The Ecological and Monetary Impact of Garden Suites on Urban Forests in A Toronto Neighborhood

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1. Abstract

Urban densification initiatives, such as the Garden Suites By-law in Toronto, aim to address housing challenges by increasing residential density. However, these developments often require the removal of urban trees, resulting in significant ecological and economic impacts. This study examines the effects of garden suite construction on urban forests within the Ashdale Avenue and Parkmount Road neighbourhoods. Through a detailed inventory of 1,114 trees, geospatial analysis in ArcGIS Pro, and the iTree Eco model, the research quantifies the loss of ecosystem services, including carbon sequestration, stormwater management, and energy savings, and evaluates the replacement cost of removed trees.

Findings reveal that urban intensification in residential areas could cause a potential canopy cover reduction of 70.64% under full development scenarios, which equates to substantial ecosystem service losses, including an estimated Can$ 409,960 in replacement value. On average, parcels could lose 40.37 m² of canopy area, with a 95% confidence interval indicating a true mean loss of at least 30.16 m². Moreover, the potential total canopy loss across 43 inventoried parcels was calculated as 1,735.88 m². Tree species such as Northern white cedar (*Thuja occidentalis*), green ash (*Fraxinus pennsylvanica*), and Norway maple (*Acer platanoides*) emerged as key contributors to ecological services such as carbon storage and avoided runoff.

This study underscores the importance of developing policies that harmonize urban densification with the conservation of urban forest ecological services, promoting sustainable urban development.

2. Introduction

The rapid urban expansion and densification in Toronto, particularly through initiatives such as garden suites, have raised significant community concerns about the loss of urban forest canopy. A garden suite is a self-contained living accommodation located in an ancillary building, usually in the rear yard, separate from the primary dwelling on the lot. This project is part of the City of Toronto's "Expanding Housing Options in Neighbourhoods (EHON)" initiative, aimed at increasing housing supply and diversity (City of Toronto, 2022). However, constructing garden suites often necessitates removing urban trees, posing ecological challenges in neighborhoods like Ashdale Avenue and Parkmount Road. Tree canopies are crucial to community livability, environmental quality, and shared values in these areas. The removal of urban trees for garden suites not only diminishes the visual appeal of neighborhoods but also results in a significant loss of ecosystem services, including carbon sequestration, stormwater management, cooling effects, and air quality improvement.

Toronto's urban forest currently covers 26.6% of the city, with an aim to reach a 40% canopy cover target by 2050 (City of Toronto, 2021). Urban trees contribute to enhancing climate resilience, air quality, and biodiversity through their regulating functions. For instance, urban trees are crucial in alleviating the urban heat island effect by reducing surface temperatures through processes such as shading and evapotranspiration, effectively decreasing temperatures in densely populated areas by 1°C to 8°C (Bowler et al., 2010; Greene & Millward, 2017; Smithers et al., 2018).

Additionally, urban trees help manage stormwater by intercepting rainfall, with studies indicating that they can capture between 14% and 44% of precipitation, thereby reducing the burden on drainage infrastructure and minimizing the risk of urban flooding (Livesley et al., 2014; Szota et al., 2019). Poor air quality remains a prevalent issue in urban areas, contributing to adverse health effects, damage to landscape materials, and reduced visibility. Urban trees capture pollutants like nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3) through dry deposition while indirectly improving air quality by lowering temperatures, reducing energy demands, and minimizing emissions from power generation (Nowak & Dwyer, 2000; Lin et al., 2020). Urban trees also act as natural air filters, creating a buffer between human activities and sources of pollutants (Abhijith & Kumar, 2019; Kumar et al., 2019).

Structural characteristics such as canopy height and density significantly influence the ability of trees to capture pollutants, with dense and continuous canopies proving most effective at mitigating pollution levels (Ali et al., 2022; Brantley et al., 2015). However, the effectiveness of trees in mitigating air pollution is also impacted by the characteristics of specific tree species (Gómez-Moreno et al., 2019). A well-established urban forest canopy can reduce the downward transport of harmful air pollutants, leading to lower concentrations of substances like nitrogen dioxide (NO_2) (Brantley et al., 2015). Studies also indicate that areas with abundant tree cover often have reduced levels of NO_2 compared to regions with less vegetation (Fantozzi et al., 2015; García-Gómez et al., 2016). Although trees can emit volatile organic compounds that may contribute to ozone formation, studies have shown that increasing tree cover generally reduces ozone levels (Nowak & Dwyer, 2000).

Urban forests are also critical for biodiversity conservation. For example, Jim and Liu (2001) found that in Guangzhou, China, over 250 tree species were recorded in urban areas, surpassing the biodiversity of the surrounding degraded forests. Similarly, Stewart et al. (2004) observed that Christchurch, New Zealand, harbors greater plant diversity than rural areas. These examples illustrate the role of urban trees in sustaining plant diversity, even within densely populated areas.

Furthermore, urban trees contribute significantly to carbon sequestration, with species-specific variations influencing their capacity to store and absorb atmospheric carbon dioxide. Fast-growing species such as Norway maple (*Acer platanoides*) and boxelder (*Acer negundo*) exhibit high rates of carbon sequestration due to their robust growth patterns (Kloeppel & Abrams, 1995; Wyckoff & Webb, 1996). The invasive characteristics of the Norway maple highlight concerns regarding its influence on the stability of native ecosystems, underscoring the importance of deliberate and thoughtful tree species selection (Randall & Marinelli, 1996; Webb & Kaunzinger, 1993).

Urban forests also provide essential regulating services such as cooling effects and building energy savings. By moderating energy use, trees reduce cooling demand in summer through shading and heating costs in winter by acting as windbreaks. Studies have shown that trees within 18 meters of buildings significantly influence energy use, reducing indoor temperatures by as much as 3°C and generating substantial economic and environmental benefits (Chen & Jim, 2008; McPherson & Simpson, 2003). These services underscore the importance of integrating urban forests into sustainable city planning to address climate challenges effectively (Wong et al., 2011).

Building on the critical importance of preserving urban forests amidst urban densification, this study utilized i-Tree Eco to assess the ecological and monetary impacts of tree loss associated with garden suite developments. i-Tree Eco was chosen due to its seamless integration with the Neighbourwoods dataset, which captures essential attributes such as tree species, Diameter at Breast Height (DBH), and canopy width. This compatibility ensured efficient data processing and accurate valuation of ecosystem services, including carbon sequestration, runoff reduction, and air quality improvement. Compared to alternatives like CITYgreen, UFORE, and 3PG, i-Tree Eco's localized adaptability and user-friendly interface made it the most suitable tool for this study (Rötzer et al., 2020).

Recognizing that urban trees store approximately 20% less biomass than traditional forest trees due to environmental stressors, i-Tree Eco adjusts its biomass estimates accordingly (Nowak, 1994). The model calculates carbon storage as the cumulative carbon content of tree biomass, while carbon sequestration represents the annual rate at which carbon is captured and stored through tree growth. Energy conservation estimates in the i-Tree Eco model incorporate both direct effects, such as shading, and indirect effects, such as windbreaking, to reduce cooling and heating demands, resulting in ecological and economic benefits. Urban trees can lower indoor temperatures by up to 3°C, which reduces energy consumption and associated costs (McPherson et al., 2006; Chen & Jim, 2008).

The i-Tree Eco model also calculated the replacement value of urban trees, defined as the cost of replacing a tree with one of similar size, species, and condition (CTLA, 1992). By quantifying replacement costs, this research provides a tangible framework for understanding the financial implications of tree loss due to garden suite construction. Incorporating these insights into urban planning can help balance the competing demands of housing development and environmental conservation.

3. Objectives

While the importance of urban forests is widely recognized, research quantifying the ecological and economic impacts of tree removal for developments like garden suites remains limited. This study aims to fill this critical gap by assessing the ecological and economic repercussions of urban tree loss.

In light of these considerations, the following project objectives are established:

1. Evaluate Tree Canopy Loss by Scenario: Assess potential tree canopy loss under different development scenarios: loss in parcels with larger properties, all parcels, and no construction.
2. Quantify Economic and Ecosystem Service Loss: Determine the financial impact of tree loss, including replacement value and ecosystem service losses such as carbon sequestration, stormwater management, and energy savings.

4. Methods

4.1 Study Area

This study focuses on the residential neighborhood along Ashdale Avenue and Parkmount Road in Toronto, Ontario, Canada, spanning from Danforth Avenue (latitude: 43.6782° N, longitude: 79.3310° W) to Queen Street (latitude: 43.6668° N, longitude: 79.3265° W) (Figure 1). Originally developed in the early 20th century to house lowerincome families and immigrant populations, the area is now characterized by single-family homes and small green spaces. These tree-lined streets and pockets of urban forest contribute to the neighborhood's ecological and social identity.

Ashdale Avenue and Parkmount Road are sections of the same road, divided by a railway line. While Craven Road and Rhodes Avenue are also part of the broader neighborhood, their back-to-back property layouts limit the feasibility of garden suite developments due to insufficient rear-yard space (City of Toronto, 2022). Additionally, the area includes alleyways, making it representative of Toronto's low-density residential areas where development pressures often conflict with conservation goals.

The study area comprises 167 property parcels, of which 43 were fully sampled during the summer of 2024. This neighborhood provides an important context for evaluating the impacts of garden suite developments on urban tree cover, as tree removal and land-use changes are inevitable components of urban densification efforts (Kaspar et al., 2017).

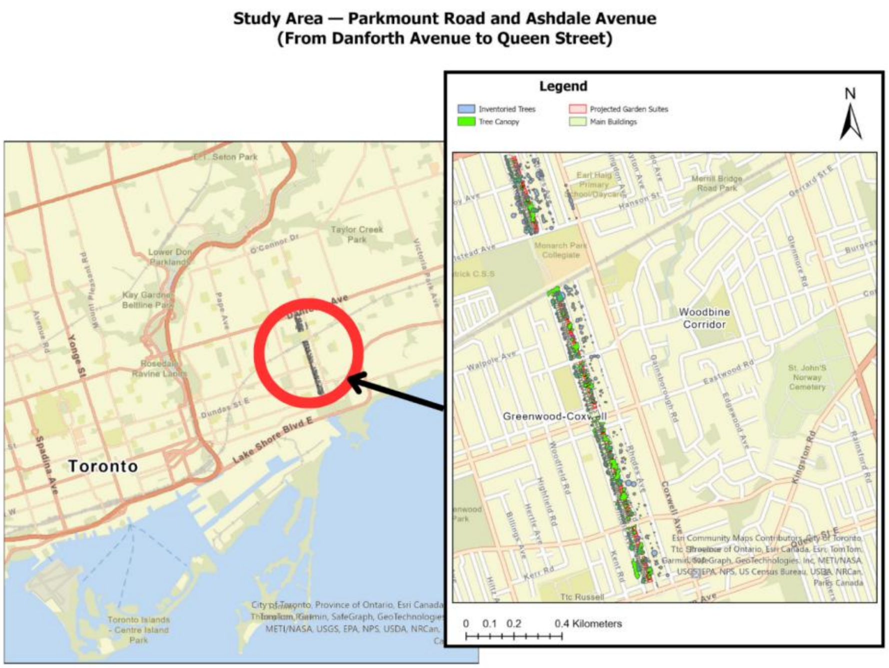

Figure 1. *Study area: A line of parcels that back on an ally, located on Ashdale Avenue and Parkmount Road between Danforth Avenue and Queen Street.*

4.2 Data Collection

This project began when Ms. Claudia Aenishanslin, a member of the Craven Road Residents Association, approached Dr. Danijela Puric-Mladenovic to collaborate on the Neighbourwoods project. Dr. Puric-Mladenovic provided me with the opportunity to conduct the tree inventory as part of a two-month case study during my internship. To support the project, Ms. Aenishanslin reached out to residents along Ashdale Avenue and Parkmount Road, as well as adjacent streets like Craven Road and Rhodes Avenue. She distributed emails and pamphlets to inform the residents about the study and its objectives.

Following this outreach, I arranged appointments with residents and conducted door-to-door inquiries to seek permission to inventory trees on their properties. This direct engagement with the community facilitated access to various sites for data collection and fostered an understanding of local perceptions regarding urban forest management.

The data collection methodology utilized the Neighbourwoods® program, developed by Dr. W.A. Kenney and Dr. D. Puric-Mladenovic, to support community-based urban forest management (Kenney and Puric-Mladenovic, 2021). This program provided a structured framework to assess several tree characteristics, including canopy width, height, and overall health. Special attention was given to identifying signs of tree stress or damage, as these indicators are critical for determining the long-term sustainability of urban trees. The Neighbourwoods® program was specifically designed to be adaptable to i-Tree Eco, ensuring excellent data compatibility for further analysis of ecosystem services.

Neighbourwoods® inventory data provided the foundation for estimating tree loss and its impact on ecosystem services in areas targeted for garden suite developments. By processing the data's geospatial format, which detailed tree locations and attributes, I mapped canopy coverage within the sampled properties

4.3 Mapping Footprints of Potential Buildings

To approximate the potential footprints of garden suites, I replicated the dimensions of the main buildings on each property and transformed them into rectangular forms to align with existing structures. For properties that shared a single building footprint, I assumed residents would share one garden suite, as spatial constraints made multiple units impractical. These adjustments aimed to provide a realistic representation of potential garden suite developments.

To assess the potential impacts of garden suites on tree canopy, a 3-meter buffer zone was applied around proposed garden suite footprints. This buffer distance was based on the Tree Protection Zone (TPZ) guidelines provided by the City of Toronto, which recommend a TPZ of 2.4 meters for trees with a Diameter at Breast Height (DBH) of 30–

40 cm (City of Toronto, 2021). The additional 0.6 meters accounted for material storage and construction activities, reflecting realistic development scenarios.

To include unsampled parcels and digitize the full tree canopy for the study area, satellite imagery from Google Earth Pro was utilized. Google Earth Pro was selected for its updated and high-resolution imagery, which allowed for precise delineation of canopy coverage. The digitized canopy data were then imported into ArcGIS Pro for further spatial analysis.

These datasets were subsequently analyzed in ArcGIS Pro to evaluate the spatial relationships between trees and potential garden suite developments. By combining spatial data with georeferenced tree canopy information, this study provided critical insights into the ecological and monetary consequences of urban densification within the study area.

4.4 Scenario Development

The total canopy area of inventoried trees was derived using the "Buffer" tool to define canopy zones for each tree based on the average canopy radius (from Neighbourwoods® measurements). I then used the "Dissolve" function to merge the individual canopy buffers, obtaining the total canopy area. Finally, I divided the total replacement value by the canopy area to determine the replacement value per square meter.

$$Replacement\ Value\ per\ m^2 = \frac{Total\ Replacement\ Value}{Total\ Tree\ Canopy\ Area}$$

To establish the existing canopy cover percentage in the study area, I calculated the total canopy area and divided it by the study area's total size.

This value provided a baseline for comparing canopy cover in different development scenarios. The replacement value of the entire canopy was then estimated by multiplying the canopy area by the replacement value per square meter.

The impact of garden suite development on tree canopy was evaluated under three scenarios:

Scenario 1: Larger Parcels Only

This scenario assumes that only parcels larger than the average size (229.92 m²) would develop garden suites. The canopy loss for this scenario was calculated by proportionally scaling the estimated canopy loss of all parcels based on the area of the larger parcels:

$$Estimated\ Canopy\ Loss = Total\ Loss \times \frac{Area\ of\ Larger\ Parcels}{Area\ of\ Study\ Area}$$

The remaining canopy area, canopy cover percentage, and replacement value loss were then calculated based on this estimated loss.

Scenario 2: All Parcels

In this scenario, all parcels in the study area are assumed to develop garden suites. I used the 43 fully sampled parcels to determine the canopy loss by removing all trees within a 3-meter buffer of the garden suite footprints in these parcels. This calculated loss was then scaled to estimate canopy loss for the entire study area:

$$\begin{aligned}&\mathit{Estimated\ Canopy\ Loss}\\&= \mathit{Canopy\ Loss\ in\ Fully\ Sampled\ Parcels} \times \frac{\mathit{Area\ of\ Study\ Area}}{\mathit{Area\ of\ Fully\ Sampled\ Parcels}}\end{aligned}$$

The replacement value and remaining canopy cover percentage for Scenario 2 were calculated based on this canopy loss.

Scenario 3: No Construction

This scenario assumes no garden suite development, preserving the existing canopy cover in the study area. It served as the baseline for comparison, with canopy cover and replacement value metrics reflecting current conditions.

4.4 i-Tree Eco variables used

To assess the impacts of garden suites on tree canopy, I utilized data from a tree inventory of 1,114 trees, encompassing the study area and two adjacent streets, Craven Road and Rhodes Avenue. The inventory was conducted using the Neighbourwoods® program, developed by Dr. W.A. Kenney and Dr. D. Puric-Mladenovic, which provides a systematic framework for urban forest management. Tree attributes such as species, Diameter at Breast Height (DBH), canopy width, tree height, crown size (including crown width, height to live top, and height to crown base), crown health (dieback), and land use (residential) were recorded and directly input into i-Tree Eco for analysis.

To account for the spatial relationship between trees and buildings, the distance between each tree and its nearest structure was calculated using ArcGIS Pro's "Generate Near Table" tool. For the analysis, it was assumed that all backyards were situated east of the main buildings, with each tree positioned west of its nearest structure. Direction was measured as the angle of the tree relative to the closest part of a building, while distance was determined as the shortest measurement from the tree to the building (Nowak, 2021). These variables were essential for calculating energy-related benefits, such as reduced cooling and heating demands. Trees within 18 meters of a building were considered to significantly influence energy use (McPherson & Simpson, 2003).

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The study area includes parcels along Ashdale Avenue and Parkmount Road. However, not all property owners in the study area granted permission for their trees to be inventoried. As a result, tree inventory data were collected only for parcels where permission was obtained. Extrapolation was conducted by leveraging the canopy area of inventoried trees and the total canopy area within the study area. The canopy area of the inventoried trees was calculated in ArcGIS Pro by applying a buffer-and-dissolve operation to map the extents of individual tree canopies. For the entire study area, the total canopy area was determined by digitizing canopy coverage from high-resolution satellite imagery using Google Earth Pro. This approach provided a comprehensive view of tree canopy distribution within the study area. The proportional relationship between the inventoried canopy area and the total study area canopy was then used to scale up metrics such as ecosystem services and replacement values, ensuring accurate representation of the entire study area.

i-Tree Eco was then used to calculate the monetary valuation of urban trees based on their ecosystem services, including carbon storage, runoff reduction, and air quality improvement. Weather and pollution data were incorporated into the analysis from three sources: Erie Station ID 1014, Niagara Station ID 1006, and another station in Erie (Station ID 0023), using pollution data from station 712650-99999. These data enhanced the precision of ecosystem service estimations. Additionally, i-Tree Eco performs species-specific analyses for different ecosystem services, allowing for tailored insights into the contributions of individual tree species.

In terms of surface runoff reduction, i-Tree Eco estimates annual avoided runoff by comparing two scenarios: one that includes both vegetated and non-vegetated areas and another with only non-vegetated areas. The difference in runoff volumes between these scenarios is attributed to the presence of vegetation, highlighting the hydrological benefits provided by urban tree canopies.

Furthermore, all figures related to species-specific ecosystem service analyses presented in this study were generated directly from i-Tree Eco, emphasizing the platform's capability to provide detailed and localized insights.

4.4.1 Carbon Storage and Carbon Sequestration

i-Tree Eco estimates urban forest carbon storage (CS) and gross carbon sequestration (GCS) by employing a combination of peer-reviewed tree growth models and biomass equations specifically designed for urban environments. The model estimates carbon storage and sequestration using tree-specific data, including species, diameter at breast height (DBH), canopy coverage, and tree health (Nyelele et al., 2019; Nowak et al., 2013). To account for variability among tree species, the model incorporates over 150 allometric equations. When species-specific equations are unavailable, genus-level or family-level approximations are utilized (Ma et al., 2021).

The dollar value of carbon storage and sequestration is derived using the present value of expected ecosystem services over the tree's lifetime. This process integrates discounted annual ecosystem service values to provide an economic estimate of these benefits (Stern, 2007).

In cases where trees were recorded at the genus level due to species identification limitations, the model accounts for potential variability in sequestration and storage capacities among species within the same genus. These adjustments ensure that the model provides a robust and realistic assessment of carbon-related ecosystem services.

4.4.2 Oxygen Production

The i-Tree Eco model estimates annual oxygen production by urban trees through its link with carbon sequestration, as both processes are interconnected via photosynthesis and biomass accumulation (Nowak et al., 2007). The calculation accounts for the net difference between oxygen produced during photosynthesis and oxygen consumed during plant respiration, providing an accurate estimate of net oxygen production.

To calculate net oxygen release, i-Tree Eco applies the following equation:

$$\textit{net } O_2 \textit{ release (kg/yr)} = \textit{net C sequestration (kg/yr)} \times (32/12)$$

This relationship reflects the stoichiometric balance of photosynthesis, where oxygen release is proportional to carbon sequestration, taking atomic weights into account (Nowak, 2020).

Tree-specific factors such as species, diameter at breast height (DBH), canopy coverage, and health status are integrated into the model to assess oxygen production rates. The inclusion of these parameters ensures that the model provides species-specific outputs, highlighting the variability in oxygen production among different trees (Liu et al., 2021).

While oxygen production is an important ecosystem service, i-Tree Eco does not assign monetary value to it, recognizing the minimal contribution of urban trees to global oxygen reserves due to the abundance of atmospheric oxygen (Ghosh et al., 2017). Instead, the model focuses on quantifying oxygen as a supplementary ecological benefit linked to carbon sequestration, reinforcing its role in supporting urban ecosystem functionality.

4.4.3 Avoided Runoff

The i-Tree Eco model was utilized to estimate the role of urban trees in reducing surface runoff. This method evaluates annual avoided runoff by comparing two scenarios: one that includes both vegetated and non-vegetated areas and another that accounts only for non-vegetated areas. By isolating the effects of vegetation, i-Tree Eco provides a robust assessment of the hydrological benefits of urban trees, specifically their ability to intercept rainfall, enhance soil infiltration, and reduce the volume of runoff reaching drainage systems. Developed by Hirabayashi (2015), this methodology offers a reliable framework for quantifying the impact of urban tree canopies on mitigating surface runoff.

4.4.4 Building Energy Savings

The i-Tree Eco model was utilized to quantify the impact of urban trees on building energy savings. The model calculates energy savings based on variables such as tree species, height, crown structure, and the distance and direction of trees relative to buildings.

4.4.5 Air Pollution Removal

The i-Tree Eco model evaluates air quality improvements facilitated by urban trees through the process of dry deposition. This method quantifies the removal of air pollutants by analyzing the relationship between pollutant concentrations and their deposition velocities (Vd) on tree surfaces. For pollutants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3), dry deposition velocities are influenced by factors like temperature, leaf area index (LAI), and pollutant characteristics. The model uses median deposition velocities sourced from peer-reviewed studies to estimate the rate of pollutant capture by tree canopies (Nowak et al., 2013; Lin et al., 2020).

The model assumes that dry deposition does not adversely affect tree physiological functions, ensuring reliable estimates of pollutant removal. By isolating tree effects on air quality, the methodology provides a nuanced understanding of the role of urban vegetation in reducing atmospheric pollutants. Developed by Hirabayashi (2015), this approach integrates localized environmental data with robust computational frameworks to effectively model the ecological contributions of urban forests.

4.4.6 Replacement Value

The replacement cost of trees in this study was calculated using i-Tree Eco, which applies methodologies established by the Council of Tree and Landscape Appraisers (CTLA, 1992). This approach estimates the structural value of trees, which represents the cost of replacing a tree with one of similar species, size, and condition. Replacement values also account for the costs associated with planting, establishment, and maintenance.

To calculate replacement costs, the total replacement value of inventoried trees was first normalized by dividing it by the total canopy area of those trees. This normalization yielded a per-square-meter replacement value, which was then multiplied by the total canopy area of the study area to estimate the aggregate replacement costs. This method enabled a detailed economic evaluation of potential tree loss and its implications for urban forest management.

For this analysis, all monetary values were standardized using a conversion rate of 1.00 USD = Can$1.38925. This adjustment ensured consistency in valuation and facilitated comparisons across datasets.

4.5 Statistical analysis

For the fully inventoried property parcels in the study area, a paired t-test was performed to compare the original canopy area under Scenario 3 (no construction) with the remaining canopy area under Scenario 2 (all parcels).

To expand the analysis, a one-way ANOVA was conducted to assess changes in canopy area across three development scenarios: (1) larger parcels only, (2) all parcels, and (3) no construction. This approach evaluated the overall differences in canopy area among the scenarios. Tukey's Honest Significant Difference (HSD) post-hoc test was subsequently applied to identify and analyze pairwise differences between the scenarios in greater detail.

5. Results

5.1 Analysis of Canopy Cover Impact and Replacement Value

The average canopy area across three scenarios: Scenario 1 (larger parcels only), Scenario 2 (all parcels), and Scenario 3 (no construction), is presented in Figure 2. The chart reveals a significant reduction in canopy area from Scenario 3 to Scenarios 1 and 2.

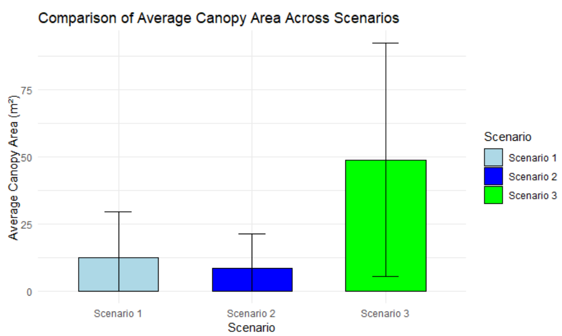

Figure 2. *Boxplot Comparison of Average Canopy Area Before and After Garden Suite Development*

The mean initial canopy area for the 43 inventoried parcels in the study area was 48.92 m^2, while the mean canopy area loss under Scenario 2 was 40.37 m^2 per parcel, representing a significant reduction. The total canopy loss across all parcels amounted to 1,735.88 m^2, corresponding to a mean percentage loss of 70.64%. These findings are summarized in Table 1, highlighting the extent of canopy reduction associated with garden suite developments in larger parcels.

Table 1: *Summary Statistics of Canopy Loss (Scenario 2) in the 43 Inventoried Parcels within the Study Area*

Description	Value
Mean Initial Canopy	48.92 m^2
Mean Canopy Loss	40.37 m^2
Total Canopy Loss	1735.88 m^2
Total Area of 43 Parcels	11,148.95 m^2
Mean Percentage Loss	70.64%

The one-way ANOVA test revealed a statistically significant difference in canopy area between the scenarios ($F = 27.29$, $p < 0.001$). This analysis highlights substantial variability in tree canopy area, both within parcels and between development scenarios.

The Tukey HSD post-hoc test was used to further examine pairwise differences between scenarios. The comparison between Scenario 3 (no construction) and both Scenario 1 (larger parcels only) and Scenario 2 (all parcels) revealed significant differences in canopy area ($p < 0.001$ for both). However, no significant difference was observed between Scenario 1 (construction in larger parcels only) and Scenario 2 (construction in all parcels) ($p = 0.786$) (Table 2).

To extend the analysis and compare canopy area across all three scenarios, a one-way ANOVA test was conducted. The results, summarized in Table 2, reveal a statistically significant difference in canopy area between the scenarios ($F = 27.29$, $p < 0.001$). The analysis indicates substantial variability in canopy area, both within and between groups.

The Tukey HSD post-hoc test further investigated pairwise differences between scenarios. The comparison between Scenario 3 and both Scenarios 1 and 2 revealed significant differences in canopy area ($p < 0.001$ for both). However, no significant difference was observed between Scenario 1 and Scenario 2 ($p = 0.786$).

Table 2. *Results of One-Way ANOVA and Tukey HSD Post-Hoc Test on Canopy Area Across Scenarios*

Metric	Value
F-statistic (F)	27.29

Degrees of Freedom (df)	2 (Between Groups), 126 (Residuals)
p-value (ANOVA)	1.42e-10 (<0.001)
Sum of Squares (Between Groups)	42,562
Sum of Squares (Within Groups)	98,257
Mean Square (Within Groups)	780
Tukey HSD: Scenario 2 vs Scenario 1	-3.98 (p = 0.786).
Tukey HSD: Scenario 3 vs Scenario 1	36.39 (P < 0.001)
Tukey HSD: Scenario 3 vs Scenario 2	40.37 (P < 0.001)

The comparison of canopy cover metrics and the monetized ecological functions of tree loss, including replacement values, across three development scenarios reveals key insights into the impacts of garden suite developments on urban ecosystems. As shown in Table 3, Scenario 2, representing development in all parcels, exhibits the highest canopy loss of 10,567.53 m², resulting in an 8.45% canopy cover and a 20.33% loss in canopy cover percentage. This contrasts with Scenario 1, limited to larger parcels, which demonstrates a lower canopy loss of 5,071.61 m² and a 19.03% canopy cover, reflecting a 9.75% canopy cover loss percentage. Scenario 3, involving no construction, maintains the highest canopy cover at 14,955.67 m², with no loss in canopy area. In Scenario 2, the replacement value loss is estimated at Can$409,960.65, more than double the Can$196,266.31 recorded for Scenario 1.

Table 3. *Comparison of Canopy Metrics and Replacement Values Under Different Scenarios*

Description	**Scenario 1: Larger Parcels Only**	**Scenario 2: All Parcels**	**Scenario 3: No Construction**
Total Area of the Study Area (m^2)	51,962.33	51,962.33	51,962.33
	5,071.61		0

Estimated Canopy Loss (m^2)		10,567.53	
Existing Canopy Area (m^2)	9,884.06	4,388.14	14,955.67
Canopy Cover Percentage	19.03%	8..45%	28.78%
Canopy Cover Loss Percentage	9.75%	20.33%	0%
Replacement Value per Square Meter (Can$/$m^2$)	38.70	38.70	38.70
Replacement Value Loss(Can$)	196,266.31	409,960.65	0

5.2 Ecosystem Services and Replacement Value

The valuation of ecosystem services and replacement values highlights the significant contributions of urban trees to environmental and monetary benefits within the study area. Table 4 provides an overview of key ecosystem services, including carbon storage, carbon sequestration, avoided runoff, annual building energy savings, air pollution removal, and carbon avoided, alongside their corresponding replacement values. The total value of inventoried trees and their extrapolated values across the study area are presented.

Notably, carbon storage contributes Can$44,500 for inventoried trees and an estimated Can$13,195.70 for the entire study area, while avoided runoff and annual building energy savings are valued at Can$1,430 and Can$1,330, respectively, for inventoried trees. These figures underscore the integral role of urban trees in enhancing hydrological benefits, mitigating climate impacts, and supporting urban sustainability goals. Furthermore, the replacement value for all inventoried trees stands at Can$1,950,000, with an extrapolated study area replacement value of Can$578,781.43.

Table 4. *Value of ecosystem services*

Ecosystem Services	Value of Inventoried Trees	Estimated Value in Study Area
Carbon Storage (Can$)	44,500	13,195.70
Carbon Sequestration (Can$/year)	688	204.05
Annual Oxygen Production (Can$/year)	0	0
Avoided Runoff (Can$/year)	1,430	423.14
Annual Building Energy Savi ngs (Can$/year)	1,330	394.49
Air Pollution Removal (Can$/year)	3,810	1129.05
Carbon Avoided (Can$/year)	176	52.19
Replacement Value (Can$)	1,950,000	578,781.43

5.3.1 Carbon Storage and Carbon Sequestration

Inventoried trees are estimated to store approximately 427 tons of carbon, with a monetary value of Can$44,500. The estimated value of carbon storage for the trees in the study area, based on the proportional canopy area, is approximately Can$13,195.70.

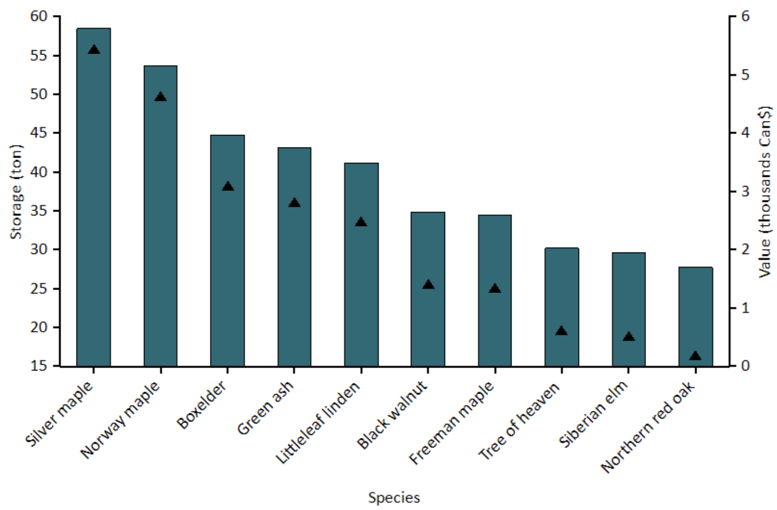

Figure 3. *Species-specific estimated annual gross carbon storage (points) and associated monetary value (bars) for inventoried urban trees (output generated from i-Tree Eco).*

The estimated value of carbon sequestration for the trees in the study area, based on the proportional canopy area, is approximately Can$204.05.

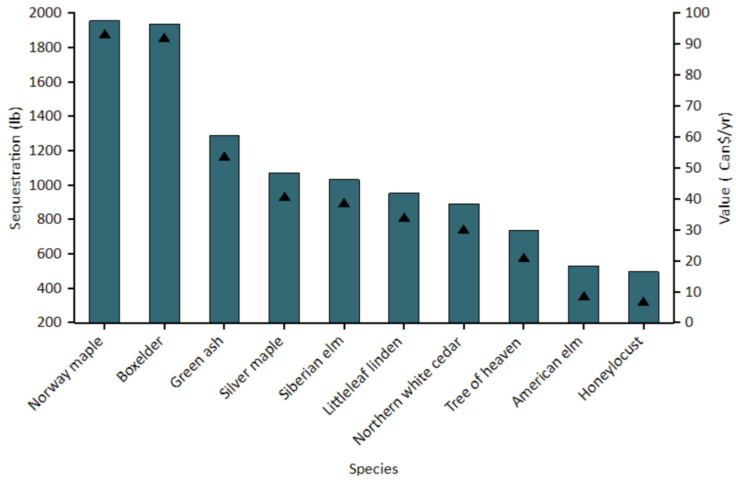

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Figure 4. *Estimated annual carbon sequestration (points) and associated value (bars) for Inventoried urban trees (output generated from i-Tree Eco).*

5.3.2 Oxygen Production

Oxygen production is a vital ecosystem service provided by urban trees, directly tied to their ability to sequester carbon. The estimated production for the trees in the study area is approximately 5.22 tons. Among the inventoried species, Norway maple and Boxelder exhibit the highest levels of oxygen production, generating approximately 4,992.55 pounds and 4,942.83 pounds respectively. These species are followed by Green Ash and Silver Maple, which also play notable roles in oxygen generation. The detailed contributions of the top 20 species in terms of oxygen production, gross carbon sequestration, tree count, and leaf area are presented in Table 5.

Table 5. *Top 20 Species by Oxygen Production*

Species	Oxygen Production (pounds)	Gross Carbon Sequestration (pounds/year)	Number of Trees	Leaf Area (acre)
Norway Maple	4,992.55	1,872.21	54	6.20
Boxelder	4,942.83	1,853.56	87	5.44
Green Ash	3,090.66	1,159.00	66	8.40
Silver Maple	2,477.32	929.00	31	5.98
Siberian Elm	2,368.05	888.02	34	1.98
Littleleaf Linden	2,141.75	803.16	24	3.35
Northern White Cedar	1,962.60	735.98	227	1.57
Tree of Heaven	1,523.22	571.21	18	1.34
American Elm	936.68	351.26	30	1.43
Honeylocust	840.67	315.25	17	0.86
Quaking Aspen	827.60	310.35	11	0.54
Red Mulberry	796.67	298.75	32	0.73
Black Walnut	564.19	211.57	7	1.70
Freeman Maple	561.17	210.44	14	1.94
Wych Elm	514.04	192.76	5	0.55
Black Oak	484.14	181.55	6	0.46

Common Chokecherry	464.13	174.05	12	0.18
Common Linden	408.07	153.03	4	0.63
Northern Red Oak	369.61	138.60	6	0.73
Common Lilac	316.12	118.55	35	0.18

5.3.3 Avoided Runoff

Inventoried trees are estimated to prevent approximately 162,500 gallons of stormwater runoff annually, valued at Can$1,430. For the study area, the estimated runoff prevention is approximately 48,236 gallons per year, with an associated value of about Can$423.14. This calculation is based on local weather data, including total annual precipitation of 26.4 inches recorded in 2021.

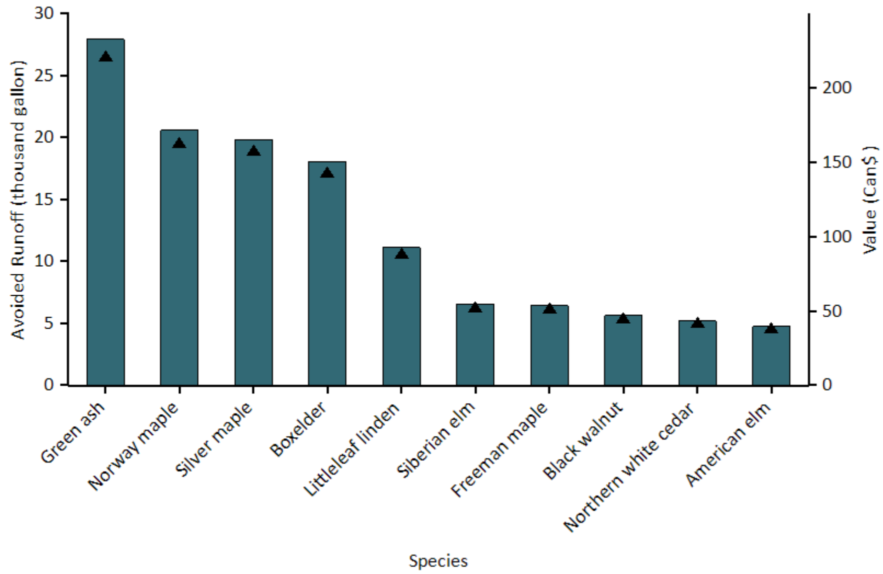

Figure 5. *Avoided runoff (points) and associated value (bars) for species with the greatest overall impact on runoff (output generated from i-Tree Eco).*

5.3.4 Building Energy Savings

Inventoried trees are estimated to save approximately Can$1,330 per year in energy-related costs for residential buildings. For the study area, this energy savings is estimated to be around Can$394.5 annually. Additionally, these trees contribute an extra Can$176 in value by reducing carbon emissions from fossil fuel power plants, preventing approximately 1.69 tons of carbon from being released into the atmosphere. In the study area, this carbon avoidance value is estimated at about Can$52.1, with a reduction of approximately 0.50 tons of carbon emissions.

Table 6. *Annual Energy Savings and Cost Savings Due to Trees*

Description	Heating	Cooling	Total for Inventoried Trees	Estimated Total for Study Area
MBTU (Million British Thermal Units)	26	N/A	26	7.71
MWH (Megawatt-Hour)	271	15	286	84.80
Carbon Avoided (tons)	1	1	2	0.59
Total Cost Savings (Can$)	1,330	688	2,018	598.15

5.3.5 Air Pollution Removal

Trees inventoried are estimated to remove approximately 477.8 pounds of air pollution annually, including pollutants such as ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter less than 2.5 microns ($PM_{2.5}$), particulate matter between 2.5 and 10 microns (PM_{10}), and sulfur dioxide (SO_2), with an associated value of Can$3.81 thousand. The estimated amount of air pollution removal for the study area is approximately 141.7 pounds annually, valued at around Can$1.13 thousand.

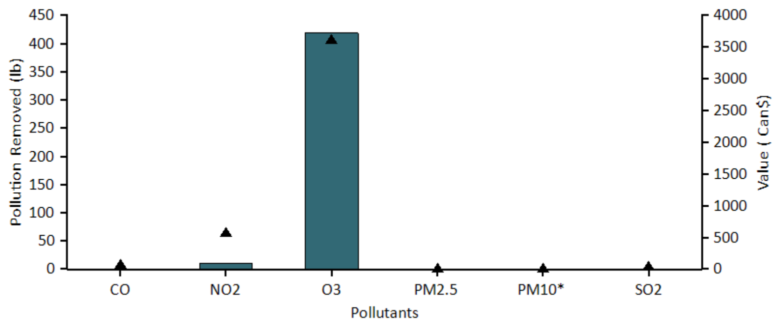

Figure 6. *Annual pollution removal (points) and value (bars) by urban trees inventoried (output generated from i-Tree Eco).*

5.3.6 Replacement Value

The estimated replacement value of the inventoried trees is approximately Can$1.95 million, with Green Ash contributing the highest replacement value among the species analyzed. For the study area, the extrapolated replacement value of trees is estimated at Can$578,781.43

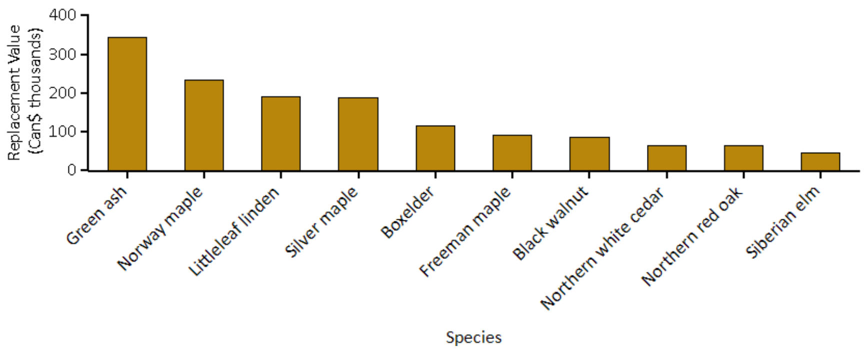

Figure 7. *Tree species with the greatest replacement cost in the study area (output generated from i-Tree Eco).*

6. Discussion

The results of this study highlight the potential impacts of garden suite development on urban forest canopy based on a case study from Toronto's neighborhood, Ashdale Avenue and Parkmount Road. The canopy cover in the study area is approximately 28.8%, which is slightly above Toronto's citywide average of 26.6% (City of Toronto, 2021). Despite this positive figure, it remains below Toronto's ambitious target of achieving a 40% canopy cover, a goal intended to enhance climate resilience, air quality, and biodiversity across the city (City of Toronto, 2021). Tree canopy cover alone is not an adequate indicator of urban forest health. A resilient urban forest requires a focus on species diversity, structural complexity, and managing invasive species like *Acer platanoides* (Norway maple), which threatens native biodiversity and ecosystem stability (American Forests, 2021). Continued development of garden suites presents significant challenges not only to the existing but also to future canopy cover and maintaining its ecological services.

The results of this study highlight the importance of specific tree species in contributing to ecosystem services such as carbon sequestration and oxygen production. *Acer platanoides* (Norway maple) and *Fraxinus pennsylvanica* (green ash) stand out as significant contributors to carbon storage and oxygen generation, primarily due to their dominance and the large size of individual trees within the study area. The notable carbon contribution of *Acer platanoides* can be attributed to its high population density, as it is the second most common maple species and the fifth most common species overall in the study area. These characteristics emphasize the species' role in delivering ecosystem benefits, underscoring the value of maintaining diverse and well-distributed urban tree populations.

The study also revealed contributions of urban trees to energy conservation. The inventory indicated an additional Can$176 in value due to carbon emissions reductions from fossil-fuel-based power plants, amounting to approximately 1.69 tons of avoided carbon emissions annually. Regarding air pollution removal, the analysis was limited by the lack of available data for pollutants such as $PM_{2.5}$, PM_{10}, and CO, which restricted the scope of this study for these specific pollutants. Nonetheless, urban trees were found to contribute to improving air quality by removing pollutants like nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3), enhancing environmental health.

The monetary analysis using i-Tree Eco also estimated a total replacement value of approximately Can$578,781.43 for trees in the study area. Although this highlights the monetary importance of maintaining a healthy urban forest, it is acknowledged that the valuation likely underestimates the true value of urban trees. i-Tree Eco lacks biodiversity and cultural/social value quantifications; the WTP (Willingness-to-Pay) method addresses this by capturing public preferences and values for biodiversity enhancements and non-market benefits (Collins et al., 2017). Future valuations should aim to integrate broader dimensions, including cultural, social, and biodiversity values, to better reflect the comprehensive benefits of urban forests.

During field data collection, non-response bias emerged as a potential limitation. Some property owners declined to permit tree sampling, including three parcels where owners explicitly planned to remove trees for construction—such as a large *Acer platanoides* (Norway maple; Appendices – Figure 8). To better extrapolate data for the entire study area, future studies could employ Response Homogeneity Groups (RHGs) to estimate values for non-responding parcels by modeling data from similar properties with comparable trees. This approach could improve the reliability of urban forest valuation and policy-making (Westfall & Edgar, 2022).

The valuation framework used in i-Tree Eco has been critiqued for overestimating the replacement value of large, mature trees. Hollis (2009) highlighted that the Adjusted Trunk Area Formula (ATAF) may inflate costs by not adequately factoring in species, condition, and location. The Depreciated Replacement Cost (DRC) method offers a more precise alternative by incorporating these variables. Moreover, i-Tree Eco allows for tree condition data to be included in valuations, which can adjust values for trees in poor health. For example, a mature tree in poor condition would be assigned a lower value compared to one in good health. However, this study did not incorporate tree condition data, limiting the precision of results. Future studies should prioritize including tree health assessments to refine valuation accuracy. Despite these limitations, research from urban forestry projects in New York and Indianapolis indicates that the benefits of investing in tree care far outweigh the costs, underscoring the importance of preserving urban forests (Tan et al., 2021).

Although i-Tree Eco allows for the incorporation of tree health conditions to refine valuations, this parameter was not included in the analysis due to time constraints. Future research should integrate this variable to enhance the accuracy of ecosystem service valuations, particularly in contexts involving urban development.

This study does not directly evaluate the impact of urban trees on property values, focusing instead on their ecological and monetary contributions through ecosystem services. While urban trees are widely recognized for their aesthetic and ecological benefits, such as carbon storage, stormwater management, and air quality improvement, their influence on property values represents an additional dimension of value that was beyond the scope of this analysis. Future research could integrate property value assessments alongside ecological service valuations to provide a more holistic understanding of the benefits urban forests deliver. Studies have shown that even modest increases in tree cover can significantly influence property values. For instance, a 1% increase in tree cover near a property in the Midwest results in an $8.88 increase in the value of a single-family home for each green ash tree on the property (Kovacs et al., 2022). Such insights highlight the multifaceted contributions of urban forests, which extend beyond ecological functions to include tangible monetary benefits for property owners. Incorporating these considerations into urban planning and forest management strategies would allow for a more comprehensive valuation of urban trees' contributions to communities.

The findings of this study emphasize the necessity of aligning garden suite developments with urban forest management goals. The comparison across three scenarios demonstrates that any level of garden suite development results in considerable canopy loss. However, no significant difference was observed between Scenarios 1 and 2 ($p = 0.786$), indicating that parcel size does not significantly mitigate the impact on canopy cover. These results highlight the need for targeted mitigation strategies to address the canopy reduction associated with garden suite developments. Effective urban planning should prioritize integrating tree preservation measures, promoting native biodiversity, and involving communities to balance housing needs with environmental conservation. By doing so, cities like Toronto can enhance ecological resilience, community well-being, and sustainable development outcomes.

7. Conclusions

Building garden suites provides property owners with financial benefits and offers Toronto a solution to address its housing crisis by increasing property values and creating additional living spaces. However, this study finds that garden suite development can result in substantial tree canopy loss, with reductions potentially exceeding 70% in the study area. Such losses threaten the provision of critical ecosystem services—including carbon storage, stormwater management, building energy savings, and air pollution mitigation—that are vital for urban sustainability.

The findings also indicate a significant replacement value loss, with the estimated total replacement value for trees in the study area reaching approximately Can$578,781.43. This economic valuation underscores the importance of maintaining a healthy urban forest to mitigate these costs. Notably, species such as Norway Maple, Green Ash and Boxelder are particularly valuable for their roles in carbon sequestration, stormwater interception, energy conservation, and overall replacement value, emphasizing the need to prioritize their preservation.

In addition, the broader values of urban forests, such as cultural, social, and biodiversity benefits, are not adequately captured by current models. Addressing these nonmarket values through approaches like the WTP method would provide a more comprehensive understanding of the urban forest's worth.

To balance housing development with urban forest conservation, it is crucial to implement targeted strategies that address both the ecological and urban planning aspects of Toronto’s growth. Strengthening tree preservation through urban planning policies can be achieved by integrating specific measures, such as enforcing stricter penalties for unauthorized tree removal to deter violations. Enhanced monitoring systems, including regular inspections and satellite imagery analyses, would help identify unauthorized activities and ensure compliance with tree protection bylaws.

Additionally, requiring developers to submit detailed arborist reports and implement compensatory planting for any tree removals would help maintain canopy coverage. Allocating resources to establish a dedicated urban forest management team would further support these efforts. Ensuring that the ecological, economic, and social contributions of trees are considered will help align housing initiatives with sustainability goals, contributing to the long-term viability of Toronto's urban ecosystems.

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10. Appendices

10.1 Scientific Names

Table 7. *Scientific and Common Names of Tree Species Mentioned above*

Common Name	***Scientific Name***	***Common Name***	***Scientific Name***
Green Ash	*Fraxinus pennsylvanica*	Honey locust	*Gleditsia triacanthos*
Norway Maple	*Acer platanoides*	Northern Red Oak	*Quercus rubra*
Boxelder	*Acer negundo*	Common Lilac	*Syringa vulgaris*
Silver Maple	*Acer saccharinum*	Japanese Maple	*Acer palmatum*
Siberian Elm	*Ulmus pumila*	Red Mulberry	*Morus rubra*
Northern White Cedar	*Thuja occidentalis*	Black Oak	*Quercus velutina*
Freeman Maple	*Acer × freemanii*	Rose-of-Sharon	*Hibiscus syriacus*
Black Walnut	*Juglans nigra*	Common Linden	*Tilia americana*
American Elm	*Ulmus americana*	Quaking Aspen	*Populus tremuloides*
Littleleaf Linden	*Tilia cordata*	Wych Elm	*Ulmus glabra*
Tree of Heaven	*Ailanthus altissima*	Common Chokecherry	*Prunus virginiana*

10.2 Appendix – Figures

Figure 8. *A Spruce tree (Likely Picea abies) with a DBH greater than 30 cm removed in the study area. Photograph by Claudia Aenishanslin.*

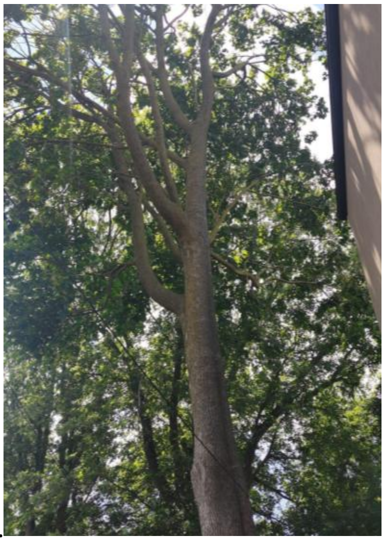

Figure 9. *Norway Maple (Acer platanoides) in the Study Area Proposed for Removal. Photograph by Hongyu Zhang*