0.30	34.17	4.71	10.94	0.00	3.48	15407.56
Scarlet oak	30	0.09	9.83	0.02	2.32	0.58	1.35	0.00	0.43	2593.86

Species	Trees	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Replacement Value
	Number	(metric ton)[1]	($)[1]	(metric ton/year)[1]	($/year)[1]	(m^3/year)[2]	($/year)[2]	(metric ton/year)[3]	($/year)[3]	($)[4]
Shingle oak	48	1.05	120.76	0.08	9.48	1.65	3.83	0.00	1.22	4106.51
Bur oak	376	8.42	966.99	0.23	26.11	25.91	60.24	0.00	19.16	75284.34
Pin oak	111	15.65	1798.16	0.46	53.09	34.79	80.87	0.01	25.72	80083.31
English oak	34	2.30	264.39	0.09	10.23	4.93	11.47	0.00	3.65	14230.45
Northern red oak	1511	666.89	76605.18	9.93	1140.93	882.06	2050.53	0.15	652.08	3361060.75
Black oak	1	0.00	0.36	0.00	0.08	0.01	0.02	0.00	0.01	74.40
Black locust	37	24.19	2778.23	0.52	59.36	24.56	57.08	0.00	18.15	70126.52
Weeping willow	18	38.43	4414.76	0.35	40.19	21.58	50.17	0.00	15.95	85154.82
Black willow	6	0.52	60.12	0.02	2.35	1.66	3.86	0.00	1.23	2110.18
Small-leaved rowan	7	1.18	135.33	0.00	0.54	1.09	2.53	0.00	0.81	4585.36
Lilac spp	429	11.33	1301.48	0.72	82.21	16.65	38.72	0.00	12.31	54237.57
Common lilac	5	0.38	43.66	0.02	1.85	0.45	1.04	0.00	0.33	2006.48
White cedar	133	28.26	3246.29	0.79	91.08	35.77	83.16	0.01	26.45	148503.02
Northern white cedar	1	0.09	10.77	0.00	0.26	0.10	0.22	0.00	0.07	351.58
American basswood	1	0.26	30.02	0.01	0.64	1.07	2.49	0.00	0.79	2356.33
Littleleaf linden	1531	804.66	92430.99	13.06	1500.36	1463.76	3402.82	0.25	1082.12	5142594.26
Bigleaf linden	2	1.58	181.69	0.02	2.72	2.93	6.82	0.00	2.17	10169.61
Eastern hemlock	57	7.99	918.23	0.12	13.31	19.29	44.84	0.00	14.26	75775.34

Species	Trees	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Replacement Value
	Number	(metric ton)[1]	($)[1]	(metric ton/year) [1]	($/year) [1]	(m^3/year) [2]	($/year) [2]	(metric ton/year) [3]	($/year) [3]	($)[4]
European white elm	561	364.82	41906.66	1.51	173.12	280.17	651.32	0.05	207.12	1308893.45
Chinese elm	1	0.02	2.08	0.00	0.25	0.06	0.14	0.00	0.05	52.45
Siberian elm	51	20.99	2410.59	0.47	53.75	32.80	76.25	0.01	24.25	53276.11
Slippery elm	4	0.26	29.77	0.01	1.62	0.96	2.23	0.00	0.71	1264.15
Elm spp	140	118.61	13624.23	1.30	149.26	83.83	194.88	0.01	61.97	431403.26
Total	**19287**	**7,014.46**	**805,750.70**	**124.35**	**14,284.51**	**10,835.25**	**25,188.84**	**1.88**	**8,010.23**	**34,939,999.66**

Source: i-Tree model using Fredericton data

[1] Carbon storage and gross carbon sequestration value is calculated based on the price of Can$114.87 per metric ton. This is the i-Tree default valuation. Tree species, size, and condition are all factors in the calculation. For detailed calculation methods and literature please refer to the program documentation. Due to limits of available models, i-Tree Eco will limit carbon storage to a maximum of 7,500 kg (16,534.7 lbs) and not estimate additional storage for any tree beyond a diameter of 254 cm (100 in). Whichever limit results in lower carbon storage is used.

[2] Avoided runoff value is calculated by the price Can$2.325/$m^3$. The user-designated weather station reported 118.1 centimetres of total annual precipitation. Eco will always use the hourly measurements that have the greatest total rainfall or user-submitted rainfall if provided.

[3] Pollution removal value is calculated based on the prices of Can$1,485.80 per metric ton (CO), Can$2,044.05 per metric ton (O3), Can$304.44 per metric ton (NO2), Can$110.76 per metric ton (SO2), Can$71,079.38 per metric ton (PM2.5), Can$0.00 per metric ton (PM10*).

4 Replacement value is the estimated local cost of having to replace a tree with a similar tree.

A value of zero may indicate that ancillary data (pollution, weather, energy, etc.) is not available for this location or that the reported amounts are too small to be shown.

Appendix G Urban Species Importance Values

Species	Percent Population	Percent Leaf Area	Importance Value
Norway maple	18.50	20.50	39.00
Sugar maple	11.80	10.50	22.30
Red maple	12.40	9.50	21.90
Littleleaf linden	7.90	13.50	21.40
Green ash	8.30	10.60	18.90
Northern red oak	7.80	8.10	16.00
White ash	3.60	5.00	8.60
Silver maple	1.80	6.00	7.80
European white elm	2.90	2.60	5.50
Eastern white pine	1.00	2.20	3.20
Acacia dempsteri	1.60	1.00	2.60
Lilac spp	2.20	0.20	2.40
Asian white birch	1.10	1.20	2.30
Bur oak	1.90	0.20	2.20
Boxelder	0.90	1.10	2.00
Honeylocust	1.70	0.40	2.00
White spruce	0.90	0.80	1.70
Elm spp	0.70	0.80	1.50
Blue spruce	0.70	0.60	1.30
European hackberry	0.90	0.20	1.10
White cedar	0.70	0.30	1.00
Swamp white oak	0.90	0.00	1.00
Red pine	0.50	0.50	1.00
Pin oak	0.60	0.30	0.90

Species	Percent Population	Percent Leaf Area	Importance Value
Austrian pine	0.40	0.30	0.70
European crabapple	0.60	0.00	0.60
Siberian elm	0.30	0.30	0.60
Hawthorn spp	0.50	0.00	0.60
Downy serviceberry	0.50	0.00	0.50
Eastern hemlock	0.30	0.20	0.50
Ornamental pear	0.40	0.00	0.40
Black locust	0.20	0.20	0.40
White poplar	0.20	0.20	0.40
European beech	0.30	0.00	0.40
London planetree	0.30	0.00	0.30
Norway spruce	0.10	0.20	0.30
Quaking aspen	0.20	0.10	0.30
Tamarack	0.20	0.20	0.30
Gray birch	0.20	0.10	0.30
Weeping willow	0.10	0.20	0.30
Mountain Ash	0.20	0.10	0.30
Schmitt's Cherry	0.20	0.00	0.30
Shingle oak	0.20	0.00	0.30
Common pear	0.30	0.00	0.30
Balsam fir	0.20	0.10	0.30
English oak	0.20	0.00	0.20
Horse chestnut	0.10	0.10	0.20
Yellow birch	0.10	0.10	0.20
Red spruce	0.10	0.10	0.20
Lombardy poplar	0.10	0.10	0.20
Scarlet oak	0.20	0.00	0.20

Species	Percent Population	Percent Leaf Area	Importance Value
Freeman maple	0.00	0.10	0.20
Sawtooth oak	0.20	0.00	0.20
Te	0.10	0.00	0.20
Ironwood	0.10	0.10	0.20
Scots pine	0.10	0.10	0.10
Jack pine	0.10	0.00	0.10
Amur corktree	0.10	0.00	0.10
American beech	0.00	0.10	0.10
Bigtooth aspen	0.00	0.10	0.10
Pin cherry	0.10	0.00	0.10
Ginkgo	0.10	0.00	0.10
Black walnut	0.10	0.00	0.10
Amur maple	0.10	0.00	0.10
White fir	0.10	0.10	0.10
Cottonwood spp	0.00	0.10	0.10
Larch spp	0.00	0.10	0.10
Black spruce	0.10	0.00	0.10
Callery pear	0.10	0.00	0.10
Katsura tree	0.10	0.00	0.10
Japanese larch	0.00	0.00	0.00
Black willow	0.00	0.00	0.00
Small-leaved rowan	0.00	0.00	0.00
Hedge maple	0.00	0.00	0.00
Bigleaf linden	0.00	0.00	0.00
Japanese maple	0.00	0.00	0.00
Douglas fir	0.00	0.00	0.00
Dawn redwood	0.00	0.00	0.00

Species	Percent Population	Percent Leaf Area	Importance Value
Common lilac	0.00	0.00	0.00
Slippery elm	0.00	0.00	0.00
Silver fir	0.00	0.00	0.00
Black cherry	0.00	0.00	0.00
European white birch	0.00	0.00	0.00
Mountain maple	0.00	0.00	0.00
Canada plum	0.00	0.00	0.00
Kentucky Coffee tree	0.00	0.00	0.00
Carolina poplar	0.00	0.00	0.00
American basswood	0.00	0.00	0.00
Junipero	0.00	0.00	0.00
Northern catalpa	0.00	0.00	0.00
Birch spp	0.00	0.00	0.00
Grand fir	0.00	0.00	0.00
Common chokecherry	0.00	0.00	0.00
Dawson crabapple	0.00	0.00	0.00
Oak spp	0.00	0.00	0.00
Butternut	0.00	0.00	0.00
Maple spp	0.00	0.00	0.00
Ohio buckeye	0.00	0.00	0.00
White oak	0.00	0.00	0.00
River birch	0.00	0.00	0.00
Northern white cedar	0.00	0.00	0.00
Chinese elm	0.00	0.00	0.00
White mulberry	0.00	0.00	0.00
Yellow cedar	0.00	0.00	0.00
Paper birch	0.00	0.00	0.00

Species	Percent Population	Percent Leaf Area	Importance Value
Paperbark maple	0.00	0.00	0.00
Cherry plum	0.00	0.00	0.00
Saucer magnolia	0.00	0.00	0.00
European filbert	0.00	0.00	0.00
Black oak	0.00	0.00	0.00
Source: i-Tree model using Fredericton data.			

APPENDIX B:
Canopy Change Detection Methods

Appendix B: Canopy Change Detection Methods

The urban forest canopy was extracted from a canopy height model with a 2-m ground resolution, derived from LiDAR data collected by the Province of New Brunswick in 2015. To extract the forest canopy from the continuous canopy height model, Esri's Remap Raster Function was used to reassign individual canopy height pixels into canopy height classes. The following canopy height classes were extracted:

- 2-5 meters
- 5-10 meters
- >10 meters

Vegetation below 2 meters in height was considered not to contribute significantly to the urban forest canopy and was omitted.

The extracted canopy class raster was smoothed using Esri's Spatial Analyst extension tools, including Majority Filter (parameters used were: 8 neighbours, replacement threshold of half) and Boundary Clean (Figure 8). It was then exported to a feature layer and integrated with Fredericton administrative boundaries of interest using Esri's Union geoprocessing tool. Administrative boundaries were obtained from the Fredericton Open Data portal and included:

- Zoning (2013)
- Census tracts (2016)
- Wards (2016)
- Neighbourhoods (2020)
- Urban Growth Boundary
- Census Dissemination Areas
- New Development Areas

In addition, areas already included in the City of Fredericton's existing tree inventory were identified. This was accomplished by buffering all inventoried tree point locations to produce an approximate known tree inventory canopy extent. The buffer radii bins noted in Table 18 were used to approximate tree canopy, based on tree DBH.

Table 18: Canopy Diameter Estimated from DBH

Diameter at Breast Height (cm)	Canopy Radius (m)
<15	2
16 – 30	4
31 – 60	6
61 – 80	8
>81	10

The existing tree inventory buffer was integrated into the canopy height class feature layer with the administrative boundaries.

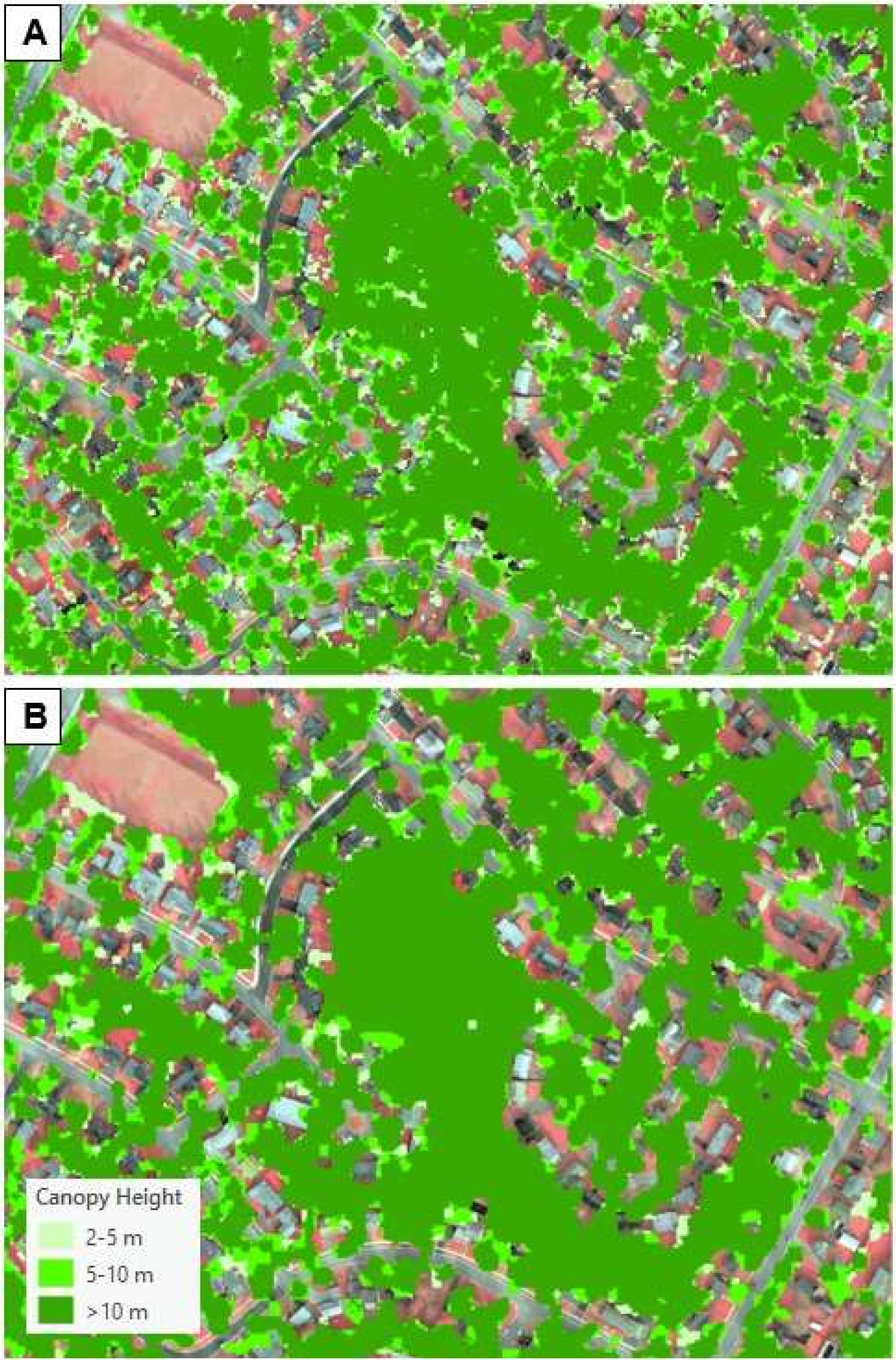

Figure 8: A) Canopy height classes extracted from LiDAR canopy model. B) Canopy height classes after smoothing using Majority Filter and Boundary Clean.

Change Detection Analysis

A change detection analysis was preformed to assess the amount of canopy loss in Fredericton between 2015 and 2023. The change detection analysis used an NDVI layer to identify areas of canopy present in 2015 but lost by 2023.

Four-band (red (R), green (G), blue (B), near infrared (N)) imagery with a resolution of 30 cm was captured by the Pléiades Neo 4 satellite on July 21 and 24, 2023. To reduce processing time, the imagery was resampled to a resolution of 1 m. To facilitate canopy layer development, a Normalized difference Vegetation Index (NDVI) was calculated. NDVI measures the greenness and density of vegetation as captured in satellite or aerial imagery. It is calculated as the difference between the visible red and near-infrared spectral bands using the following equation:

NDVI = (NIR – Red)/(NIR + Red)

This equation produces an index ranging from -1 to +1, with values greater than 0.2 representing vegetation. Higher values indicate healthier and denser vegetation.

2023 CANOPY SURFACE DEVELOPMENT

An object-based image analysis (OBIA) was used to delineate the 2023 urban canopy surface extent. OBIA segments multiple image layers into polygons based on image spectral signatures (colour/brightness), texture (homogeneity/heterogeneity), size (area/perimeter) and shape (compact/linear), allowing for detailed feature delineation. This use of the OBIA automated digitization process effectively replacing replaces a manual digitizing processes and eliminates human bias, while reducing processing time and errors.

The RGBN imagery and derived NDVI layer were segmented in Trimble’s eCognition Developer (v 10.3) software, using the following parameters: Scale 50, Shape 0, Layer weights (R-G-B-N-NDVI): 2-3-2-1-1. The forest surface was then classified using a Random Trees algorithm trained manually selected samples to separate treed areas from developed and grassed areas.

In ArcGIS Pro software, Esri’s Eliminate geoprocessing tool was used to remove forest canopy polygons less than 150 m^2 in size. This threshold was chosen because canopy changes of less than 150 m^2 were considered too small to be relevant to a regional canopy area change assessment. The 2015 LiDAR-based canopy layer was also used to manually identify and remove misclassified areas, primarily lush grass, that were erroneously classified as tree cover based on NDVI values but were not present in the 2015 canopy layer.

CHANGE DETECTION

To assess the change in canopy area between 2015 and 2023, the 2015 canopy height model and 2015 canopy surface were combined using Esri’s Union geoprocessing tool. All areas of overlap between 2015 and 2023 were deleted, preserving only areas in 2015 missing from 2023, i.e. areas of canopy loss between 2015 and 2023 (Figure 9). Percentage change statistics were calculated.

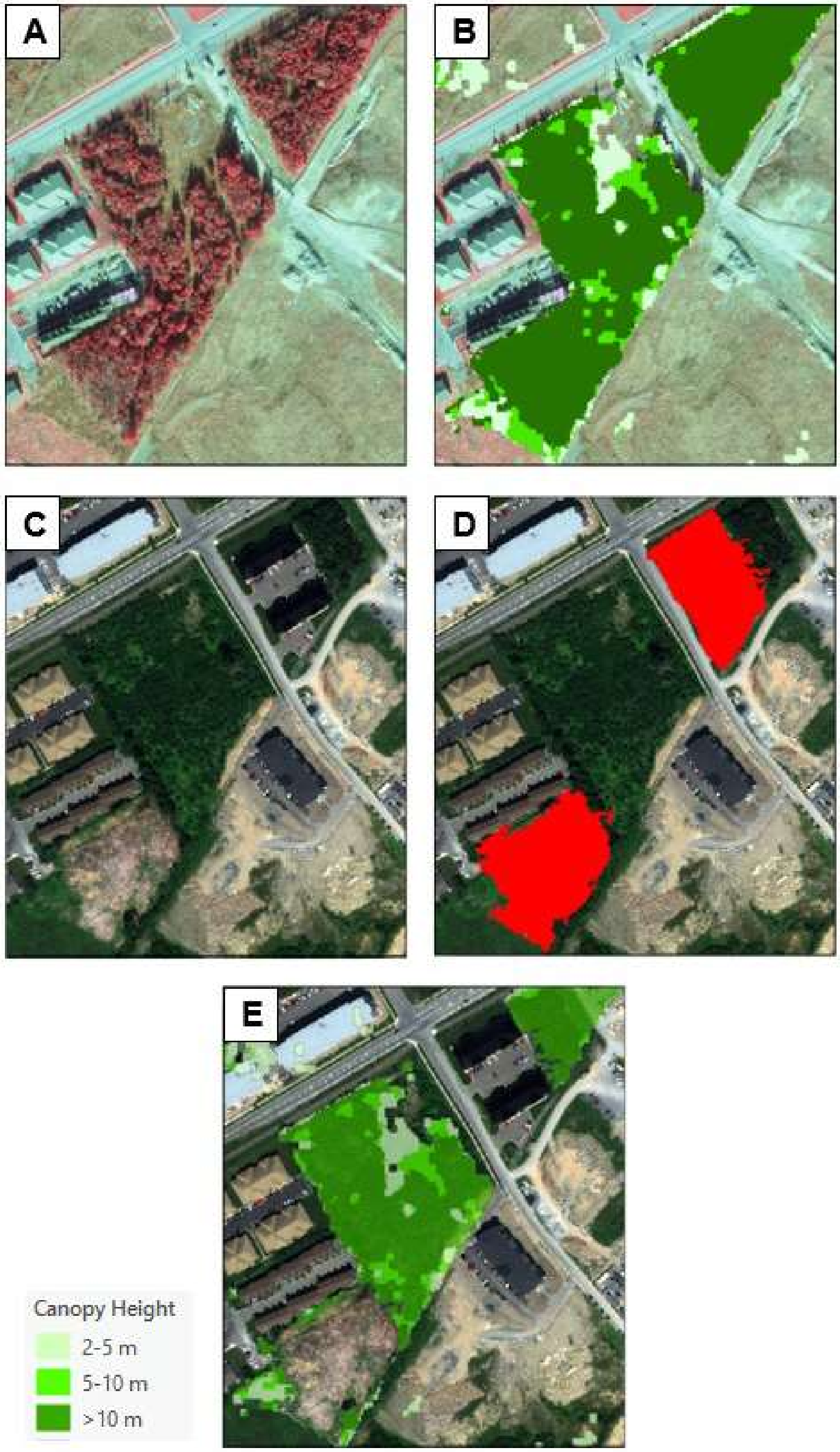

Figure 9: A) Colour infrared imagery (2012); B) LiDAR canopy height model (2015); C) RGB imagery (2023); D) Canopy loss layer; E) LiDAR canopy height model updated with 2023 canopy loss.

Data Limitations and Recommendations for Future Update

CANOPY HEALTH AND HEIGHT

The 2015 canopy cover layer was developed using only LiDAR-derived canopy height data. As a result, the layer represents only canopy extent and does not include any measure of canopy health. Colour infrared aerial imagery was collected by the city of Fredericton in 2012, which included visible (red, green) and near-infrared (NIR) bands, allowing for the calculation of a Normalized Difference vegetation Index (NDVI).

However, the 2012 imagery was captured at a time when deciduous trees were without leaves; as a result, NDVI had to be omitted from the analysis, as it would have resulted in deciduous trees being classified as unhealthy, or even being omitted entirely. Figure 10 shows that the canopy height model detects all tree cover, while NDVI calculated from leaf-off imagery results in deciduous trees being assigned non-vegetated values.

Conversely, the 2023 canopy surface layer developed for the change detection analysis did not include canopy height information, an important component of identifying tress large enough to include in the urban canopy (>2 m). Consequently, this layer was used only to update the LiDAR-based 2015 layer.

Future work should include both LiDAR-based canopy height information and a near infrared (NIR) band, which should be collected during the summer months, when deciduous trees are in leaf. This would allow for both canopy height differentiation and a canopy health assessment based on calculated NDVI values.

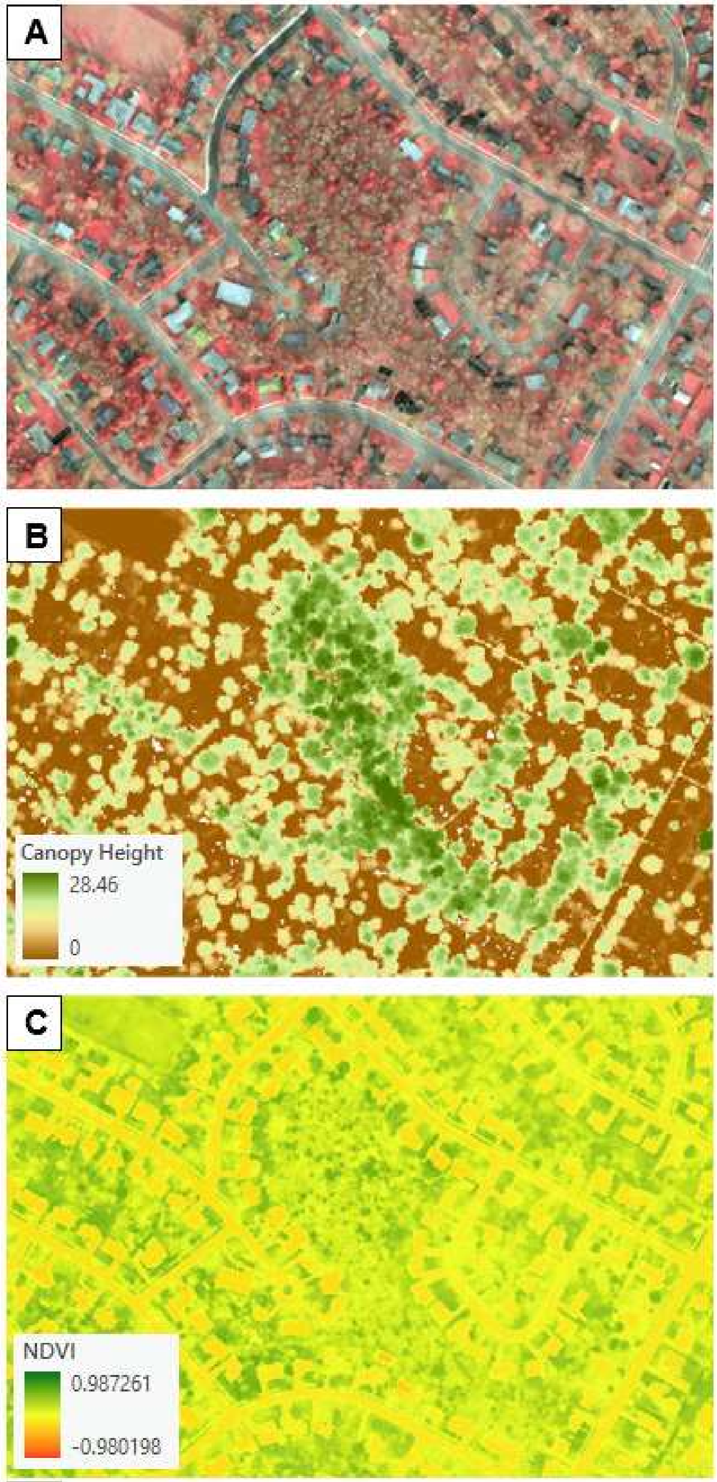

Figure 10: A) Colour infrared imagery (2012); B) LiDAR canopy height model (2015); C) NDVI derived from 2012 CIR, showing that the canopy height model captures the full canopy extent, while leaf-off deciduous trees are missed by the NDVI layer.

APPENDIX C: Heat Island and Demographic Analysis Methods

Appendix C: Heat Island and Demographic Analysis Methods

Landsat Heat Island Mapping Methods:

Landsat 8 level-1 data can be used to determine land surface temperature using a scripted process in ArcGIS Pro. Landsat data contains enough information to decipher land surface temperatures for any image. The process starts with the selection of an image and accessing that imagery via an assortment of online portals. That data is processed via a set of scripts that transform the data into a land surface temperature via numerous calculations and combinations of raster data. The results give an approximation of land surface temperature at the time the imagery was taken. This process can be repeated to produce comparable results for any Landsat imagery or for repeat imagery at the same location, at different times. Refer to Tsou et al. (2017) for detailed methods of the calculations. Figure 11 shows the results with building footprints included for context of the City's built form.

Social Index Mapping Methods:

The social index dataset is made up of census data at the dissemination area (DA) for all of Canada in 2021. The index focuses on key indicators of socio-economic status such as income, housing status, age, low-income cutoffs (LICO), and mobility combined into a single value. Each measure is evaluated relative to the average value for all of Canada. When a value falls above or below the average but in a direction that indicates lower socio-economic status, that DA is given a value of 1. The index score is the sum of each socio-economic measure, meaning that a higher value indicates negative socio-economic conditions and a lower value the opposite. The data can be presented in a map form for any location in Canada. The result approximates the characteristics of each area in Canada. Figure 12 shows the results as a bivariate analysis of median land surface temperature and social index by census dissemination area.

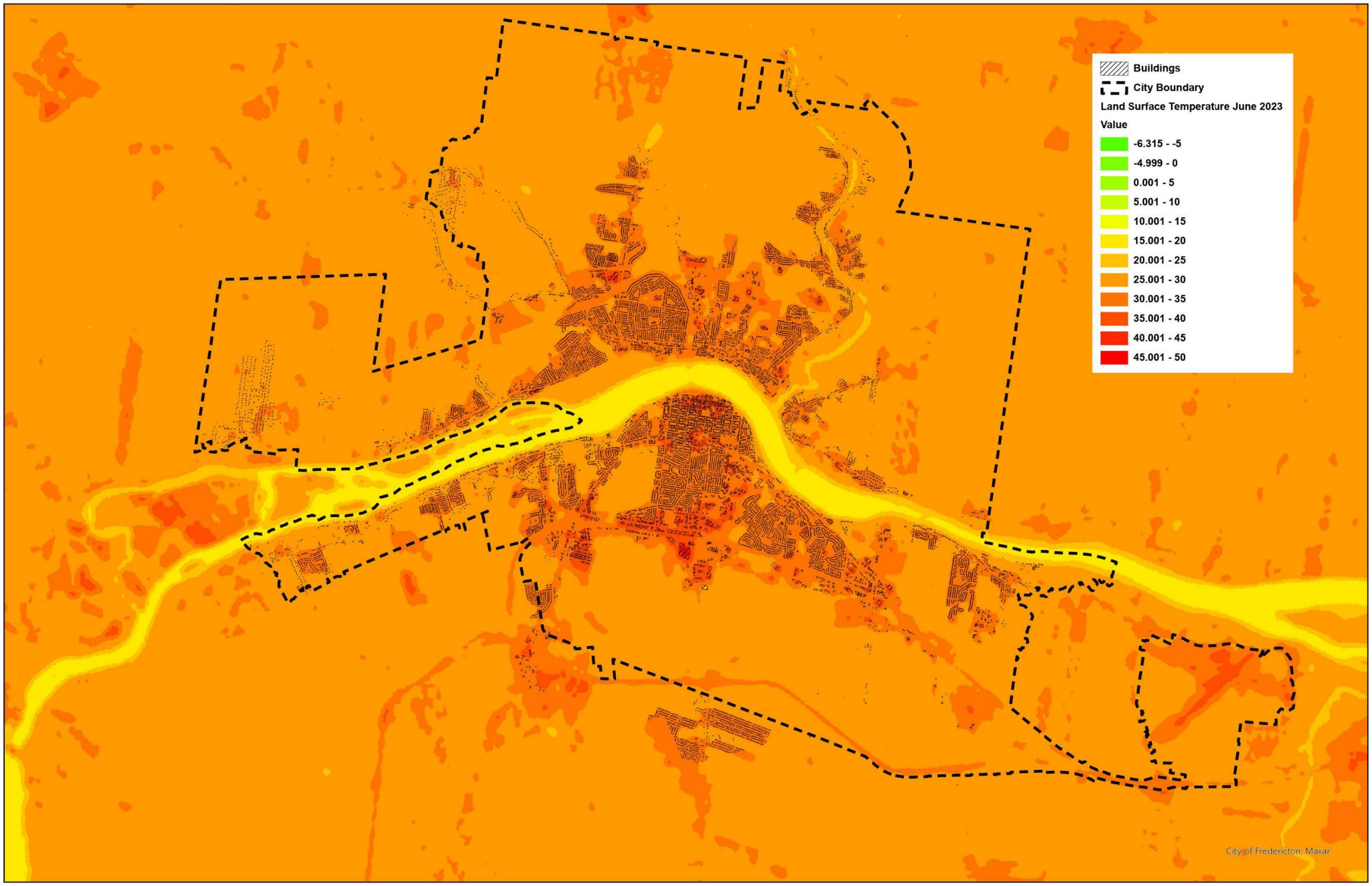

Figure 11: Land Surface Temperature

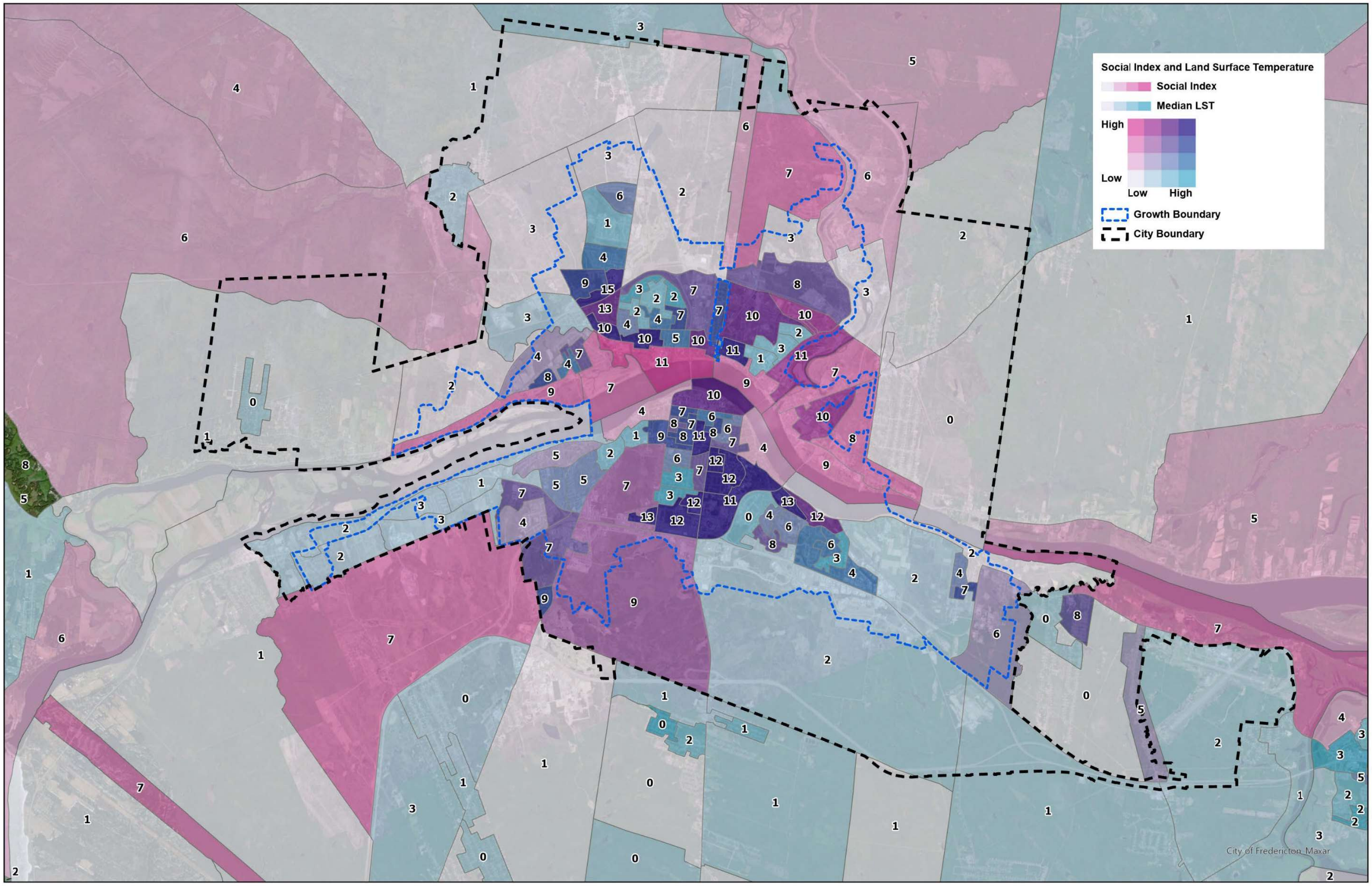

Figure 12: Social Index and Land Surface Temperature