The HRM Urban Forest in 2016

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Preface

David and I are honoured to present to HRM this report outlining the methods, results and conclusions from a study of the HRM urban forest using iTree software from the USDA Forest Service. We benefitted greatly from: (a) funding from HRM Urban Forestry to carry out the work; (b) advice and assistance from HRM staff including John Simmons, John Charles, Kevin Osmond, and Shilo Gempton; (c) data collection services provided by Katherine Witherspoon as well as several of my graduate students; and (d) advisory assistance from Dalhousie Killam post-doctoral fellow Dr. James Steenberg.

A report such as this can serve many purposes. It can be educational for any readers who want to learn more about the HRM urban forest and some of its key ecosystem services. It can be useful to HRM urban-forest managers who seek insight on the state and condition of the trees in the city as they design and implement appropriate management measures. Finally, it can be useful to members of HRM Council as they consider the importance of supporting a vigorous program of urban-forest management. There is no question that managing the trees in the city can be an expensive proposition, but studies like this one make it ever so clear that investments in such management pay exceptional dividends in both financial and non-monetary terms.

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Summary

Halifax Regional Municipality (HRM) hosts a wide diversity of trees in city streets, front and back yards and other private property, parks, and peri-urban areas (i.e. forested areas near urban development) that provide a wide range of benefits. Management of trees on municipal property is guided by the Urban Forest Master Plan (UFMP), which was adopted by Regional Council in 2012. The UFMP was largely informed by the results of a 2007 analysis of the urban forest (UF), and called for periodic reassessment to monitor canopy cover changes. To this end, an i-Tree Eco assessment was conducted by a research team led by us at Dalhousie University's School for Resource and Environmental Studies.

Methods

The UFMP area was selected for this assessment because it is the region of greatest concern for UF management. Within these bounds, trees require the most consideration in planning to ensure a healthy canopy. The assessment was carried out using a plot-based approach, using the 10 UFMP communities as strata to provide the potential for future research on a community level. Each stratum was randomly assigned 20 plots, for a total of 200 plots, each 0.04 ha. Field data were collected from 200 plots between the months of July and September 2016.

Using the collected data, i-Tree Eco can calculate the following metrics:

- Population – total number of trees in the study area, stratified by ownership and status as street tree or not
- Study area land use – land use of total study area (e.g. residential, commercial/industrial, transportation)
- Study area cover – amount and proportion of ground and canopy cover across total study area (e.g. asphalt, maintained grass, tree canopy)
- Structural value – assessed replacement value of all trees in study area
- Carbon storage – currently stored carbon in the UF
- Annual carbon sequestration – amount of carbon stored annually by the UF
- Energy effects –building energy savings derived from tree shading and wind speed reduction
- Avoided runoff – stormwater runoff mitigated due to precipitation capture by trees
- Pollution removal – removal of particulate and gaseous pollutants from the air by trees

Results

After data collection and entry, the i-Tree Eco model calculated that the UFMP UF is comprised of 7.4 million trees with a structural value of $1.6 billion. These trees currently store 380 thousand tonnes of carbon, sequestering an additional 20 thousand tonnes annually. Interactions between trees and buildings save property owners $1.8 million annually in reduced heating and cooling costs. Trees mitigate 1 million litres of stormwater from entering grey infrastructure each year, saving Halifax Water and its ratepayers associated storage and treatment costs. Finally, trees in the UFMP area contribute to cleaner air by removing 547 tonnes of pollutants annually.

The model calculated that the top three land uses in the UFMP area are residential (27%), vacant (26%, no discernable purpose of the land), and commercial/industrial (16%). The UFMP area has 34% canopy cover from trees, and the top three ground covers are herbaceous cover (19%, non-

grass, low-level vegetation), maintained grass (17%), and asphalt (17%). Based on both existing canopy cover and ground cover, an additional 15% of the UFMP area is deemed plantable for trees based on suitable ground type (e.g. not asphalt) and lack of overhead competition from other trees.

The sum of annual financial benefits of the urban forest depends on the method of valuation of the sequestration of carbon, whether it is based on a tax-oriented price of carbon ($20/tonne) or holistic social cost of carbon ($181.13/tonne), and is valued at either $4.3 or $7.8 million respectively. Deducting an annual management cost of $2.8 million (as determined by the HRM Urban Forester), the net financial benefit of the urban forest is $1.5 or $5.0 million depending on method of carbon valuation. For every dollar spent on the UF, $1.55 or $2.78 is returned in benefit annually.

Discussion

The canopy found in developed and peri-urban settings differs greatly in composition and provision of benefits, but both represent an important component of the UF. While trees in developed areas provide benefits nearer where more people live, the vast quantities of trees in peri-urban environments significantly impact pollution capture and other diffuse benefits. The benefits of the peri-urban forest were strongly represented in the 2007 study that examined a much larger study area. The inclusion of large forested areas outside of the UFMP area resulted in a substantially larger tree population and significantly greater calculated benefits. Because of a significant change in scope of study between the two years, however, meaningful comparisons that demonstrate actual changes to the UF were not possible. To meet this challenge, the 2007 assessment was rerun using only the points that fell within today's UFMP area. Comparing the results of the modified 2007 assessment to the 2016 assessment found that many metrics are similar between the studies including tree population and provision of benefits. Owing to low statistical confidence in the modified 2007 assessment, these comparisons likely do not reveal actual changes in the urban forest over the nine intervening years.

Of the total UFMP study area, 6,271 ha (34% of the total) is publically owned, where this study found that 60% of trees are growing. The remaining 40% of trees are found on private property that comprises the majority (66%) of the UFMP area. Significant efforts are required by all levels of government, but especially HRM (the majority land-owner in this area) to ensure the continued presence of our disproportionately publically owned urban forest. Private landowners have a tremendous potential to impact the UF, and HRM must take actions to prevent the loss of existing canopy, and to encourage further contributions to a fuller canopy.

Although i-Tree Eco offers a convenient method for contrasting the costs and financial benefits associated with the UF, several issues with this type of assessment should be considered. First, monetizing carbon storage and sequestration is a common practice, but ascribing financial value to this service does not mean that HRM will see real cost savings. If such opportunities arise in the future, it would be beneficial to look at the impact of the forest of HRM as a whole given the vast number of trees in the municipality's hinterlands. Second, even though the UFMP area is a relatively small area compared to the whole HRM, assessing 200 plots still means that only 0.044% of the total study area has been inventoried. This yields a statistically significant snapshot of today's urban forest, but such a small inventory will struggle in the future to capture small changes in UF size and composition. Given that trees planted today will take decades to contribute significant canopy cover, it could also take decades for a similar assessment to show an impact from tree planting initiatives. In the meantime, future assessments may indicate more about the random placement of individual plots than actual canopy change. Finally, although the i-Tree Eco assessment provides an understanding of directly monetizable UF benefits, there is a wide range of less directly and non-monetizable benefits that are also critical to healthy and enjoyable urban environments.

Recommendations & Conclusions

Based on the results of this study, it is clear that trees provide HRM, its citizens, and the environment substantial financial benefits. Improvements to the UF provide a fantastic return on investment based solely on directly monetizable benefits, plus a wide range of less tangible benefits not explored herein. To increase the benefits we enjoy from a healthy canopy in our city, we suggest that HRM continue its tree planting program, focusing on the 94,000 plantable street-side spots identified in the UFMP. Street trees provide benefits not offered by trees in any other location, and generally will not propagate naturally. Increasing levels of investment will yield substantially higher returns in future years when the canopy nears maturity. On other publically owned land where open space is not critical for view planes or recreation, UF managers should consider naturalization programs to add low-maintenance canopy to the cityscape. Finally, while HRM cannot (currently) directly influence trees on private property, we encourage the municipality to work with property owners and through NGOs to increase private tree ownership whether through incentive programs for planting, policy that provides a disincentive to tree removal, or both.

In conclusion, the UF leadership momentum that has been generated over the past decade in HRM has led to the creation of award-winning plans and the planting of thousands of street trees, and puts us on track to a greener future. It is important that this momentum be sustained through adequate funding to ensure that HRM continues to lead by example in creating a healthy, livable city.

1 Introduction

Halifax Regional Municipality (HRM) hosts a wide diversity of trees in city streets, front and back yards and other private property, parks, and peri-urban areas (i.e. forested areas near urban development). From these trees, we enjoy a cooler city, energy savings, cleaner air, more aesthetically pleasing places to live, and a cleaner harbour (Duinker et al., 2015). Undeveloped areas in Nova Scotia typically maintain a state of forestation without interference, but much of the urban area, where many of these benefits are most substantial, requires human management intervention to ensure continued canopy cover.

Urban forest (UF) management requires investment throughout the lifecycle of a tree including planting, watering, pruning, potential treatment for pests, and eventual removal. Lack of continual investment in tree planting will create gaps in the urban canopy as trees fail due to circumstances natural or otherwise. HRM has invested greatly in tree planting since approval of the Urban Forest Master Plan (UFMP) in 2012, and the municipality has seen more than 5,600 additional trees planted in the last four years. Failing to prune trees sufficiently and proactively can lead to conflicts with infrastructure and properties including powerlines, sidewalks, and buildings. Similarly, timely removal of failing trees can prevent incidents that damage infrastructure and property, and potentially endanger citizens.

It is important to examine investments in urban forest improvement and management in the context of the range of benefits provided by trees in our city. The monetary valuation of the services provided by urban forests is an exercise conducted by many municipalities around the world, supported by a wealth of research. Assessments evaluate tangible cost savings to the public (e.g. stormwater runoff mitigation, energy savings through shade) as well as less tangible values such as carbon sequestration. By comparing these values to annual expenditures on maintaining this vital resource, we can better understand the cost-benefit relationship associated with our urban forest.

This document contains the results of a study of the HRM UF carried out by a research team at Dalhousie University in an effort to better understand the relationship between UF costs and benefits in HRM. We hope that an understanding of the range and magnitude of benefits provided by trees in our city will lead to a greater appreciation of the importance of a healthy urban forest.

1.1 HRM's Urban Forest

An urban forest effects (UFORE) analysis was carried out in 2007 by HRM, examining an area approximately three times the size of the UFMP area. This study found that the 55,934 ha study area had approximately 41% canopy cover, including an estimated 157,000 trees planted and managed along roadways, and an additional 552,000 that were naturally regenerated along roadways (HRM Urban Forest Planning Team, 2013). These figures were important in the development of the UFMP and understanding the range and magnitude of effects provided by trees to the municipality and its residents. This can also provide a useful point of comparison with other urban centres.

Table 1.1 Summary of select urban canopies in cities and municipalities in Canada (Alexander & DePratto, 2014)

City/Municipality	Canopy Cover
Greater Vancouver, BC	43%
HRM, NS (2007)	41%
Surrey, BC	32%
Toronto, ON	30%
Montreal, QC	20%
Vancouver, BC	18%

1.2 HRM Urban Forest Master Plan

Adopted by Municipal Council in 2012, the HRM UFMP used an award-winning neighbourhood and community approach to urban forest study and planning in HRM. Features of the UFMP include neighbourhood-level canopy cover and composition baseline measurements, and targets to guide future planting initiatives. The Plan is available on the HRM website in two forms: (a) the full plan dated July 2013, and a digest version dated August 2014 (www.halifax.ca/property/ufmp).

The UFMP called for reassessment of the HRM canopy through i-Tree Eco, the successor to UFORE produced by the United States Department of Agriculture (USDA) Forest Service and its partners. The UFORE analysis of 2007 provided urban forest managers and researchers a starting point for understanding the trees of HRM, but trees are organisms that grow, change, and die, and a single assessment only provides a picture of what the canopy was like at a single point in time. Ideally, a sequence of assessments will provide insight into canopy change over time elucidate for policy-makers the benefits of canopy increases, and the consequences of neglecting our most prominent green infrastructure.

1.3 i-Tree Eco

i-Tree Eco is a sample or inventory based model that assists in calculating the composition and structure of urban forests. The model also uses pollution, weather, and other location-specific information to determine the tangible benefits provided by trees in an urban setting (USDA Forest Service, 2016a). This model was developed for the United States, but has since been adapted for other countries, including Canada.

Understanding the benefits provided by today's urban forest allows managers and policy-makers to contextualize investments in trees. While many believe a thriving canopy is an intrinsically valuable component of a healthy city (e.g. Duinker et al., 2015), municipal expenditures often require proof of efficacy and value. When put in terms of stormwater management savings, carbon capture and sequestration, air quality improvements, and more, maintaining the urban forest is clearly an investment with rewards that are reaped by all who inhabit the city for generations to come. i-Tree Eco is the foremost such tool that provides a comprehensive understanding of a wide range of tree benefits, and is available for analysis free of charge.

1.4 Dalhousie University Research Team

The preparation, fieldwork, and writing for this report was carried out by a team at Dalhousie University's School for Resource and Environmental Studies (SRES), supervised by Dr. Peter Duinker. The study was led by David Foster with fieldwork primarily carried out by Katherine

Witherspoon, both graduates of SRES. Other major contributors to fieldwork included Bimal Aryal, Kelsey Hayden, Sophie Nitoslawski, and Natalie Secen, all students at SRES.

The forest research team based at SRES has conducted a substantial amount of UF-related research that has contributed to the international effort to better manage trees in cities. Most significant to HRM, faculty and students at SRES were part of the HRM Urban Forest Planning Team that undertook the research and writing of HRM's award-winning UFMP. The SRES research team hopes that this report provides further evidence that will help inform municipal urban forest policy and allocation of resources, to provide a healthy urban forest to this and future generations.

2 Methods

The full range of methods for conducting an i-Tree Eco sample assessment are detailed in the user manuals found at itreetools.org. The methods used for this assessment are explained herein.

2.1 Plot-based approach

An i-Tree Eco sample-based inventory was chosen because of time and resource limitations. Complete inventory assessments are substantially more accurate, but require a census of every tree within the study area, making this form of assessment unrealistic for the UFMP area.

The urban forest may be examined at many spatial levels depending on the objective of study, from UFMP neighbourhood or smaller, to the entire HRM. Community-level comparisons of urban canopy may be useful and yield insightful results, and in anticipation of future potential research, the ten communities defined within the UFMP were selected as strata. To ensure statistically valid comparisons, 20 plots were randomly assigned in each stratum through the use of ArcGIS 10.2, for a total of 200 plots (yielding a standard error of approximately 10% (USDA Forest Service, 2016b)). Additional plots were also generated in each stratum to be used in case areas were inaccessible for assessment.

2.2 Data collection

The i-Tree Eco system offers researchers the opportunity to collect and integrate a wide variety of information about trees and the environment to provide insights into the landscape. Not all metrics are necessary depending on intended use of the final dataset. We assessed only metrics deemed necessary by the SRES research team and urban forest managers from HRM (Table 2.1).

Table 2.1 Summary of assessed metrics in the i-Tree Eco assessment for HRM in 2016, including a description of each and relevance to the project, or necessity of the metric to the model.

Information	Description	Relevance
Percent measured	Percent of plot assessed	Extrapolation of data for plots where less than 100% is measurable
Percent tree cover	Percent of plot covered by tree canopy	Calculation of overall canopy cover
Land use	Proportion of plot used for transportation, residential, commercial, etc.	Understanding of study area land use
Percent plantable space	Percent of area that could currently host new trees	Calculation of potential for new tree planting
Plot address	Where relevant, civic address associated with plot	Easier location system for quick reference than coordinates
GPS Coordinates	Coordinates associated with centre of plot	Mapping and potential return to plots

Information	Description	Relevance
Ground cover	Proportion of plot covered by grass, asphalt, bare soil, etc.	Calculation of ground permeability
Percent shrub cover	Proportion of plot covered by shrubs	Calculation of smaller woody plant population
	Per-tree information	
Species	Species of tree	Understanding of population composition
Diameter at breast height	Diameter of trunk(s) at 1.37 m above the ground	Understanding of population size and age
Land use	Land use in which the tree is planted	Understanding of tree population by land use
Status	Tree is planted by humans or naturally seeded	Understanding context of tree's growth
Street tree/non	Tree is rooted adjacent to street or not	Understanding context of tree's growth
Public/private	Tree is on public or private property	Determining who is primarily responsible for tree care
Total tree height	Distance from ground to tallest woody material	Determining overall dimensions of tree
Crown size	Height and width of tree crown	Determining overall dimensions of tree's photosynthetic apparatus
Condition & percent dieback	Fullness of crown and proportion of dead and dying material	Determining volume of photosynthetic apparatus
Crown light exposure	Measure of crown's access to light	Determining competitive conditions
Proximity to buildings	Distance and direction to conditioned (heated/cooled) buildings	Calculating energy effects of trees

Not all metrics available within the i-Tree Eco model were deemed necessary for our assessment. Because of the information omitted from data collection and subsequent analysis, future studies will not be able to visit the same plots accurately, and our study does not track individual trees or provide maintenance recommendations (Table 2.2)

Table 2.2 Summary of metrics not collected during the i-Tree Eco assessment for HRM in 2016, including a description of each and rationale for exclusion.

Information	Description	Rationale for exclusion
Reference objects	Distance and direction to semi-permanent fixtures	Important if future studies will revisit the same plots; not anticipated
Shrub details	Species and dimensions of shrubs	Used for more accurate stormwater runoff mitigation calculation; purpose of study is trees
	Per-tree information	
Relative to plot centre	Distance and direction to plot centre	Important for tracking individual trees longitudinally; not necessary for this study
GPS coordinates	Coordinates of individual trees	As above, not necessary for this study and requires additional, high-precision equipment
Cover under canopy	Ground cover under individual canopy	More precise calculation of stormwater runoff mitigation; broader results acceptable
Maintenance recommended	Yes/No field	Important for tracking maintenance requirements of the urban forest; not the purpose of this study
Maintenance task	Specific maintenance treatments required	
Sidewalk conflict	Sidewalk lifting by tree roots	
Utility conflict	Contact between overhead infrastructure (e.g. power lines) and branches	
Pests	Observable signs of pests	

Each plot was mapped in GIS software on top of background aerial imagery. We located plot centres in the field first by the use of location coordinates and a GPS-enabled smartphone. Once the approximate location was arrived at, individually generated maps with aerial imagery allowed for contextual situation of the plot in the environment using visible landmarks (e.g. buildings, roads, sidewalks, large rocks). Where the environment provided no visible landmarks (typically in a completely forested or barren plot), the coordinates alone provided a reasonable approximation of the plot's centre. All plots were visited between the months of June and September, 2016.

Plots that were either partially or fully comprised of privately owned property required the landowner's permission to enter and assess trees. We established contact with property owners at the doorstep, and if no one responded, a letter was left identifying ourselves, the purpose of the study, activities we wished to carry out on their property, and how to contact the research team (see Appendix B). We kept a written record of verbal consent and other interactions in case later re-visitation was necessary. If consent was not given or multiple attempts at contact were unsuccessful, we either abandoned the plot, or, if there were few trees and the entire plot was visible from public property, assessed the plot and its trees from a distance.

We gathered location information and bearings using a GPS-enabled smartphone. Tree diameters were measured at breast height (DBH, 1.37 m) to the nearest centimetre using a diameter tape. Tree height, crown dimensions, and distance to buildings were approximated by the field crew to the nearest metre, frequently checked with a Nikon Forestry Pro digital rangefinder and clinometer to ensure accuracy.

Management Costs

Management costs associated with urban forest maintenance are important to include in an i-Tree Eco study as they provide a point of comparison in the cost-benefit relationship of urban forest upkeep. These data are obtained from municipal officials or through analysis of municipal budgets. In our study, the municipal urban forester provided estimates of annual expenditures in a number of categories (e.g. planting, pruning, removal, etc.) based on annual budgets and expenses.

2.3 Data processing and analysis

The collected data were entered electronically into i-Tree Eco version 5.2.2. The most recent version (version 6.0.x (beta)) was not used for data entry because the data entry interface in the older version was easier to use. Once data entry was complete, the newer version upgraded the database for processing.

2.3.1 Calculated UF Metrics

Using data gathered in the field, i-Tree Eco calculated a variety of metrics contributing to urban forest benefits. The method of calculation for each primary result metric is explained in this sub-section.

Structural Value

Structural value is a tree valuation method established by the Council of Tree and Landscape Appraisers that is often used to determine the structural value of trees lost from a landscape (Nowak, Crane, & Dwyer, 2002). This value is calculated using tree diameter, species, condition, and location. A tree's value increases as it grows in diameter, and is highest in good health and in valuable locations such as golf courses and institutional lands where the impact of an individual tree is often greatest (Nowak et al., 2002).

Carbon Storage of Trees

Trees capture carbon from the atmosphere as they grow, integrating it into the tree's tissues. This capture is an important component of the global carbon cycle. It can be measured in tonnes of carbon, or as tonnes of carbon dioxide equivalent (CO_2eq), a conversion accomplished by multiplying the amount of carbon by the ratio of their atomic weights (44/12). This is often helpful in comparisons with emissions data of CO_2 and other greenhouse gas (GHG) emissions.

Annual Carbon Sequestration

Trees capture (or sequester) carbon throughout their growing life. The annual capture of carbon is represented by the gross annual carbon capture. Carbon sequestered in tree tissues is part of a global carbon cycle of capture and release. Release occurs annually as the relatively small quantity of carbon that comprises leaves is released back to the atmosphere after leaf-fall, and on a much larger scale as carbon stored in the trunk, roots, and branches of a tree is released through decomposition after a tree dies. Annual release is calculated by the combination of a number of variables, especially the proportion of the canopy that is currently standing dead-wood that will soon decompose. The estimated release of carbon is subtracted from gross annual carbon capture and represented by the net annual carbon capture.

Value of Carbon Capture and Storage

The value of carbon captured and stored can be calculated in one of two ways. The first method is based on the current cost of carbon, as determined by the federal and provincial governments of Canada. A price on carbon is currently or will soon be levied in four Canadian provinces as either a direct tax on GHG emissions, or through a cap-and-trade permit system. The amount charged per tonne of carbon varies by province and ranges from approximately $4.09/tonne in Quebec's cap-and-trade system, to $30/tonne in British Columbia's direct tax on emissions. In general, many current and proposed systems aim for approximately $20/tonne by 2020 (Ecofiscal Commission, 2015). The recently proposed federal carbon tax requires that provinces implement a carbon tax of $10/tonne in 2018, rising by $10/tonne each year until reaching $50/tonne in 2022 (Government of Canada, 2016). For the purposes of this analysis, we selected $20/tonne as a representative rate based on current fees and a conservative estimate of future pricing schemes. This calculation is not automatically performed by i-Tree Eco, as the USDA uses the social cost of carbon instead.

The second method of valuing carbon is through the social cost of carbon (SCC). SCC is an attempt to acknowledge more fully the range of impacts associated with current and past GHG emissions. The US Environmental Protection Agency's (EPA) estimates take into account "(1) the future emissions of GHGs, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages" (Greenstone, Kopits, & Wolverton, 2013). The SCC rate is substantially higher than carbon tax rates because it considers the broad range of environmental and financial implications of anthropogenically influenced climate change. The rate used by i-Tree Eco is USD $139.33/tonne of carbon, based on the US Government's middle discount-rate estimate for the cost of CO_2eq for 2015 ($38/tonne CO_2eq)

(IWGSCC, 2013). This is converted to CAD at a rate of CAD $1.30/USD $1.00 (an approximate exchange rate average for the latter half of 2016) to CAD $181.13/tonne of carbon.

Energy Effects

Trees influence energy budgets in numerous ways and in all seasons. The shade cast onto buildings by trees in summer reduces cooling requirements (Heisler, 1986). In winter months, the reduction of wind velocity near buildings affected by trees reduces heat stripping from buildings and subsequent heating costs (Akbari, Pomerantz, & Taha, 2001). Trees may also have the opposite effect, where shade cast in winter and wind reductions in summer increase expenses for heating and cooling respectively. Overall, the net impact of trees is expected to be positive in temperate climates (Akbari & Taha, 1992).

Energy effects are calculated based on proximity of trees to buildings, and only considers trees of sufficient height (6 m) and proximity (18 m) to affect buildings that use active cooling and/or heating. Because heating is accomplished both electrically and through residential usage of fossil fuels, calculation of energy savings is through mega-British thermal units (MBTU) and mega-watt hours (MWH). Cooling is assumed to be accomplished only electrically, and is presented in MWH. Default values of the i-Tree Eco software are: electricity at $108.98/MWH, heating at $27.01/MBTU, as set by default in the i-Tree suite. These may be underestimates because of relatively high energy prices in Nova Scotia.

Avoided Runoff by Trees

Tree leaves capture some of the rainwater that falls onto the canopy and reduce costs associated with stormwater treatment and flood control (Xiao & McPherson, 2002). In HRM, Halifax Water estimates that the blended flow-and-strength-related cost of stormwater treatment is $\$1.9049/m^3$ of wastewater (J. Campbell, e-mail message, November 18, 2016). This is below the default i-Tree Eco value of $\$2.32/m^3$, and may be an underestimate of total costs. The i-Tree Eco value takes into account money saved through mitigating the necessity of additional stormwater detention and treatment facilities that are likely not included in the Halifax Water estimate, but the more conservative estimate was used because of the regional specificity.

Pollution Removal by Trees

Pollutants common to urban environments often have negative impacts not only on the environment, but on human health as well. Trees have a demonstrated ability to filter these pollutants from the air, including ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and particulate matter under 2.5 μm in size ($PM_{2.5}$), to the benefit of human health (Tiwary et al., 2009). The USDA acquires hourly pollution data from an air quality monitoring centre close to the study area, in this case at the Halifax International Airport. The most recently available information through i-Tree Eco is from 2010.

Pest Vulnerability

Based on the species composition of a study area, i-Tree can look for vulnerability to pests that may affect the urban forest. Unfortunately, this ability is limited to a national scope in Canada, and some pests are known to be localized to certain regions within the country. We carried out further analysis to understand this threat to the HRM urban forest. A study of pest distribution, effect on trees, and management outlook (e.g. spreading rapidly, becoming contained) was conducted to determine relative threat to the HRM urban forest from the total list of potential pests. We relied heavily on information from Natural Resources Canada (NRCan), the Canadian Food Inspection Agency (CFIA), USDA Forest Service, and provincial and state forest authorities.

3 Results

This section presents a wide range of results that assist in better understanding the composition, costs, and benefits of HRM's urban forest. Except where otherwise noted, monetary values are provided in Canadian dollars and all results are in metric measures.

3.1 Measured Results

200 plots were assessed during the leaf-on months of July to September either remotely where necessary, or on location where possible. A total of 3,670 trees were inventoried and all requisite information gathered.

3.1.1 Management Costs

The HRM Urban Forester provided estimates of expenses associated with urban forest maintenance totalling $2.80 million annually (Table 3.1). These expenses vary from year to year as some activities, such as tree removal, depend on environmental factors. The Urban Forester expects that this expense will soon experience a significant increase as ageing tree cohorts, especially older Norway maples, begin to fail en masse.

Table 3.1 Management costs associated with maintaining the urban forest in the HRM UFMP study area.

	Estimated Annual Cost ('000 CAD)
Purchasing trees and planting	785
Contract pruning	350
Irrigation	5
Removal	570
Administration	835
Inspection/service	39
Infrastructure repairs	100
Litter clean-up	40
Other costs	80
TOTAL	**2,804,000**

3.2 i-Tree Eco Results

The following sub-sections display the composition and benefit summaries of the HRM UFMP urban forest as calculated by i-Tree Eco.

3.2.1 Population

There are over 7.4 million trees in total in the HRM UFMP area, approximately 60% of which are owned publically; the remainder (40%) are growing on privately owned property (Table 3.2). Within this area, 1.3% of trees grow adjacent to streets.

Table 3.2 Summary of tree population in HRM UFMP study area by ownership.

	Population ('000)	Proportion (%)	SE ('000, %)
Publically owned	4,480	60.3	+/- 843 (18.8%)
Privately owned	2,955	39.7	+/- 686 (23.2%)
Street trees	96	1.3	+/- 29 (30.4%)
Non-street trees	7,339	98.7	+/- 986 (13.4%)
TOTAL	**7,435**	**100**	**+/- 981 (20.6%)**

3.2.2 Study Area Land Use

From the 200 plots assessed in the HRM UFMP area, over half of the study area is comprised of residential (27.2%) and vacant (26.0%) land uses (Table 3.3). The category "vacant" implies no discernable active land use. Other major land uses include commercial/industrial, transportation, and water/wetland.

Table 3.3 Summary of land usage in HRM UFMP study area.

Land Use Type	Proportion (%)
Residential	27.2
Vacant	26.0
Commercial/Industrial	15.8
Transportation	11.3
Water/wetland	8.5
Institutional	4.8
Park	2.9
Multi-family residential	2.2
Cemetery	1.1
Golf course	0.2

3.2.3 Study Area Cover

Cover types are separated into canopy cover and ground cover; the former is not mutually exclusive of the latter as tree canopy can grow over all ground cover types, and ground cover such as grass and bare soil may be plantable space. Ground cover approximately sums to 100%. Tree canopy in the HRM UFMP study area is calculated by the i-Tree Eco model at 34.3%, with an additional 17.4% of smaller shrubs cover (Table 3.4). An additional 15.5% of land is plantable space, determined so based on a lack of overhead canopy and infrastructure as well as suitable ground cover (e.g. grass or herbaceous cover, not asphalt or cement). The majority of ground cover in the study area is herbaceous cover (19.3%), ground-level vegetation not considered shrubs or grass. Maintained grass and asphalt, ground covers associated with developed areas, each comprise 17.3% of the UFMP area.

Table 3.4 Summary of ground cover in HRM UFMP study area.

Cover Type	Proportion (%)	SE (%)
Canopy cover		
Tree	34.3	+/- 3.3
Shrub	17.4	+/- 2.1
Plantable space	15.5	+/- 1.5
Ground cover		
Herbaceous cover	19.3	+/- 2.0
Grass	17.3	+/- 2.0
Asphalt	17.3	+/- 2.7
Duff/mulch	12.9	+/- 2.6
Rock	10.0	+/- 2.1
Building	9.0	+/- 1.5
Water	6.7	+/- 2.4
Cement	3.6	+/- 0.8
Wild grass	3.3	+/- 0.9
Bare soil	0.5	+/- 0.2

3.2.4 Structural Value

The combined structural value of all trees in the UFMP study area is calculated at over $1.5 billion (TABLE 3.5). Individual trees in urban areas are valued higher than single trees in naturalized environments, as are trees that are larger in diameter, but the vast quantity of trees in naturalized stands has a huge impact on the total valuation.

Table 3.5 Compensatory value of trees in HRM UFMP study area.

Species	Structural Value (million, CAD)
Red maple	357
Red spruce	226
Norway maple	204
Eastern white pine	111
Eastern hemlock	95
Littleleaf linden	88
American elm	71
Northern red oak	63
American basswood	42
White spruce	35
Remainder	295
TOTAL	**1,587**

3.2.5 Carbon Storage

The UFMP study area's trees currently store an estimated 380,541.80 tonnes of carbon, valued at $7.61 million and $68.93 million based on carbon price and SCC respectively (Table 3.6). The trees of the peri-urban forest provide substantial carbon storage, with the native red maple and red spruce (species predominantly represented in less-urban areas) cumulatively storing nearly as much carbon (186,453 t) as all other species combined (194,089 t). Other species that are well represented in naturalized environments include eastern white pine, northern red oak, eastern hemlock, birch spp., and black spruce.

Table 3.6 Carbon currently stored in trees in HRM UFMP study area and associated value calculated by the price of carbon ($20/t) and social cost of carbon ($181.13/t).

Species	Carbon Storage ('000 tonne)	Value (C Price, '000 CAD, $20/t)	Value (SCC, '000 CAD, $181.13/t)
Red maple	112	2,243	20,314
Red spruce	74	1,486	13,458
Norway maple	32	650	5,886
Eastern white pine	18	367	3,321
Northern red oak	17	346	3,132
Eastern hemlock	12	232	2,103
Yellow birch	11	224	2,031
Paper birch	11	216	1,960
American elm	11	212	1,919
Black spruce	9	179	1,622
Remainder	73	1,455	13,181
TOTAL	**380**	**7,610**	**68,927**

3.2.6 Annual Carbon Sequestration

Trees in the UFMP study area annually sequester an estimated 20,392 tonnes gross, or 18,552 tonnes net of carbon (Table 3.7). The annual gross sequestration is valued at approximately $735 thousand or $2.84 million based on carbon price and SCC respectively. Similar to currently stored carbon (Table 3.6), the peri-urban forest has a strong influence on annual sequestration as represented especially by the relative importance of red maple and red spruce.

Table 3.7 Gross and net annual carbon sequestration of trees in HRM UFMP study area and associated value of gross sequestration calculated by the price of carbon ($20/t) and social cost of carbon ($181.13/t).

Species	Gross Carbon Sequestration (tonne/yr)	Net Carbon Sequestration (tonne/yr)	Gross Value (C Price, '000 CAD, $20/t)	Gross Value (SCC, '000 CAD, $181.18/t)
Red maple	6,057	5,614	121	1,097
Red spruce	3,963	3,699	79	718
Northern red oak	1,084	987	22	196
Norway maple	1,074	907	21	195
Paper birch	1,009	945	20	183
Yellow birch	831	817	17	151
Eastern white pine	778	709	16	141
Gray birch	652	609	13	118
Balsam fir	575	532	11	104
Black spruce	542	509	11	98
Other	3,827	3,224	77	693
TOTAL	**20,392**	**18,552**	**408**	**3,694**

3.2.7 Energy Effects

The trees in HRM's urban areas directly reduce energy demand through heating and cooling by an estimated $1.66 million annually (Table 3.8). In addition, the reduced heating and cooling demand results in an estimated annual reduction of 988 t of carbon emissions. Only 46 of the total 200 plots demonstrated energy interactions between trees and buildings, including 164 trees. Given the low incidence of recorded interactions and the substantial number of trees in

HRM near buildings, the calculated energy and emission savings may be an underestimate, though this cannot be accounted for in this assessment.

Table 3.8 Energy and carbon savings associated with trees' reduction in energy demands and carbon emissions in the HRM UFMP study area.

Type	Heating	Cooling	Total	Value (C Price, '000 CAD, $20/t)	Value (SCC, '000 CAD, $181.18)
MBTU	42,757.05	n/a	42,757.05	1,155	1,155
MWH	366.83	4,318.72	4,685.56	510	511
Carbon Avoided (tonne)	714.13	274.41	988.54	20	179
			TOTAL	**1,685**	**1,845**

3.2.8 Avoided Runoff

Trees in the UFMP study area contribute 36,285 ha of leaf area to the urban canopy (Table 3.9). Based on historical weather data, this leaf area is capable of intercepting up to 1.06 million m^3 (1.06 billion L) of rainfall annually. The mitigation of stormflow into grey infrastructure is strongest where trees occur near impermeable surfaces such as asphalt. Canopy in peri-urban areas also intercepts rainfall that may otherwise enter grey infrastructure downslope. Therefore, in respect of avoided runoff, peri-urban trees must also be considered an important asset for HRM. All water that enters grey infrastructure requires treatment wherever combined infrastructure delivers both wastewater and stormwater to treatment plants. The mitigation of stormwater runoff is valued at $2.01 million annually (based on a treatment cost of $1.9049/$m^3$). This is likely an underestimate because the rate ($1.9049/$m^3$) supplied by Halifax Water does not take into account avoided costs (avoided stormwater retention and treatment capacity) included in the i-Tree Eco default value of $2.32/$m^3$.

Table 3.9 Stormwater runoff mitigated by trees in the HRM UFMP study area.

Species Name	Leaf Area (ha)	Avoided Runoff ('000 m^3/yr)	Avoided Runoff Value ('000 CAD/yr, $1.9049/m3))
Red maple	9,688	282	537
Red spruce	6,239	182	346
Norway maple	2,921	85	162
Northern red oak	1,870	55	104
Yellow birch	1,443	42	80
Eastern white pine	1,319	38	73
Balsam fir	1,244	36	69
Eastern hemlock	1,010	29	56
Paper birch	1,000	29	55
Gray birch	927	27	51
Remainder	8,624	251	479
TOTAL	**36,285**	**1,056**	**2,012**

3.2.9 Pollution Removal

Based on annual pollution data, a collective 546,928.8 kg of pollutants are removed from the air annually (Table 3.10). The removal of these pollutants is valued at $240,355.

Table 3.10 Pollutants removed from the air and associated value by trees in the HRM UFMP study area.

Pollutant	Annual Mean Removed (t)	Value (CAD)
CO	1.3	1,868
NO_2	306.4	15,126
O_3	218.3	73,456
$PM_{2.5}$	12.7	149,758
SO_2	8.2	147
TOTAL	**546.9**	**240,355**

3.2.10 Summary of Net Benefit

While compensatory value and currently stored carbon are benefits worth cumulatively over $1.6 billion, a comparison of annual benefits and expenses omits these long-lasting legacy values (Table 3.11). Because the price and cost of carbon are drastically different, the net financial savings due to our urban forest varies significantly depending on which metric is used, either $1.54 million or $4.97 million respectively (Table 3.11).

Table 3.11 Summary of financial benefits and expenses associated with trees in the HRM UFMP study area.

Factor	Benefit (+)/Expense (-)	Value (C Price, '000 CAD)	Value (SCC, '000 CAD)
Structural Value	Compensatory value of existing trees (legacy value)	1,587,665	1,587,665
Carbon storage	Existing carbon storage (legacy value)	7,610	68,927
	Sum of existing values	1,595,275	1,656,592
Carbon capture	Annual gross carbon sequestration	408	3,694
Energy effects	Energy saved through reducing heating and cooling	1,685	1,845
Avoided runoff	Runoff diverted from stormwater treatment facilities	2,012	2,012
Pollution removal	Airborne pollution removed annually	240	240
Management costs	Cumulative estimated costs of urban forest management	-2,804	-2,804
	Net annual benefit (without existing values)	1,541	4,986

4 Discussion

From the results of this study, it is clear that trees in HRM provide substantial benefit to people and the environment. Considering monetizable benefits alone, the annually derived value of HRM's urban forest outweighs costs, and for every dollar spent on urban forest maintenance, trees deliver $1.55 or $2.78 depending on the valuation method for carbon sequestration. However, the benefits of the urban forest go beyond the financial benefit calculated herein, and Duinker et al. (2015) argue that a thriving canopy is indispensable to a sustainable city.

4.1 Developed and Peri-Urban Settings

Trees in developed settings provide significant and immediate financial savings in the form of stormwater runoff mitigation, energy savings, and other monetizable benefits not assessed through i-Tree Eco such as prolonging the life of infrastructure (McPherson & Muchnick, 2005), increased property values (e.g. Donovan & Butry, 2011), and more. These trees also provide numerous other benefits that cannot be monetized, and cannot be realized in any other setting. For example, a mature street-tree canopy hides unsightly overhead infrastructure, shades the sidewalk, calms traffic (Naderi, Kweon, & Maghelal, 2008), enhances community safety (Kuo & Sullivan, 2001), provides habitat for countless species, and more. Trees are a form of green infrastructure that offers unparalleled benefits in developed areas.

Though perhaps less apparent in many citizens' day-to-day activities, naturalized stands of trees in the city and peri-urban forests offer substantial benefit to HRM as well. These trees require minimal management investment and provide benefits to the urban environment. The capacity for high tree densities in these settings supports benefits that are location-independent such as carbon and pollution capture. On the other hand, benefits often associated with developed settings take a different importance in these environments. Stormwater runoff mitigation, for example, is important in peri-urban forests because a denuded landscape may allow surface flow into urban settings (and the grey infrastructure that serves them), and erode the peri-urban landscape while removing valuable soil nutrients in the process.

4.2 Comparison to Past Assessment

Urban forest management in HRM was influenced partly by the results of the 2007 UFORE analysis. The purpose of successive assessment, such as this, is to follow trends in the urban forest. We hope that sufficient study will eventually elucidate canopy cover and composition changes that result from action (or inaction) such as tree planting programs, clearing of the peri-urban forest for development, etc. However, urban forest management in HRM has changed substantially since 2007, primarily due to the approval of the UFMP by Council in 2012. The UFMP changed the scope of study significantly, focusing management and research efforts on a smaller, primarily urban area.

As a consequence of the readjustment of scope, calculated canopy cover was adjusted from 40.5% to 34.3% in 2007 and 2016 respectively. While a small fraction of canopy change will be due to tree removal and planting, it is primarily due to the change in relative proportions of land use within the study area. Using the NS Department of Natural Resources forest resources inventory classification of land, the UFMP area is proportionately much more urban (71.2%) than the UFORE area (37.9%) (Table 4.1, Figure 4.1). This drastic change in scope substantially affects the calculated benefits. Because of the vast abundance of trees in the less-urban UFORE area, the 2007 study showed higher provision of benefits in all measured categories (Table 4.2).

Table 4.1 Total land areas and areas considered urban in the UFMP and UFORE study areas.

	Total (ha)	Urban (ha)	% Urban
UFMP Area	18,311.79	13,031.29	71.2
UFORE Area	55,934.52	21,227.04	37.9

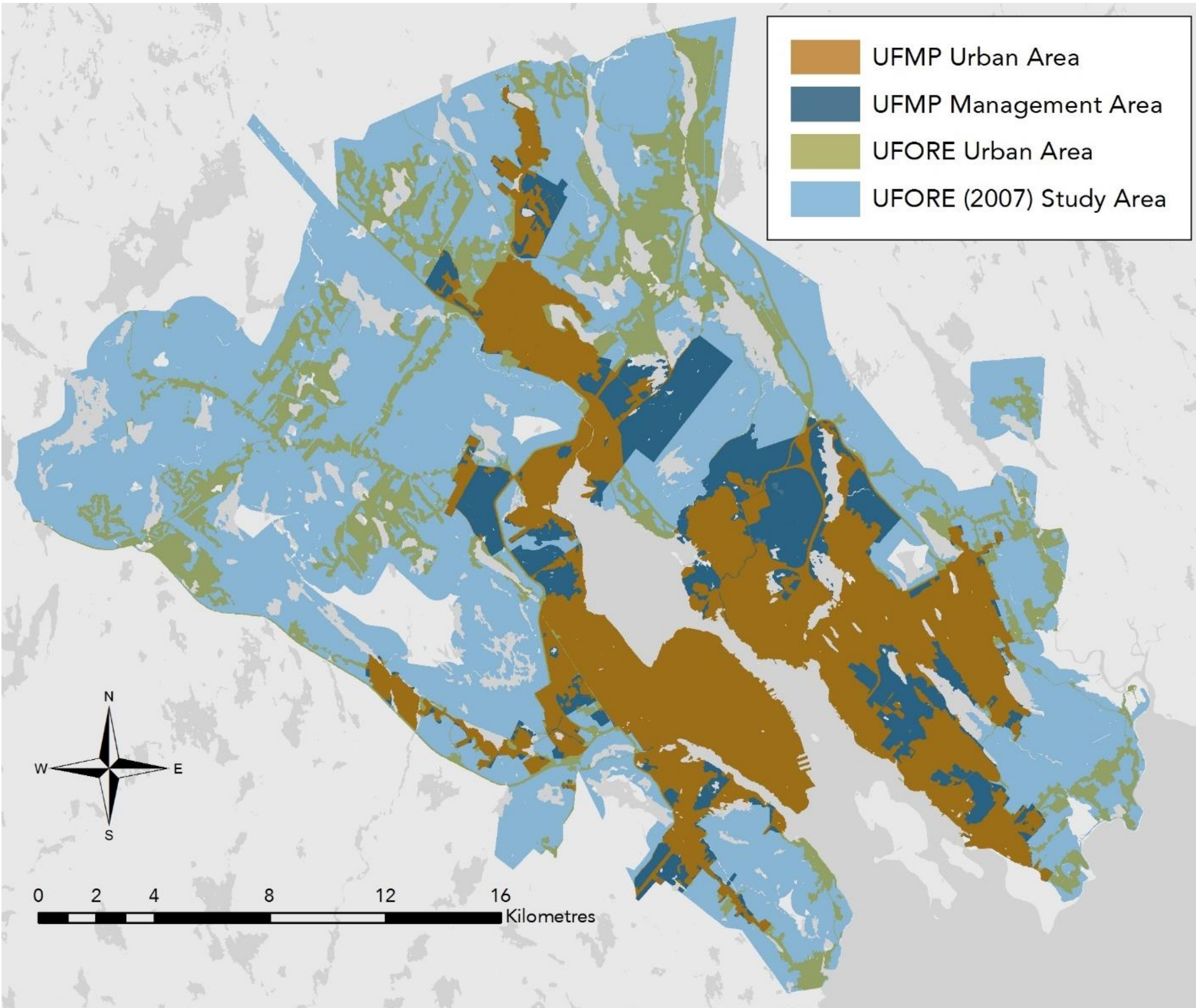

Figure 4.1 Map illustrating areas considered urban within the UFMP and UFORE study areas. (Data from NS DNR)

To meet the challenge of significantly different study areas, we can focus on 2007 data that fall within the area studied in 2016. The methods of the 2007 study were similar to those herein (except for scope) and therefore the studies may be comparable. To re-examine the results of 2007 in the same context as this study, the 2007 data were reprocessed using only the 59 plots contained in the UFMP study area (Figure 4.2). These data and the original 2007 data were rerun through the i-Tree Eco model, using the same pollution and weather statistics as the 2016 assessment. All monetary values, including exchange rate, are the same as the 2016 assessment for the sake of comparison.

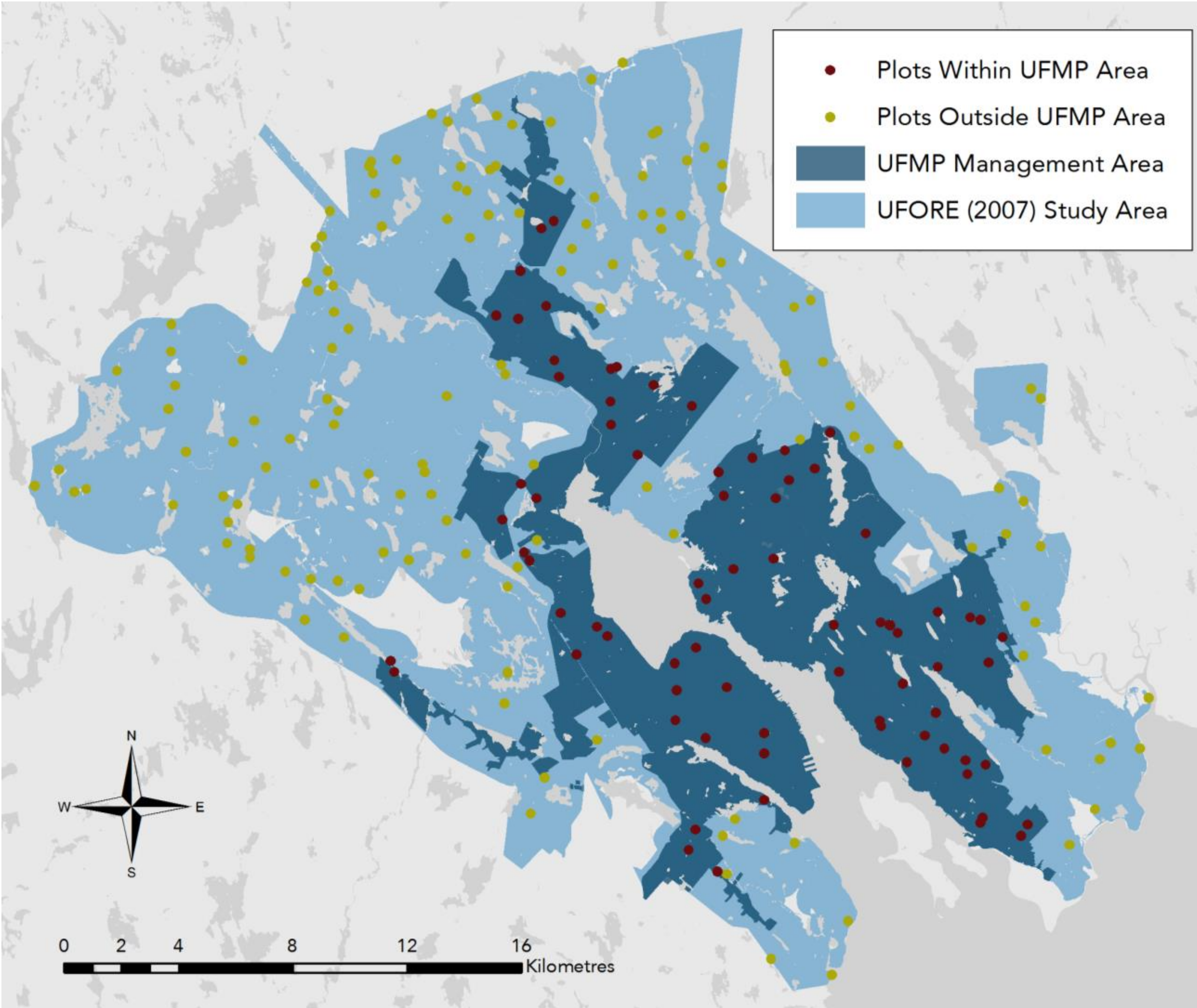

Figure 4.2 Map illustrating the 200 plots of the 2007 UFORE study, highlighting those than fell inside the UFMP area established in 2012.

While every benefit calculated for the 2007 UFORE UFMP area is substantially lower than the total UFORE area, many results are similar to the 2016 study, most notably the estimate of the total number of trees (Table 4.2). With the exception of structural value, all benefits calculated in the 2016 study are higher than the 2007 UFORE UFMP-area analysis. However, it should be noted that the 59 UFORE plots in the UFMP area do not comprise a large enough sample set on which to make statistically valid conclusions. With 200 plots, the 2016 study represents the most statistically confident estimate of the benefits of the UFMP area.

Table 4.2 Comparison of results from 2007 UFORE analysis of original study area (total area), only plots in the UFMP area, and results of the 2016 i-Tree study. All funds are in CAD, adjusted for inflation and using 2016 exchange rates from USD.

	2007 UFORE (total area)	2007 UFORE (UFMP area)	2016 i-Tree ECO
Study Area (ha)	55,934	18,312	18,312
Plots	191	59	200
% total area inventoried	0.014%	0.013%	0.044%
Number of trees assessed	6,423	918	3,670
Mean number of trees per plot	33.63	15.56	18.35
Calculated total number of trees (million)	47.0	7.1	7.4
Canopy cover %	40.5%	24.9%	34.3%
Structural value (billion CAD)	$8.5	$1.7	$1.6
Carbon storage ('000 t)	1,730	303	380
Gross carbon sequestration ('000 t/yr)	82	15	20
Energy savings (million CAD/yr)	NA*	NA*	$1.8
Avoided runoff ('000 m^3/yr)	5,272	910	1,056
Pollution removal (t/yr)	2,680	471	547

The large variance in canopy cover does not indicate mass changes to the urban forest, but highlights the importance of drawing boundaries. When the total study area includes a lower proportion of forested area, the overall canopy cover will be lower accordingly. Greater Vancouver boasts a canopy cover of 43% (Table 1.1), but municipal units within the region have lower canopy cover, e.g. Surrey and Vancouver at 32% and 18% respectively. The same discrepancy is observed in HRM when examining only the UFMP area. This boundary was drawn to include only the parts of the municipality that receive sewer and water service (HRM Urban Forest Planning Team, 2013). While the UFMP area is a functionally relevant boundary for management purposes, it excludes many millions of trees that provide uncalculated benefits to the HRM and beyond. Therefore, the limited scope of the 2016 study discounts the benefits of trees outside of the UFMP area and this broader understanding of the value of peri-urban trees is better represented by the 2007 study.

Similar to the comparison of all urban forest values, a financial comparison between the 2007 and 2006 studies illustrates more about change in study area delineation and methods than change in canopy itself (Table 4.3). Regardless of the study year and methods used, however, it is clear that trees are not only a valuable asset (structural value), but deliver a substantial financial savings and incentive to maintaining and further developing our urban forest.

Table 4.3 Comparison of financial values resulting from 2007 UFORE analysis of original study area (total area), only plots in the UFMP area, and results of the 2016 i-Tree study. Carbon sequestration is based on SCC ($181.13/tonne)

	2007 UFORE (total area)	2007 UFORE (UFMP area)	2016 i-Tree ECO
Structural value (million CAD)	8,540.0	1,661.2	1,587.7
Carbon storage (million CAD, SCC)	313.3	54.9	68.9
Sum of existing values (million CAD)	8,853.3	1,716.1	1,656.6
Net carbon sequestration (million CAD/yr)	14.2	2.5	3.4
Energy savings (million CAD/yr)	NA*	NA*	1.8
Avoided runoff (million CAD/yr)	10.0	1.7	2.0
Pollution removal (million CAD/yr)	1.5	0.2	0.2
Annual benefit (million CAD/yr)	**25.7**	**4.5**	**7.5**

*Energy effects were not assessed in 2007.

4.3 Tree Ownership and Management

Of the total UFMP study area, based on the most recent available data, 6,271 ha is publically owned (Table 4.4, Figure 4.3). This study found that 60.3% of trees in the UFMP area are found on the public 34% of land (Table 4.4). The remaining 39.7% of trees are found on private property that comprises the majority of the UFMP area. It should be noted that vast populations of privately owned trees grow on properties such as untapped quarry land in Sackville and still-naturalized backyards in Beaverbank. These trees provide substantial benefits today, but their future is questionable as the quarry and other industrial activities develop, and development continues into the peri-urban forest.

Table 4.4 Summary of land and tree ownership in HRM UFMP area, as calculated by i-Tree Eco 2016 assessment.

	Land (ha)	(%)	Trees (million)	(%)
Public	6,271	34	4.50	60
Private	12,041	66	2.95	40
TOTAL	**18,312**		**7.43**	

Trees growing on public property are owned by the municipality or senior governments. These trees are maintained with public funds and are an important public resource. The majority of trees growing in the HRM UFMP area are on municipal property, including most street trees and those in municipal parks. While HRM is fortunate to have a healthy public canopy in many regions (e.g. Bedford, older parts of Dartmouth, Halifax Peninsula), other regions are not as well treed (especially developments between the 1970s to late 1990s such as Eastern Passage, Colby Village, and Fairview). Aggressive tree planting is required in the near future to ensure that the canopy of these neighbourhoods a few decades hence matches that of mature neighbourhoods today. Neighbourhoods that are fortunate to have healthy canopy today cannot be ignored, however, as tree populations within a neighbourhood tend to be of similar age. These populations will experience high rates of tree mortality within short periods and a well-treed neighbourhood today can become nearly treeless in a short time. The municipality must actively replace fallen trees as soon as possible to ensure continuity of our healthy urban forest.

Privately owned portions of the urban landscape represent a different challenge for municipal managers because HRM presently has no mechanism for regulating trees on private property.

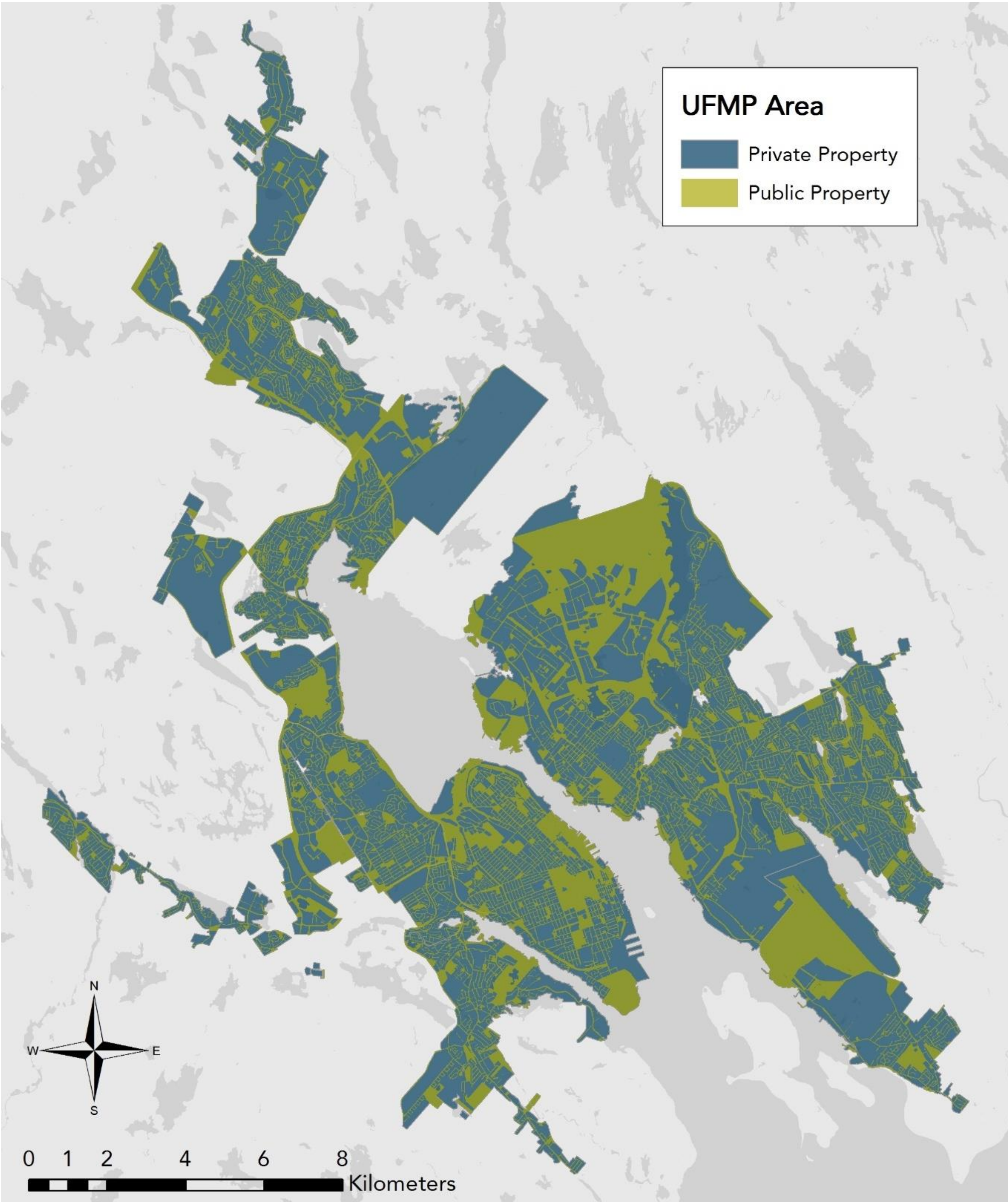

Figure 4.3 Map of land ownership in HRM UFMP area. (Data from HRM)

While these trees benefit everyone through a variety of services and other values, the expense of their planting, management, and removal is borne by the property owner alone. They also hold the right to plant and remove trees at will, and these trees should be seen as highly at-risk especially where other factors encourage land-owners to further develop their properties. This is exemplified on the Halifax peninsula where the prospect of secondary/accessory dwelling units in backyards poses a direct threat to traditionally well-treed backyards. While many members of the public may grow trees for aesthetic reasons, the wide range of other benefits is poorly understood and not often used to rationalize tree planting or continued maintenance. Without comprehending the importance of trees to the city and no apparent strong incentive to keep trees, they may be removed for simplicity or perceived safety. HRM does not currently regulate trees on private property and provides no disincentive for property owners who wish to remove trees from their property.

4.4 Challenges with i-Tree Eco Analysis

Avoided runoff and energy savings from tree shading and wind buffeting are tangible benefits with direct financial savings supported by the literature. Monetization of carbon storage and sequestration by trees is common and generally involves the preservation of forested lands (avoided deforestation) or afforestation, facilitated by payment from conscientious carbon emitters (Kollmuss, Zink, & Polycarp, 2008). Avoided deforestation is primarily a mechanism to prevent the loss of forests in tropical and subtropical regions, to avoid carbon emissions inherent in the methods used, to ensure the forest continues to sequester carbon, and to prevent associated biodiversity loss (Stephan, 2012). This scheme is unlikely to be applied to urban forests in our region. Private-public partnerships have linked carbon emitters with land holders to facilitate afforestation projects that could be applicable to HRM's land. The cost associated with planting street trees (approximately $400/tree), however, likely does not provide emitters with sufficient carbon offset to justify the expense. These offsets make more sense in rural areas where trees individually cost under $1 to plant.

Because neither of these carbon offset schemes seems likely in HRM, monetizing carbon at $20/tonne is problematic as it does not represent a financial incentive for HRM – this is likely why the USDA Forest Service does not use price of carbon for monetization purposes. Social cost of carbon, however, represents the social, environmental, and economic good that is achieved with the trees in HRM's UFMP area. While the $181.13/tonne will never be realized as direct payments or savings to HRM or its residents, it represents the contributions the area's trees make to global sustainability. However, trees in the UFMP area are a small fraction of the trees within HRM as a whole.

HRM is comprised of approximately 533,397 ha of land, 447,991 ha (84.0%) of which is forested according to data from NS DNR (Figure 4.4). In comparison, the 18,311 ha of total area that comprises the UFMP study area represents 3.4% of HRM land area and only a small fraction of its trees. If we wish to examine the carbon sequestration of trees in HRM, the most meaningful level is the municipality as a whole, where millions of tonnes of carbon are captured each year.

We measured 200 plots across the UFMP study area, each 0.04 ha in size, cumulatively inventorying approximately 8 ha of land within the total study area (18,311 ha). Assessing this proportion is statistically significant (USDA Forest Service, 2016b), and, interestingly, yielded similar results in many metrics as an assessment with fewer than one third as many plots (2007 UFORE UFMP area). However, even 200 plots as in 2016 will likely struggle to capture small changes in urban canopy over time. Detecting the effects of small clear-cuts or even a highly aggressive street-tree planting program requires that randomly assigned plots fall on the affected areas. The results of future i-Tree Eco assessments may indicate more about the differences between random plot distributions than actual canopy change. For the purpose of tracking canopy change over time, it may be more effective to look for tools that examine the whole urban forest rather than a sample-based approach.

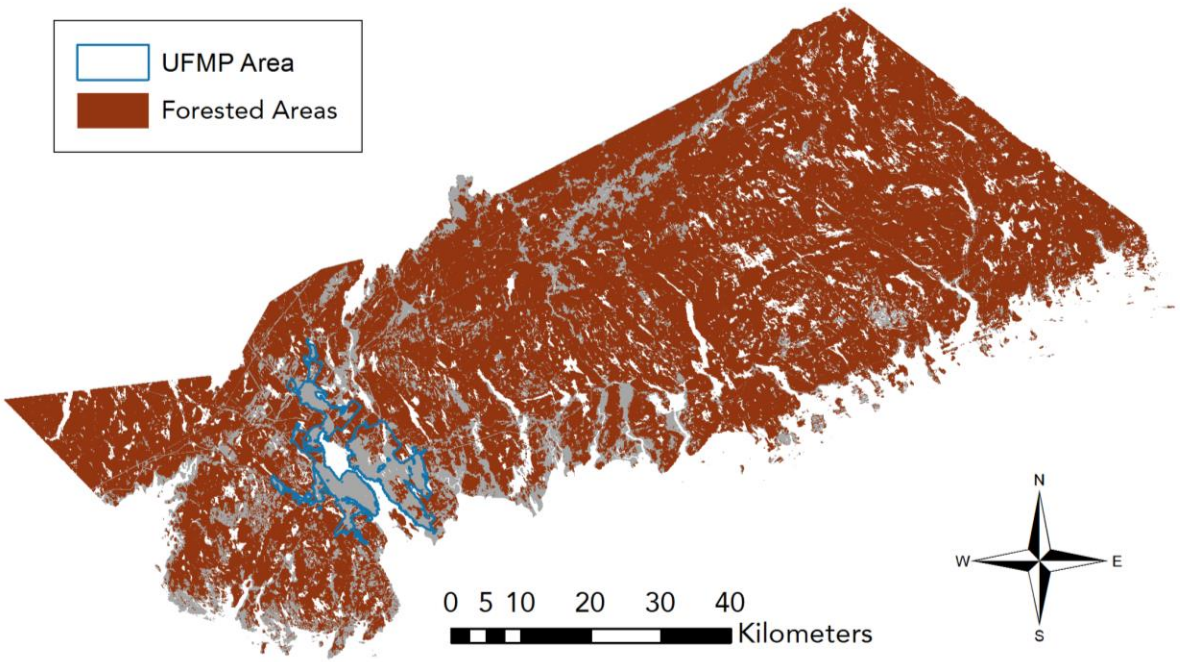

Figure 4.4 Map illustrating the forested areas of HRM. (Data from NS DNR)

In addition to the values calculated in this assessment, HRM's trees provide a wide range of benefits to the people, environment, and economy of the region. i-Tree Eco succeeds as a tool for understanding the direct financial implications of the urban forest, but does not consider the less tangible (though still monetizable in many instances) benefits offered by trees in urban settings. If an assessment were conducted on the UFMP area that examined all benefits of trees, it would be clear that our urban forest is invaluable in many respects, and requires continued effort to ensure that future generations will enjoy an even better urban forest than we enjoy today.

5 Recommendations and Conclusions

Publically owned trees adjacent to streets offer a wide range of benefits to urban areas but parts of the city with low or no street tree populations do not enjoy these benefits. The simplest step to addressing areas of low canopy cover is ensuring that existing plantable locations are filled. This is currently underway with the annual UFMP-directed tree plant of over 1,500 trees per year, but will require a far more aggressive planting program to fill the 94,000 vacant spots identified in the plan (HRM Urban Forest Planning Team, 2013). Beyond existing plantable spots, many streetscapes in HRM do not have the capacity to host trees, especially where grass strips have been removed in favour of wider sidewalks (e.g. Quinpool Road). For these streets to benefit from tree canopy, they require remodeling to allow amenities for trees. In many more streets where trees are currently planted or may be in the near future, historical planning decisions have left a legacy of narrow grass strips in which trees struggle to survive. A healthy tree canopy requires few resources once established, but insufficient soil volume will limit growth potential once trees approach maturity. Future redesign of roads must take into account the health of trees to ensure that canopy reaches its full potential near streets.

Private property owners can benefit substantially from trees, not only for the financial reasons explored in the i-Tree Eco assessment but also for a wide range of benefits including increased property value, making the neighbourhood safer, increased opportunities for play and education, and more. The municipal government does not currently regulate trees on private property, either mandating planting or restricting removal. Without policy to govern trees on private property, HRM must otherwise seek to influence property owners to plant and retain trees. This has been done successfully in other jurisdictions through partnerships with non-governmental organizations (NGOs) with a focus on urban forests (e.g. Toronto's *L.E.A.F.*). These programs often incentivize planting through subsidies and educational resources that ensure participants are more aware of the importance of trees in urban settings. Alternatively, some municipalities create by-laws regulating, on private properties, the removal of trees, species selection for new plantings, and other criteria for appropriate planting (Conway & Urbani, 2007). Municipalities that regulate trees on private properties may also work with and support NGOs to provide citizens with resources for managing their own piece of the urban forest. HRM must consider these approaches and determine how best to reach property owners to ensure that the 40% of the urban forest that is privately owned is sustained and grown into the future.

An incentive-based program that encourages property owners to plant and retain trees may capitalize on the benefit trees offer through stormwater runoff mitigation. Trees in HRM are saving an estimated $2 million annually in avoided runoff, a benefit largely incurred by the municipality's water utility, Halifax Water (HW). Newly proposed changes to the Halifax Water Site Related Flow Charge will bill property owners based on the amount of impervious surface on their property, as opposed to the current flat rate for all property owners (HRM, 2016). The published numbers reveal that HW currently bills customers approximately $2.9 million annually to help cover costs for stormwater management (Table 5.1). Whereas trees prevent the flow of stormwater into sewers, an impervious-surface-based billing scheme could take into account this benefit and encourage tree planting and retention in exchange for reduced stormwater management fees. This may provide enough incentive for property owners to ensure that driveways, roofs, patios, and other impermeable surfaces are covered by tree canopy to mitigate runoff.

Table 5.1 Schedule of fees under old and new Site Related Flow Charge schemes (modified from HRM, 2016).

Tier	Tier Parameters (Impervious Area in m²)		Old Rate	Proposed Rate	Affected Customers	Total Billed Old Rate	Total Billed Proposed Rate
Tier 1	Less than	50 m²	$33.39	$0.00	2,236	$74,660	$0.00
Tier 2	50	- 200 m²	$33.39	$14.00	44,710	$1,492,867	$625,940
Tier 3	210	- 400 m²	$33.39	$27.00	31,041	$1,036,459	$838,107
Tier 4	410	- 800 m²	$33.39	$54.00	7,768	$259,373	$419,472
Tier 5	810	- Or more	$33.39	$81.00	2,123	$70,887	$171,963
				TOTAL:	**87,878**	**$2,934,246**	**$2,055,482**

Naturalized tree stands provide substantial benefits to urban areas calculated in this assessment (e.g. avoided runoff, pollution capture, and more). Grassy areas adjacent to roadways and elsewhere, especially those that are presently maintained at great expense to the municipality, could be naturalized to save money and increase the benefits we incur from trees in the city. Except where safety concerns prevail, particularly sightlines for safe driving, naturalizing environments such as these (e.g. Figure 5.1) will be overwhelmingly cost-saving.

Figure 5.1 The junction of Highways 118 and 111 in Dartmouth displays odd patterns of forestation, and significant potential for naturalization (image from Google).

Our account above of the HRM urban forest in 2016 reveals quantified details of the enormous array of benefits provided by the trees of the city. We urge HRM Regional Council to continue its leadership in sustaining the urban forest with adequate and firm budget allocations as well as unwavering support for implementation and renewal of the UFMP. In the past decade, HRM has embarked on ambitious programming to balance its grey infrastructure with healthy and abundant green infrastructure. When one factors in the abundant blue infrastructure associated with the fresh- and saltwater assets of the city, HRM has a truly admirable and attractive environment in which its citizens can live, work, and play sustainably.

6 References

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7 Appendices

7.1 Appendix A: Pest Vulnerability

Tree pests, including fungi and insects, tend to be species- or genus-specific, meaning they affect a narrow range of trees. A range of tree pests currently in North America have the potential to spread to our region, and some are already here (Table 7.1). Risk is a rough indicator of the danger posed by each pest based on the likelihood of infestation in HRM and the potential hazard of each pest. Risk may change rapidly and drastically as pests are able to migrate at increasing rates due to large amounts of global trade.

Table 7.1 Summary of trees' susceptibility to pests in the HRM UFMP study area, including total number of trees in UF that are susceptible, and the corresponding proportion of total trees susceptible.

Pest	Susceptible	%	Description of threat	Risk
Beech bark disease	221,887	1.51%	Results from a combination of the invasive beech scale insect (*Cryptococcus fagisuga*) and two native fungi that infect holes made by the insect[1]. Currently infestations throughout Maritimes.	High
Dutch Elm Disease	23,201	0.16%	Two closely related fungi are spread by both a native and non-native elm bark beetle[2]. Infestation without treatment typically results in death. Infestation is throughout North America though not intensively in HRM.	High
Balsam Woolly Adelgid	1,405,194	9.54%	First discovered in NS in 1910[3], *Adelges piceae* still has a presence in NS and significant infestations in neighbouring provinces. Infestation of a balsam fir typically results in death in 3-4 years[4]. Found throughout Maritime provinces.	Med.
Emerald Ash Borer	183,581	1.25%	*Agrilus planipennis* was first detected in North America in 2002 in Windsor, ON, and has spread rapidly, especially though movement of firewood. Spread is projected to reach the entire extent of ash trees in North America, and is currently found as far east as Southern Quebec[5].	Med.
Gypsy Moth	3,506,288	23.81%	Discovered in NS in 1971, *Lymantria dispar* affects oak, poplar, apple, and birch. Impacts urban and peri-urban forests, though has not yet caused significant defoliation in NS. Infestations in Western NS.[6]	Med.
Pine Shoot Beetle	465,659	3.16%	First detected in Canada in 1993 (ON) and 1998 (QC), *Tomicus piniperda* is now found in western New Brunswick[7]. Infected trees do not always die, but growth is substantially stunted[8].	Med.
Sirex Wood Wasp	462,995	3.14%	*Sirex noctilio* is an invasive wood wasp from Eurasia that oviposits eggs onto stressed trees along with toxic mucus and wood decay fungus[9]. The combination typically leads to tree death, and has caused collapse of large swaths of commercial pine harvest in Australia. Currently found in the Great Lakes region, it is highly likely to reach Nova Scotia and survive on the pine population. Biological control is possible through diligent management[10].	Med.

[1] https://www.na.fs.fed.us/spfo/pubs/fidls/beechbark/fidl-beech.htm
[2] https://www.na.fs.fed.us/spfo/pubs/howtos/ht_ded/ht_ded.htm
[3] http://novascotia.ca/natr/forestprotection/foresthealth/sheets/Bwa.asp
[4] https://www.exoticpests.gc.ca/es-details/insect/5314
[5] https://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13377
[6] http://novascotia.ca/natr/forestprotection/foresthealth/sheets/gm.asp
[7] http://www.inspection.gc.ca/plants/plant-pests-invasive-species/directives/forestry/d-94-22/appendix-1/eng/1343785471448/1343785603835
[8] https://www.exoticpests.gc.ca/es-details/insect/1000093
[9] http://www.afs-journal.org/articles/forest/pdf/2006/02/F6013.pdf
[10] http://www.na.fs.fed.us/spfo/pubs/pest_al/sirex_woodwasp/sirex_woodwasp.htm

Pest	Susceptible	%	Description of threat	Risk
Brown Spruce Longhorn Beetle	4,730,973	32.12%	Landing in Halifax in 1999 and established in NS since 1990, *Tetropium fuscum* has since been detected throughout the province[11]. The beetle prefers stressed and weakened trees and tree death can result after several subsequent years of infestation. Containment and limitation of damages may be possible through new developments in trapping and breeding disruption, and public awareness[12].	Med.
Winter Moth	6,460,842	43.86%	*Operophtera brumata* was first discovered in NS in the 1930's. The defoliating moths' larvae also eat buds, substantially reducing spring foliage[13]. Infestation does not typically kill the tree, but succesive years of defoliation can reduce tree health and make it more vulnerable to other pests.	Med.
Hemlock Woolly Adelgid	305,279	2.07%	*Adelges tsugae* was introduced to the eastern US in the 1950s and now threatens eastern Canada, although sightings are currently limited to Ontario. Although the insect's range could extend as far north as NS, infestations are eradicable with timely detection and sufficient resources[14].	Low
Large Aspen Tortrix	2,908,411	19.75%	*Choristoneura conflictana* is a defoliating insect currently found in Nova Scotia that infests aspen as well as other (less-preferable) hosts later in the growing season[15]. Infestations usually only last two years and do not typically affect long-term tree health unless the tree is stressed.	Low
Mountain Pine Beetle	56,947	0.39%	Currently limited to BC & AB, *Dendroctonus ponderosae* is native to northern BC but has begun to move eastward as milder winters have ceased to cause a winter die-off[16]. Able to move up to 100 km a year under ideal weather conditions, the beetle may spread into the boreal forest in coming years[17]. Future expansion of the beetle's range into NS may be possible but there is little research to support the theory.	Low
Northern Spruce Engraver	196,052	1.33%	*Ips perturbatus'* range primarily coincides with the range of its preferred host, the white spruce, and is found in all Canadian Provinces[18]. Infestations result in substantial stand composition alterations. Little research relates to NS specifically and it does not appear to be a significant threat to NS forests.	Low
Southern Pine Beetle	5,499,247	37.34%	Previously constrained by climatic factors to the southern US, *Dendroctonus frontalis* Zimmermann has been migrating north due to climate change[19]. Fatal to nearly all infected trees, the beetle prefers species not found in NS, but has shown generalist tendencies in other regions[20] and may pose significant threat to NS pines in the future.	Low
White Pine Blister Rust	386,816	2.63%	This fungus' lifecycle involves an obligate phase on Ribes such as blackcurrants, and has caused significant forest devastation in QC[21]. It is currently in NS, but does not seem to be causing substantial stand alterations.	Low

[11] http://www.inspection.gc.ca/plants/plant-pests-invasive-species/insects/brown-spruce-longhorn-beetle/question-and-answers/eng/1330664011747/1330664223848
[12] http://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13373
[13] https://tidcf.nrcan.gc.ca/en/insects/factsheet/1000088
[14] http://forestinvasives.ca/Meet-the-Species/Insects/Hemlock-Wooly-Adelgid
[15] http://dnrc.mt.gov/divisions/forestry/docs/assistance/pests/fidls/139.pdf
[16] http://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13381
[17] http://www.cfs.nrcan.gc.ca/publications/?id=28891
[18] http://dnrc.mt.gov/divisions/forestry/docs/assistance/pests/fidls/180.pdf
[19] http://www.ctvnews.ca/sci-tech/destructive-southern-pine-beetle-appears-in-northeast-states-1.2432249
[20] http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev2_042840.pdf
[21] https://www.exoticpests.gc.ca/es-details/disease/24

Pest	Susceptible	%	Description of threat	Risk
Asian longhorned beetle	5,279,797	35.85%	*Anoplophora glabripennis* is a destructive wood-boring insect that attacks maple and other hardwoods, eventually killing them[22]. While it is incredibly destructive, it is presently declared eradicated in Canada and future infestations may be combatable given sufficient resources[23]. If spread uncontrollably, would be devastating to HRM.	Low
Aspen leafminer	273,521	1.86%	*Phyllocnistis populiella* is native to North America and limited to western regions, primarily affecting aspen and balsam poplar, rarely killing the host[24].	None
Laurel Wilt	4,887	0.03%	The result of a beetle-fungi pairing, laurel wilt only affects plants in the laurel family and is concentrated in the southern states[25].	None
Oak Wilt	546,842	3.71%	A fungal infection found only in the US, from TX to WV, oak wilt almost always results in tree death[26,27]. Observed in Wisconsin in the 1940's, its spread has been primarily southerly, and the risk to Canada appears to be minimal.	None
Polyphagous Shot Hole Borer	18,674	0.13%	*Euwallacea spp.* is found in California where it was detected on avocado trees[28]. The beetle affects a range of broadleaves including English oak, sweet gum, and more[29].	None
Sudden Oak Death	543,477	3.69%	Detected for the first time in Canada in 1993, sudden oak death (*Phytophthora ramorum*) is currently restricted to southern BC and through stringent control measures, spread currently seems to be under control[30].	None
Thousand Canker Disease	19,716	0.13%	A beetle and fungus pairing, thousand canker disease is always fatal to affected black walnut trees, but is not found in Canada and has low potential to spread to temperate climates[31].	None
Western Spruce Budworm	255,663	1.74%	*Choristoneura occidentalis* is a pest native to western Canada including BC and AB, and does not show any risk of migration east[32].	None
All Pests	14,244,436	96.71%		

Because pests tend to be genus- or species-specific, UF resilience to infestation and destruction is gained through diversity. This is recognized by the UFMP and the current planting program has been implemented to ensure that streets contain a wide range of tree species and genera. Generalist pests that threaten a wider array of our UF may be introduced to our region, such as the Asian longhorned beetle, and will require diligent monitoring for detection, and aggressive action once detected.

[22] https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases/asian-longhorned-beetle/ct_asian_longhorned_beetle
[23] http://www.inspection.gc.ca/about-the-cfia/newsroom/news-releases/2013-04-05/eng/1365168144940/1365168154936
[24] http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5347213.pdf
[25] http://www.ncforestservice.gov/forest_health/forest_health_laurelwiltfaq.htm
[26] https://www.na.fs.fed.us/spfo/pubs/fidls/oakwilt/oakwilt.htm
[27] http://www.inspection.gc.ca/plants/plant-pests-invasive-species/diseases/oak-wilt/fact-sheet/eng/1325629194844/1325632464641
[28] http://ucanr.edu/sites/pshb/overview/About_PSHB/
[29] http://cisr.ucr.edu/polyphagous_shot_hole_borer.html
[30] https://www.exoticpests.gc.ca/control-details/disease/16
[31] https://www.exoticpests.gc.ca/us-details/disease/1000145
[32] http://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13385