A First-Approximation Windthrow Risk Index for Street Trees on the Halifax Peninsula

B.Sc. Honours Thesis

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Abstract

Trees in the Halifax Regional Municipality are at particular risk to windthrow because of their proximity to the coast, and the risk of increasing storminess in the future. This study aimed to create a vulnerability index to determine the susceptibility of individual trees and neighbourhoods to wind events in the future on the Halifax Peninsula. Trees were analyzed based on specific characteristics: genus, height, diameter at breast height, distance from nearest building, height of nearest building, pruning, site conditions, distance from coast and elevation, Data from one hundred trees across the Halifax Peninsula were used to demonstrate the utility of the index. It was determined that the most susceptible trees were scattered across the Peninsula. However, the most vulnerable neighbourhood was located on the southwest coast, in the direction of the prevailing winds that pass through in the summer. Results from this study can be applied to the rest of the Halifax Regional Municipality to determine the entire region's susceptibility to windthrow. Future research could be conducted to further analyze the most vulnerable regions, and to determine which tree characteristics contribute the most to trees' vulnerability to windthrow.

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1. Introduction

Trees in an urban setting are an invaluable asset (Dywer et al., 1992). Over the past fifty years, there has been a growing realization that there is a need to incerase the amount of green infrastructure (trees and vegetation) in cities. There is an increase awareness to manage and protect our urban forests (Carreiro, 2006).

The urban forest in the Halifax Regional Municipality (HRM) is an valuable resource to the city (HRM UFPT, 2012). As a coastal city, Halifax is at risk to exposure from strong winds and hurricanes. Since 1954, there has been a documented increase in the number of hurricanes in coastal regions, through erosion analysis on beaches (Shaw et al., 2003). Increasing storminess due to predicted climate change (Christensen et al., 2007) has the potential to damage urban forests: stem failure and complete uprooting can result from high winds (windthrow) (Hauer, 1992). Canada's Atlantic coast has a long history of severe storm and hurricane events (Thompson et al., 2009). Strong winds can result in damage to the HRM's urban forests, as seen in 2003 following Hurricane Juan where significant damage was done to the trees across the Peninsula (HRM UFPT, 2012). Destructive hurricane and strong wind events require attention in light of urban forestry, as they will lead to an increase in the amount of urban trees being damaged (HRM UFPT, 2012).

Any solution aimed at raising urban trees' resilience to wind damage needs to include a catalogue of trees in vulnerable neighbourhoods and an assessment of which neighbourhoods and trees are at particular risk. Using the HRM Peninsula as a case study, I have examined the vulnerability of individual trees spread across ten neighbourhoods. The objective was to increase the general state of knowledge on the quality of the urban forest from a windthrow perspective.

In this thesis project, I assess the windthrow vulnerability of trees in an urban setting using the HRM urban core as an example, cut off by Joseph Howe Drive. Following Hurricane Juan, a tree inventory was conducted to support development of the HRM Urban Forest Master Plan (HRM UFMP, 2012). However, a neighbourhood-based inventory of trees, needed for determining which regions are more vulnerable than others, has yet to be documented. Discussion about wind vulnerability is fragmented in the literature, and this study is an attempt to integrate some of that knowledge. This study will focus solely on the Halifax Peninsula.

1.1. Urban Forests & Stressors

Trees provide many benefits to the urban environment. These include improved air quality, reducing storm water runoff to avoid flooding, soil quality, plant and animal diversity, wind and temperature control, noise reduction, and providing spaces for outdoor leisure activities (Dwyer et al., 1992). Such benefits of an urban forest outweigh the costs of upkeep and management (Dwyer et al., 1992). While this study does not analyze the benefits of the urban forest directly, it points to their importance as strong justification to take the threat of windthrow seriously.

Urban trees are subject to a multitude of stressors that trees in the natural environment do not suffer. These include a restricted volume of soil and crown space, soil and air pollution, drought and strong winds (Saebo et al., 2003; Duryea et al., 2007). Street trees (rather than trees in parks or private backyards) are exposed to even higher stressor factors such as soil compaction (from side-walks, roads, and buildings in close proximity), road salt for de-icing, snow accumulation from road clearing, and wind exposure (Saebo et al., 2003). These stressors weaken trees, and as a result, they are increasingly vulnerable to damage (especially from high winds).

The potential effects of increasing wind on the trees on the Halifax Peninsula include crown damage, branch and trunk breakage, and the complete uprooting of trees. In this study, the complete uprooting of trees is referred to as windthrow (Stathers et al., 1994). Windthrow occurs when the torque exhibited on a tree from forces (wind) exceed the resistance of the roots and soil (Stathers et al., 1994).

1.2 Urban Tree Vulnerability Index

Trees must have root quality, growth potential, wind and drought resistance, resistance to limb breakage, and air-pollution tolerance to withstand the urban environment (Saebo et al., 2003). The vulnerability index is a way to assess individual trees and potential whole neighbourhoods of trees to determine their susceptibility to damage by wind.

Data collected for the vulnerability index includes characteristics noted in the literature as affecting a trees' resilience to strong winds. These include characteristics such as site-specific soil qualities (the degree to which there is ground compaction from urban infrastructure), crown cover, height, diameter at breast height, distance to the nearest building (wind protection) (Kontogianni et al., 2011), genus, location and any notable deformities (whether natural or human-caused such as pruning) (Barry et al., 1993; Duryea et al., 2007; Foster, 1988; Kane, 2008; Kontogianni et al., 2011; Niklas, 2002; Saebo et al., 2003). The goal is to determine the most susceptible neighbourhoods, based on individual tree auditing, as well as location, slope, and the proximity to the coast.

1.3 Research approach:

1.3.1 Goals and Objectives

The goal of the study is to increase the general state of knowledge on vulnerability to windthrow in an urban setting. The objective of this project is to create a neighbourhood/tree vulnerability index to identify the trees, both individually and across neighbourhoods on the Halifax Peninsula that are most at risk to damage by strong wind events in the future. The study does not aim to make inferences about the whole urban forest of HRM but rather represents a first attempt to understand windthrow vulnerability in the HRM Peninsula through the development of a vulnerability index.

The research question to be tested was:

1. What are the urban forest sites on the Halifax Peninsula that are the most vulnerable to damage in higher winds?

a. Using a vulnerability index, what are the specific tree characteristics that make them the most vulnerable to windthrow, as collected through expert opinion and a literature review?

b. Based on the characteristics that make them more vulnerable (above), what genus of tree is the most vulnerable?

c. How are these vulnerable trees distributed, and therefore what are the most vulnerable neighbourhoods?

The predictions are:

1(a) It is predicted, based on the literature, that trees with greater ground compaction, without protection from the wind from buildings, taller, with larger diameter at breast height, and with larger crowns will be the most vulnerable to windthrow.

1(b) Using a systematic integration of qualitative and quantitative factors compiled into a vulnerability index, the more vulnerable genus will rank higher on the vulnerability scale than those that do not exhibit as many of the characteristics that increase vulnerability.

1(c) Based on neighbourhood and individual tree susceptibility to dominant wind direction and strength, it is predicted that urban neighbourhoods with higher elevations and within close proximity to the coast will be at greater risk to damage in future windstorms.

This project only looks at the Halifax Peninsula, as it is predominantly a coastal area and arguably has a greater number of stressors on the urban forests than across the HRM as a whole. I have addressed the research question using tree data on the Halifax Peninsula.

1.4 Implications of the Study for Halifax Peninsula's Urban Forest

Although this study will not assess the benefits of the urban forest, it will increase the general state of knowledge on the quality of the urban forest on the Halifax Peninsula. As a response to potentially increasing storminess in Atlantic Canada (Christensen et al., 2007), the contribution that this study makes is the proactive approach to urban forestry damage, rather than a post-storm assessment. The vulnerability index created in this study will be able to be applied to the rest of HRM's urban core to assess the total vulnerability of the city's urban forest to damage from strong wind events in the future.

2. Literature Review

This literature review outlines the main issues surrounding wind events on the Halifax Peninsula, with a focus on damage to trees due to strong winds. The general state of knowledge about the factors affecting urban trees is contained in the literature, both natural and human-induced. However, the potential impacts of severe storm events on trees on the Halifax Peninsula have not yet been studied. This review covers climate projections in the future, and the potential for an increase in wind events in

Atlantic Canada (Christensen et. al., 2007). Finally, this review outlines the characteristics of individual trees that make them particularly vulnerable to damage due to strong winds. Comparisons are also drawn between the urban forest and natural forests based on evidence from the literature.

2.1 Formal Search Method

This literature review was completed using a variety of databases provided through Dalhousie University (Table 1). Once the relevant articles from these databases were reviewed, additional articles were retrieved from the sources cited. Additionally, Atlantic-relevant climate change information was collected from the Intergovernmental Panel of Climate Change (IPCC) (2007).

The following databases were used to complete the literature review: ScienceDirect, Web of Science, Scopus, Environmental Science and Pollution Management, and Biological Abstracts. The initial list of key words included: urban* forestry* wind* damage*, however, with some databases the search was unsuccessful. With those unsuccessful databases, the keywords urban AND forestry AND wind AND damage were used. The years of publication were not used as a limitation in the searches,, although articles do not extend earlier than1977; the majority is from the late 1990s, into the 2000s. Identified articles had to include references to wind damage to trees, but not only in urban forests.

Table 1 Search results from environmental science databases. Provided through Dalhousie University, Librarian Michelle Paon.

Database	Key words	Number of articles retrieved	Host	Years covered
Web of Science	urban* forestry* wind* damage*	12	Wed of Knowledge/ Thomson Reuters	1973-2012
ScienceDirect	urban AND forestry AND wind AND damage	1,777 (only 3 used)	SciVerse/Elsevier	
Biological	urban*	12	Web of	1973-2012

Abstracts	forestry* wind* damage*		Knowledge/ Thomson Reuters	
Scopus	urban* forestry* wind* damage*	13	SciVerse/Elsevier	2002-2012
Environmental Science and Pollution Management	urban* forestry* wind* damage*	13	ProQuest	1987-2012

2.2 Urban Forestry in the Literature

Initially, this literature review was aimed at analyzing previous studies on solely urban forests. Once recognizing the gaps in knowledge, specifically surrounding damage to urban forests due to strong winds, the search was expanded to include characteristics that affect windthrow in non-urban forests. In addition, articles regarding climate change and the importance and benefits of urban forests were explored.

2.3 Climate Change and Urban Forest

Predicted climate change and increasing storminess threatens the Atlantic Canadian coast, and as a result, poses a risk for the coastal urban forest as strong wind events test their resiliency (Christensen et al., 2007). According to the IPCC (2007), an increase in mean global annual temperature of 2.4 - 6.4ºC is estimated to occur before the end of the twenty-first century as a result of continued emissions of anthropogenic greenhouses gases. Over the course of the next century, North America with most likely experience a substantial temperature rise, partly due to rising ocean temperatures (Christensen et. al., 2007). In addition, levels of precipitation are also predicted to rise because of a change in the hydrological cycle; however, there remain uncertainties surrounding regional-specific climate changes. Despite the uncertainties, the IPCC reports that the number of strong cyclones is anticipated to increase (Christensen et. al., 2007). The following section will address the effects of stronger wind events on urban trees and forests.

High winds in an urban setting can affect the trees by causing branch breakage, crown loss, trunk breakage, and windthrow (Hauer, 1992).

2.4 Effects of Predicted Increasing Storminess and Gust-Force Wind on Urban Forests

Windstorms have historically been known to shape forest ecosystems through damage (Moser & Nelson, 1992). In addition, urban forest loss has been identified as being positively correlated with wind speed (Duryea et al., 2007). Storm winds result in a force that twists and bends tree parts, which leads to either some branches to be damaged (initially being defoliated, with smaller twigs snapping off), or the soil to fail and the tree to be completely overturned and uprooted (windthrow) (Coder, 2007; Francis & Gillespie, 1993). This dynamic loading on trees is caused by rapid, periodic gusts of wind on the terrestrial environment, caused by storminess (Grace, 1977). Gusts damage trees more than constant wind, because of the swaying as a result of the inertia of the faster wind gusts from hurricane-type storms (Grace, 1977).

In addition to environmental damages to the urban forest, hurricanes can have physical impacts on urban structures, and result in significant economic damage (Everham & Brokaw, 1996). Therefore, a better understanding of predicted storms and the effects of wind on trees could help management practices in the future. In addition to an understanding of storms, a tree-level analysis must be made to look at the wind-loading characteristics that differ among genus, sizes and locations of the trees (Moser & Nelson, 1992).

2.5 Wind Direction and Topography

Determining the dominant wind direction, the elevation of each tree, and the distance to the coast are important factors for analyzing the vulnerability of trees/neighbourhoods to windthrow. According to the Nova Scotia Museum of Natural History (1996), the most frequent and intense tropical cyclones occur in the late summer/early fall; however, the strongest winds occur in the coldest months. In the summer, the winds are predominantly south-southeast, and in the winter, from the west and northwest (NSMNH, 1996). Predictions are that sloping coastal banks, in addition to prevailing winds, are where the majority of the vulnerable neighbourhoods and trees will be found.

2.6 Characteristics: Tree Vulnerability to Wind

The literature contains debates surrounding characteristics that make individual trees more susceptible to damage by strong winds. Nevertheless, this review takes into account a variety of characteristics to create an index that is representative of all characteristics that determine that the vulnerability of individual trees. Broadly, the points of view can be separated into: damage solely from high winds, damage from height/age, damage from denser crowns, and damage due to compromised soil quality (Barry et al., 1993; Duryea et al., 2007; Escobedo et al., 2009; Foster, 1988; Foster, 1988; Francis & Gillespie, 1993; Kane, 2008; Kontogianni et al., 2011; Niklas, 2002; Saebo et al., 2003; Thompson et al., 2011; Nilsson, 2000).

Damage from wind in an urban environment can be exacerbated because of a lack of protection for trees standing individually, rather than in a stand in a natural environment (Kontogianni et al., 2011). However, strong wind is not the only factor that influences a trees' susceptibility: location in the urban environment is also another important factor (Kontogianni et al., 2011).

Kotoginani et al. (2011) focuses mostly on the crown shape, size, and symmetry as factors that influence tree stability. Duryea et al. (2007) studied natural coastal forests, and observed that the amount of tree damage was influenced by genus, size, and diameter. In addition, full crowns were less wind resistant in one study (Foster, 1988), yet in another, it was stated that dense crowns were found to have higher survival than moderate or open crowns (Duryea et al., 2007); this is one area of contention in the literature.

Additional characteristics of trees that are related to wind resistance include: wood strength, crown shape and size, extent and depth of the root system, soil conditions, and shape of the stem (Barry et al., 1993). Following a hurricane in Brewster, Massachusetts, it was noted that larger trees were more damaged by the storm than smaller trees. This study also suggested that pruned trees (with less canopy cover) were not any more susceptible to damage than non-pruned trees (Kane, 2008). Kane (2008) further remarks that genus, height, diameter at breast height, and any significant defects were the major aspects that were studied to determine which trees were most at risk. Individual trees are all seen to react differently at different locations, along with differing soil conditions. Topography affects a tree's survival, as well as the built infrastructure surrounding the tree (affecting the soil condition in which the tree grows) (Kane, 2008; Niklas, 2002; Saebo et al., 2003). Street trees in particular are subject to a multitude of stressors that affect their susceptibility, because of restricted soil space, salt damage, and the built infrastructure (Saebo et al., 2003).

There are differing perspectives on the basic characteristics that influence a trees' susceptibility, as individual trees will react differently. In general, tree canopy, wind speed, soil condition, the root system, age, and height all play a significant role in the trees' potential damage during a wind storm (Escobedo et al., 2009; Francis & Gillespie, 1993).

2.7 Knowledge Gaps as Identified Through the Literature Review

This project looks at the vulnerability of the urban forest unique to the Halifax Peninsula. It involves a pre-storm assessment of the neighbourhoods on the Halifax Peninsula, rather than collecting post-hurricane debris data. The latter are highly desirable data to collect, a theme to which I return at the end of this report.

Studies around the globe have focused on analyzing post-wind storm data, including reports from China and Florida. A post-hurricane assessment on urban forests in Florida collected data by measuring and analyzing debris, but acknowledged that pre-storm data would be more valuable to collect (Escobedo et al., 2009). Additionally, studies in Guangzhou, China, assessed post-storm data, but also focused on the location of the tree and how a roadside tree was more susceptible to damage than a tree located in a park, for instance (Jim, 2004). Sani et al. (2012) used a 'pulling test' to gather information on the strength of root systems in Mediterranean urban areas. This study focuses on the strength of the root system of various urban trees in the Mediterranean.

While the literature discusses the characteristics that make a tree and neighbourhood tree populations more vulnerable, there has not yet been a study that has collected pre-storm data on individual trees with the aim to create a vulnerability index of multiple characteristics (including genus, height, diameter at breast height, soil characteristics etc.).

3. Methods

3.1 Overview

Based on the literature review, the characteristics that affect an individual tree's vulnerability were identified. To determine the individual tree's vulnerability and in addition, the neighbourhood vulnerabilities across the Halifax Peninsula, a vulnerability index was created. This index quantifies vulnerability factors and rates the trees based on these. Analysis was undertaken to compare trees and neighbourhoods.

3.2 Study Area

The study area for this project is limited to the Halifax Peninsula alone, part of the urban core of the HRM. The Peninsula was separated into ten sections (Figure 1) using major roads as boundaries. In addition, sections 9 and 10 have been separated as section 10 represents the downtown core of the Halifax Peninsula, as well as the business district. The hyperabundance of urban infrastructure in this zone is the reason for the division of the two sections, thus creating a wide range of neighbourhood qualities to analyze. High amounts of urban infrastructure translate into high ground compaction (Saebo et al., 2003), which increases the vulnerability of the urban street trees.

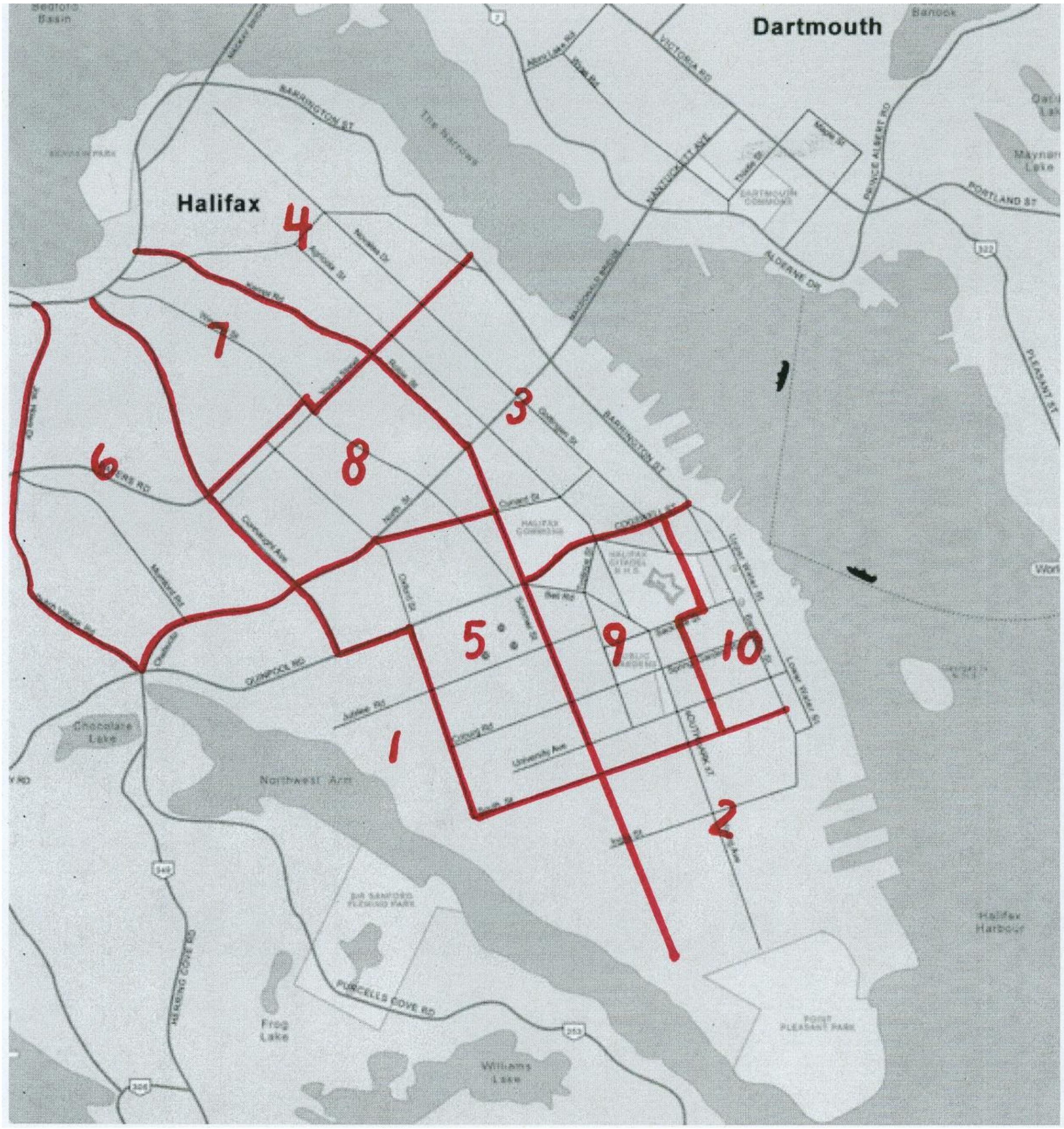

Figure 1 The Halifax Peninsula, with overlaid lines demonstrating the 10 sections for the study area. Image from http://graphics.worldweb.com PhotoImages/Articles/Canada/Halifax_DartmouthArticleMap.GIF

3.3 Data Collection Design

While the HRM contains 700,000 street trees (HRM UFPT, 2012), the number of trees on the Halifax Peninsula alone has yet to be determined, but based on expert opinion the number should be around 100000-200000 trees (HRM UFPT, 2012). This study uses a combination of quota and random sampling method to try to assemble a statistically representative data set for the Peninsula. Ten trees were randomly selected in each neighbourhood, and this randomization involved a spatial scatter throughout each section. The specific tree characteristics that make them the most vulnerable to windthrow were determined through the literature and expert opinion (Table 2).

Table 2 Characteristics included in the vulnerability index, as determined by the literature

Characteristic	Explanation
Location	The specific location of each tree was identified to determine the neighbourhood vulnerabilities; locations were mapped to generate a visual representation of the neighbourhoods.
Genus	The street trees that are found on the Halifax Peninsula are most commonly maple, elm, linden, oak and beech (HRM Urban Forest Planning Team, 2012). The genus of each tree was identified to determine any connections between vulnerability within a genus category, as different tree genus have different wood strengths and trunk flexibility (variable wind-loading characteristics) (Moser & Nelson, 1992).
Height/Diameter at breast height/Crown shape and size	The height of the tree, the diameter at breast height, and the crown shape/size were collected because the literature indicates that, in general, older, larger trees are more susceptible to damage by wind (Kane, 2008). The crown shape was determined using a visual examination as well: round or triangular, and symmetric or

	asymmetric.
Site characteristics	The site characteristics were determined using thirteen categories of soil quality (combinations of grass, gravel and/or concrete/pavement. See Appendix II), as soil compaction due to urban infrastructure can impact the ability of the roots to grow (Saebo et al., 2003). The site characteristics were determined based on a visual assessment. Based on the assumption that the root system extends to roughly the same width as the crown, the visual assessment was determined to the full extent of the crown (Smith, 1964).
Distance to nearest building	The distance to the nearest building, as well as the height to the nearest building were recorded to determine the protection for the tree from the building (Kontogianni et al., 2011).
Elevation and distance to coast	The elevation and the distance to the coast were calculated to determine the amount of wind exposure received by each tree. Trees on the lee side of rounded hills and at higher elevations are typically more prone to windthrow and exposure (Stathers et al., 1994). Using the location of the 100 trees on GIS, the elevation and proximity to the coast were determined.

As the literature is unclear about the relative importance of each trait in contributing to a tree's windthrow vulnerability, all characteristics were weighted equally in their contributions to the index. The vulnerability index for each tree was calculated at the sum of all scores (Table 3). Once the vulnerability index was created, it was applied to each of the 100 urban street trees. Using the locations of the trees, and the neighbourhood divisions (Figure 1), the relative vulnerability of the trees in each neighbourhood was determined using the associated tree scores.

Table 3 Transformation of tree data to 0-1 categories for incorporation into the vulnerability index.

Trait	Data Associated with Score Assignments		
Score	0.0	0.5	1.0
Genus	linden, oak	maple, beech	elm
Distance to Coast (m)	>= 1200	600 to 1199	0 to 599
Elevation (m)	0 to 33.52	33.52 to 63.10	> 63.10
Height/DBH* (m/cm)	0.0 to 0.20	0.21 to 4.99	> 0.50
Tree Height - Building Height (m)	< 0	1 to 9	>= 10
Crown Width (m)	0 to 7.5	7.6 to 15.0	>= 15.0
Pruning	heavily	slightly	none
Root Structure	none showing	stacked	stacked and exposed

* only for trees >= 10 m tall

3.4 Step-by-Step Methods

3.4.1 Determining the Tree Location Based on Quota Sampling

The Peninsula was split into ten sections, and ten trees were sampled from each section. The method of selection was quota sampling, as the sample area was broken down in to ten categories and then samples were collected randomly within each of the categories (Moser & Stuart, 1953). This was not full random sampling, as the entire sample area was broken down into separate sections (Moser & Stuart, 1953).

3.4.2 Tree Data Collection

Using a data collection sheet and field protocol (see Appendix I and II respectively), the individual tree data were collected. The field protocol outlines the specific steps for acquiring the information on each individual tree. Each tree was given an identification number on a city map so it can be located at a later time. In addition to the map, the street on which it was located was identified, the nearest cross street, the side of the street that the tree was located, facing a certain direction (north, south, east or west), as well as the number of trees that were between the intersection and the randomly selected tree in order have the exact position located.

Once located, the tree was identified based on genus using tree identification based on bark, leaves (if present), and crown shape (Farrar, 1995). The diameter at breast height was measured using a malleable measuring tape; due to the fact that some trees are on a slanting hill, etc., the diameter at breast height was always collected at the point where the base of the trunk met the grass/gravel/concrete. The site location was based on a division of grass to concrete to gravel ratio; a visual examination of the conditions of the ground surrounding the tree was conducted, to the extent of the root system (based on the crown width) (Smith, 1964). The site location was divided into thirteen sections (see Appendix II for site characteristics in Field Protocol). The data collection was completed with two people, and therefore an agreement was made as to which site characteristic was most representative of the ground ratio of grass, gravel and/or concrete.

Using a compass, the directions were determined, and then the crown width was measured (in meters) in a North-South and West-East direction. The shapes are restricted to a general triangular or round shape (Farrar, 1995); for the tree to be asymmetric, it had to be missing the majority of an entire side (being pruned for eliminating exposure to the power lines, or covering a road). In addition to the crown shape and size, it was noted whether there was a conflict with a power line (either near the crown of the tree, or as in most cases, running straight through the centre of the tree).

The height of the tree, and the height of the closest building were recorded using a clinometer. The distance to the nearest building was calculated in meters using a measuring tape. For residential houses, this distance was calculated to the base of the homes' front stairs. Any additional comments were made as to the general condition of the tree; whether it seemed healthy, whether it was missing any large branches, whether it was on a mound (the roots were stacking), etc. were noted.

Once all the data was collected and entered into a digital spreadsheet, the vulnerability index was calculated for each tree. The data were also uploaded onto a GIS map to see the distribution of the trees across the Peninsula (Figure 2). The indices for the trees in each of the ten neighbourhoods were averaged to determine which neighbourhoods were more at risk than others. Comparisons were drawn based on individual tree vulnerability, as well as neighbourhood vulnerability, and the specific characteristics that potentially make one tree more vulnerable than others.

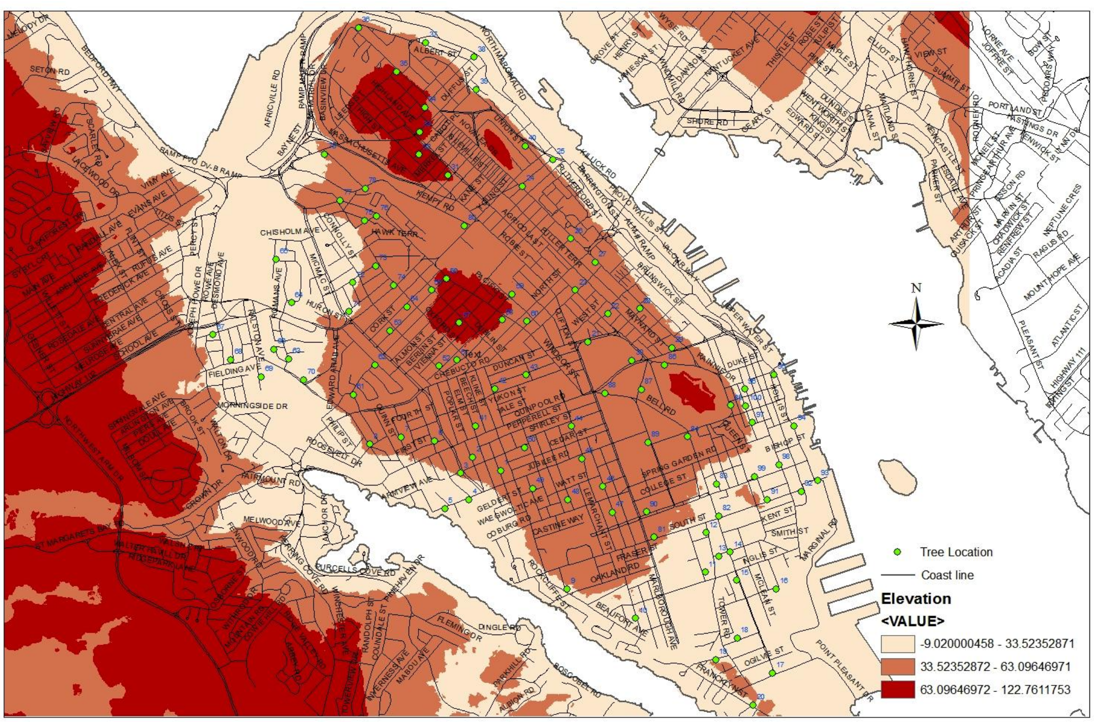

Figure 2 The elevation model, along with the individual placement of one hundred trees on the Halifax Peninsula.

3.5 Limitations and Assumptions

There are significant limitations to this study, time and individual site locations being the two most notable. Firstly, the data were collected during the months of November and December, when most to all of the leaves had fallen off the trees. While crown density can be used as a determinant of a tree's susceptibility to windthrow (Foster, 1988), this could not be measured due to the season and lack of leaves. In addition, if the leaves are missing, the tree was identified based on bark and shape alone. With younger trees, bark identification can be difficult as the bark has not differentiated as much as in older, more mature bark (Farrar, 1995). Another method altered due to time constraints was determining the soil characteristics. While a grid system could have been implemented to calculate the percentage of grass/concrete /pavement/gravel in an area, due to the fact that this study was taking place in an urban environment, it was both too time-consuming as well as dangerous to lay out a grid to the full extent of the root system. In addition, the level of rot inside the tree trunk was not measured.

Individual trees were sampled across the entire Peninsula. Limitations were encountered when the randomly selected trees were located right next to a fence, where the crown width and distance to the nearest building could not be measured. In this case, an assumption was made as to the distance from the tree to the building, and the crown width was determined from the other side of the crown to the trunk (half a measurement). The assumption made with the crown size was that the crown was symmetrical, and that there was no significant difference in the length of the crown on either side of the trunk. Finally, if the nearest building was located across a very busy intersection, or was much too far away to calculate (for example, individual trees sampled on Robie St., on the side of the Commons), the distance to the nearest building was estimated. However, as the distance to the nearest building was to determine the wind protection (Kontogianni et al., 2011), the building would not be providing any direct protection from the wind.

A key assumption for the neighbourhood comparisons was that the sampled trees were representative of the whole population of street trees in each neighbourhood. Each tree has its own individual characteristics, and different stresses are exerted on different trees in different locations.

4. Results

4.1 Vulnerability Index Results (Individual Trees)

Based on the ratings of the individual trees from the vulnerability index, the lowest score was determined to be a 2, the highest a 7, and the average was a score of 4 with a standard deviation of 0.84 (See Appendix 3 for vulnerability index scores). Trees ranged from a few meters high, with a DBH of just over 10 cm, to being over twenty meters high, with a DBH of well over 90 cm.

4.2 Vulnerability Index Results (Neighbourhoods)

Neighbourhood 1, on the south shore of the Peninsula, had the highest average tree vulnerability index of 4.35, while neighbourhood 5, inland in the centre of the Peninsula, had an average index of 3.75 (Figure 3).

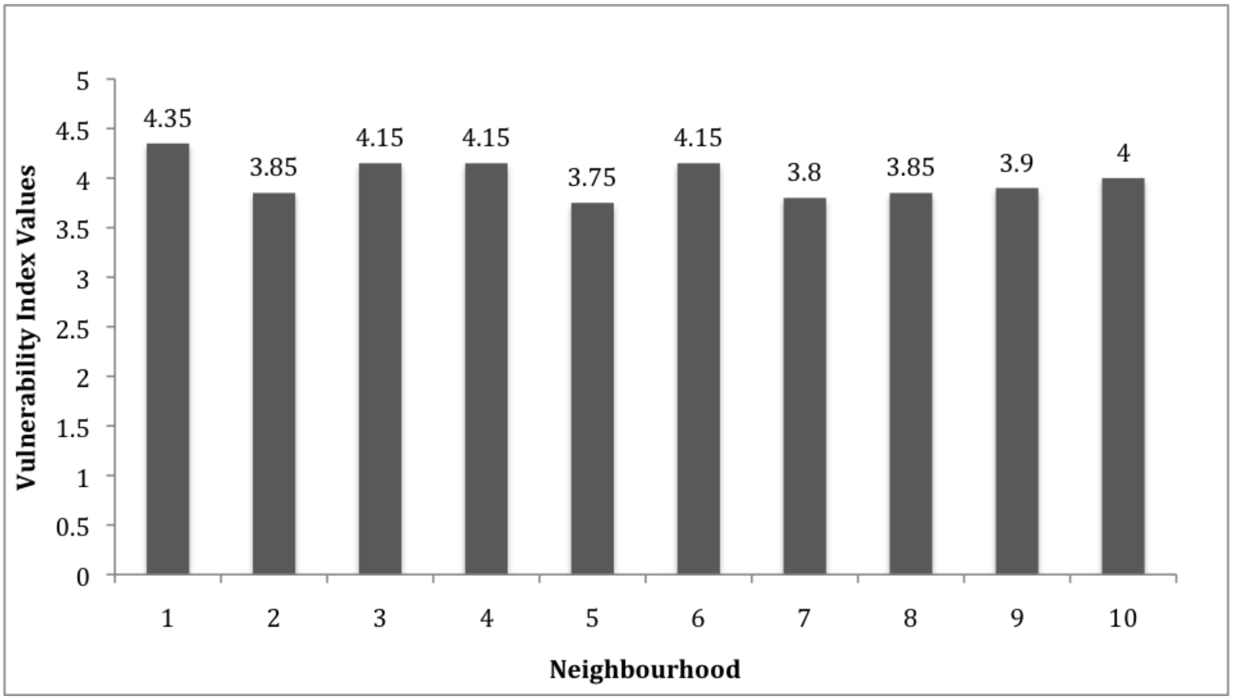

Figure 3 Neighbourhood vulnerability scores

4.2.1 Comparisons Between Neighbourhood 1 and 5

By summing the scores for each individual characteristic, the characteristics that contributed most to the vulnerability scores of the individual trees was determined. The vulnerability index scores are driven largely by the distance to the nearest coastline, whether the tree was slightly/heavily pruned, and average crown width for those trees were taller than the nearest building. Neighbourhood 1 exhibits high scores in these categories.

In turn, the neighbourhood exhibiting the lowest vulnerability index is Neighbourhood 5. This neighbourhood is located in the centre of the Peninsula, and entirely inland. Again, summing the component scores for the ten trees in this neighbourhood shows that, similar to Neighbourhood 1, the characteristic that exhibits the highest vulnerability score is the pruning. However, the second characteristic that contributes to the neighbourhood's vulnerability is the tree height minus the building height; the majority of the trees are taller than the nearest building. While Neighbourhood 1 has a greater vulnerability index total for the distance to the coast, Neighbourhood 5 is located farther away from the coast than Neighbourhood 1.

While the characteristics were all weighted equally, some characteristics contributed a great deal more to the vulnerability index outcomes than others. This was demonstrated when proportional contributions of the individual characteristics were summed (Figure 4).

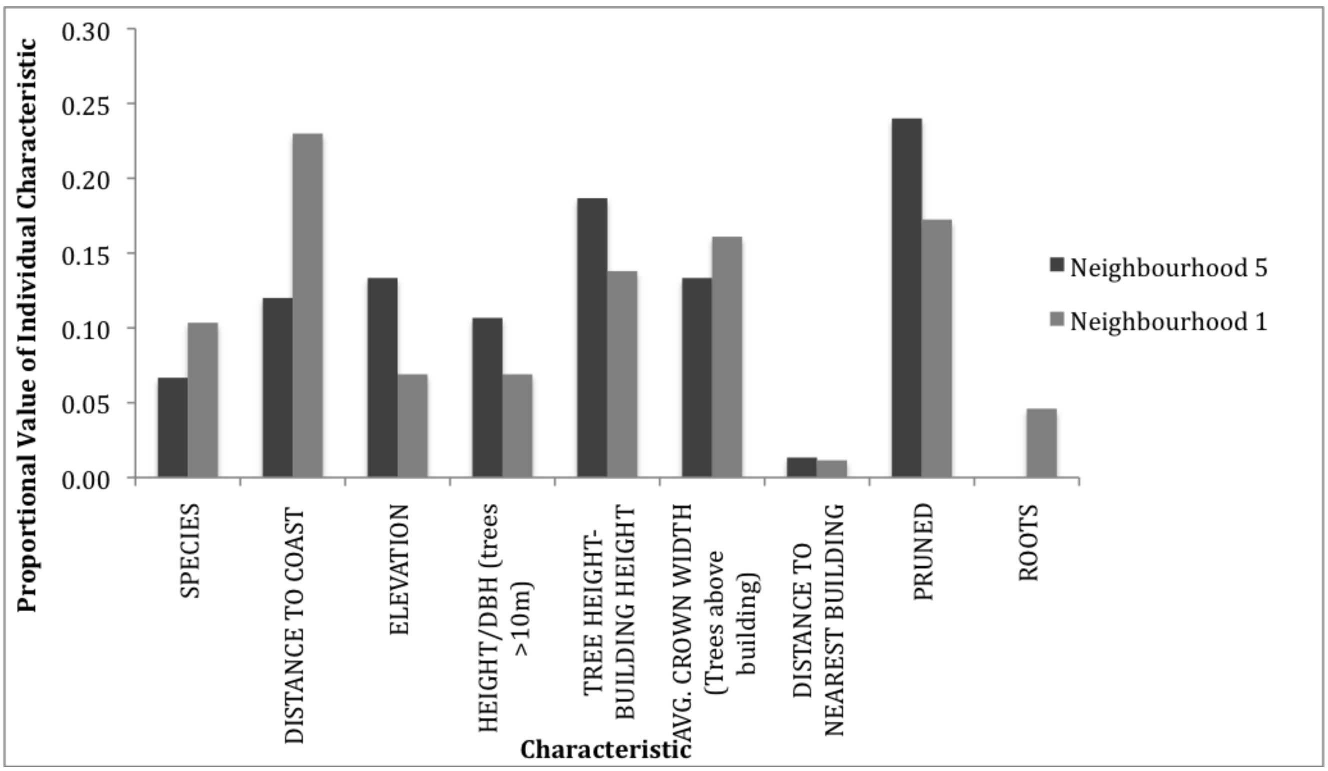

Figure 4 Individual characteristic contributions to the vulnerability index from Neighbourhood 1 and 5

Neighbourhood 1 has proportionally higher vulnerability index scores in genus, distance to coast, average crown width, and roots. Neighbourhood 5 exhibits proportionally higher vulnerability index scores in elevation, height over diameter, tree height minus building height, and slightly/heavily pruned.

4.3 Individual Characteristic Vulnerability Index Totals

The performances (0, 0.5 or 1) of the individual characteristics resulted in a variability of scores within the final vulnerability index. While the characteristics were all weighted equally, there was variability within the outcome of the amount of characteristics present throughout the sample of 100 trees (Figure 5).

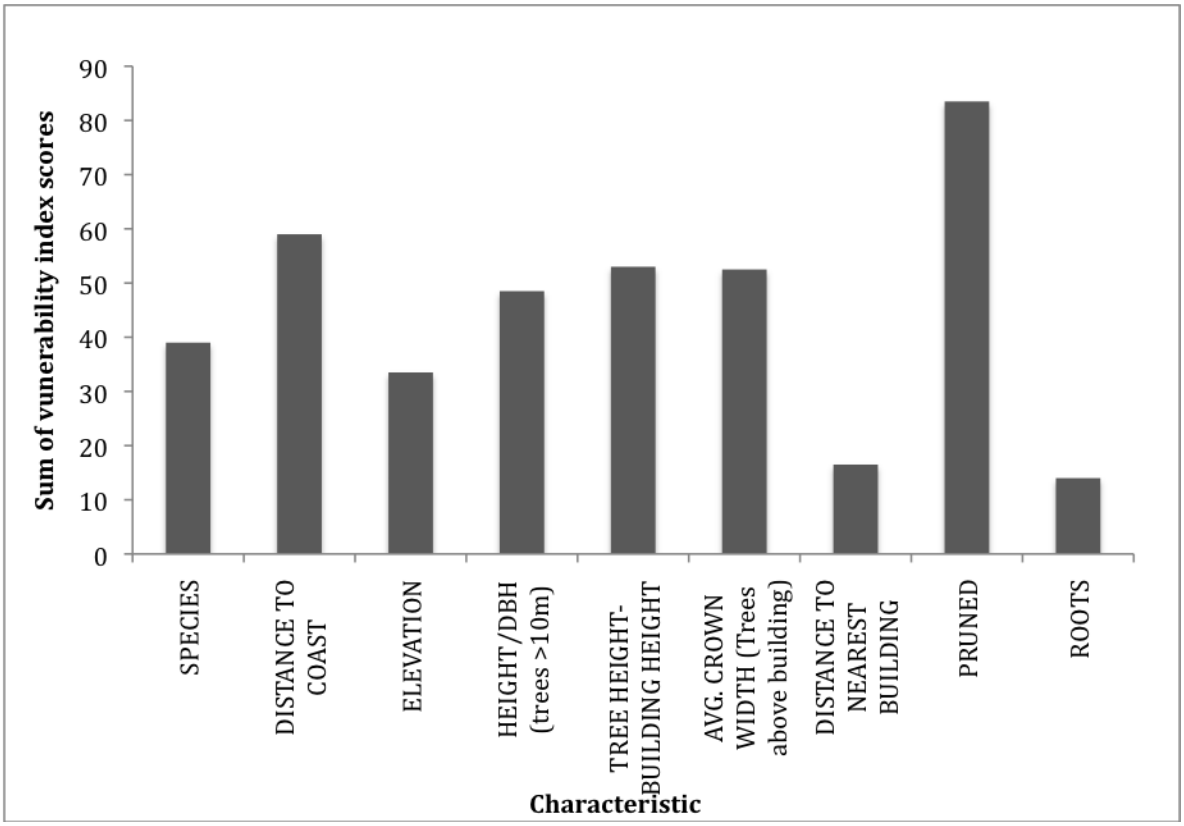

Figure 5 Individual characteristic vulnerability scores

The 'pruning' characteristic contributed the most to the final vulnerability scores (many trees were slightly or heavily pruned), followed by the distance to the coast (Figure 5). The lowest contributions were from trees that had stacked/exposed roots, and trees that were lower than the nearest building ('distance to nearest building'). From Appendix IV, it can be seen that a majority of the street trees were in contact with or near power lines. This increases the number of pruned trees, as the branches are cleared away from the nearby power lines.

Elms were deemed the most susceptible to windthrow (value of 1), maple and beech scored in the middle (0.5), and linden and oak least susceptible (0) in the vulnerability index. Averaging the results of the vulnerability index (all characteristics included), the elms had the highest average, followed by maple and beech, and finally linden and oak (Figure 6). There were 11 elm trees sampled, 4 beeches, 50 maples, 8 oaks and 27 lindens.

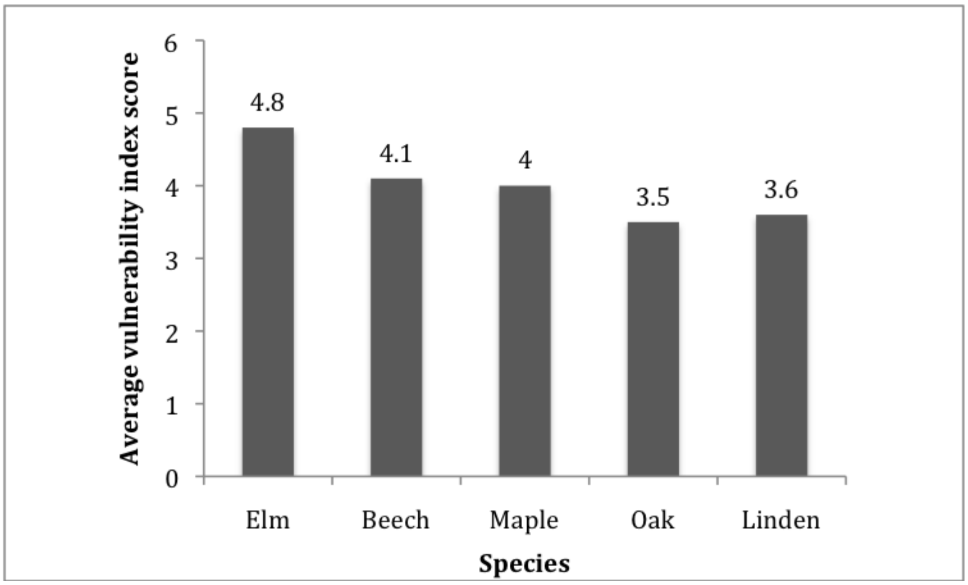

Figure 6 Average genus vulnerability score

While elm are the most susceptible to windthrow, there are many fewer than the linden and maple trees, which are more frequent throughout the Peninsula.

The average distances for the proximity to the coast were determined for all of the 10 neighbourhoods (Figure 7). The ‘distance to the coast’ characterisctic was the second highest contributor to the vulnerability index (Figure 5).

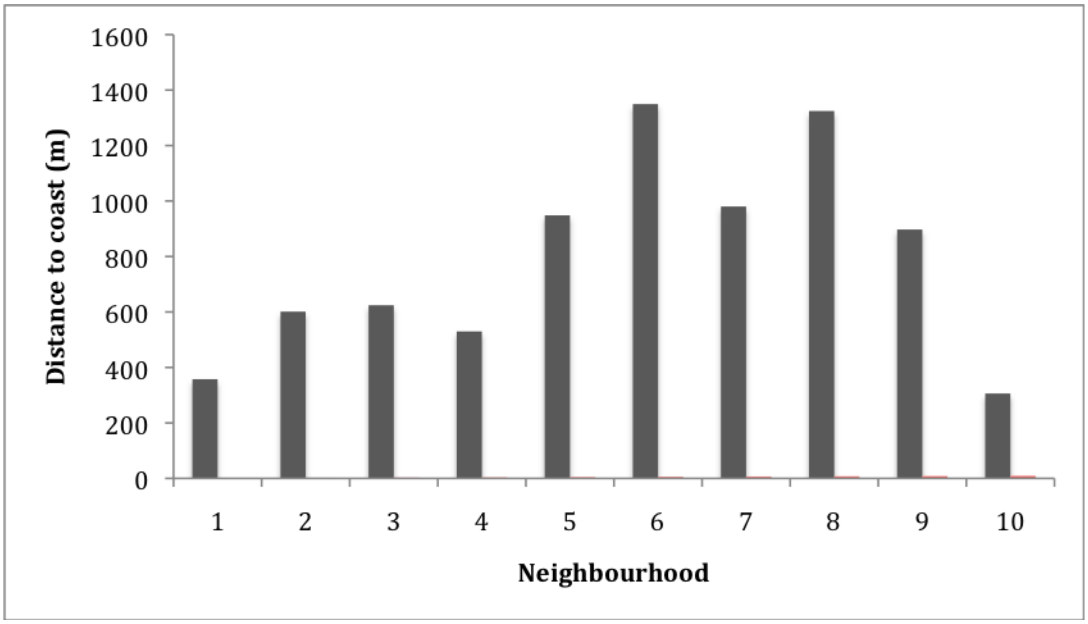

Figure 7 Average tree distance to coast (m) for each neighbourhood

4.4 Individual Tree Variability vs. Neighbourhood Variability

An ANOVA was used to determine the relationship between the neighbourhood vulnerability averages and the neighbourhood vulnerability averages within the neighbourhoods. The p-value was determined to be 0.85 (Table 4). The p-value determined by the ANOVA table (Table 4) was 0.85 which is less than the critical-F value of 1.9, demonstrating higher variability a. The null hypothesis is therefore false, and there is no variability between the neighbourhoods' vulnerability.

Table 4 ANOVA table for neighbourhood comparisons

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	10	43.5	4.35	1.725
Column 2	10	38.5	3.85	0.891666667
Column 3	10	41.5	4.15	0.336111111
Column 4	10	41.5	4.15	0.391666667
Column 5	10	37.5	3.75	0.291666667
Column 6	10	41.5	4.15	0.780555556
Column 7	10	38	3.8	0.455555556
Column 8	10	38.5	3.85	0.780555556

Column 9	10	39	3.9	0.877777778
Column 10	10	40	4	0.777777778

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.4725	9	0.385833333	0.527936146	0.850732539	1.985594964
Within Groups	65.775	90	0.730833333			
Total	69.2475	99				

5.0 Discussion

The ANOVA table demonstrates that there is not significant variability across neighbourhoods with respect to susceptibility of trees to windthrow on the Halifax Peninsula (Table 4). There exists only a slight trend within the vulnerabilities of the neighbourhoods based on their location. This trend is most notably based on their proximity to the coast: vulnerability increases the closer the trees are to the coast (Figure 4?). While there is some variability based on location, there is more variability among the individual trees in each neighbourhood (Table 4).

5.1 Assumptions

In this study, many simplifying assumptions were made and potentially important factors were not included. For example, root systems and tree density, although important factors affecting windthrow, were not calculated due to the fact that measurements of these features is either almost impossible above ground or beyond the scope of this study in terms of time and equipment. There was not enough information collected on the above-ground condition to make correlations about the underground root system. Although the type of root can be inferred from the type of genus, the variability of the root systems in an urban environment are such that inferences made regarding this factor would have been speculative and inaccurate. However, a root type and condition of the root system may be a useful addition to the vulnerability index if these limitations can be overcome. The only characteristic gathered about the root system was whether the roots were stacked or exposed. While the stacked roots do not give exclusive information on the condition of the entire underground root system, the restricted soil space of the urban street trees, demonstrated by the stacking, makes them more vulnerable to windthrow (Saebo et al., 2003). In addition, it can be seen in Appendix 3 that all trees that were less than 10 m tall were exempt from the height divided by diameter at breast height column. This is because vulnerability increases greatly above 10 m, but trees less than 10 m tall at not at great risk of windthrow based on height (Ruel, 1995). Taller trees are generally more susceptible to windthrow due to their exposure, despite the fact that they can develop some windfirmness through deepening and strengthening of roots (Stathers et al., 1994).

5.2 Spatial Patterns on the Halifax Peninsula Based on the Vulnerability Index

Neighbourhood 1, located on the southwest shore of the Halifax Peninsula, was determined to be the most vulnerable neighbourhood. This neighbourhood contains many older, large trees. The trees here are not vulnerable in account of the height-over-diameter variable. What makes this neighbourhood more vulnerable than the others is the close proximity to the coast (Figure 4), and the large crown sizes (as the trees are all taller than the closest building). In addition, the majority of the trees had not been pruned, and this increases the risk of windthrow due to the dense, large crowns (Stathers et al., 1994).

The fact that the neighbourhood is located on the southwest coast exposes it more frequently to stronger winds. This is because there are no surrounding buildings protecting the trees from the wind gusts; while there can also be a small wind-tunneling effect, the majority of the buildings are protected from the wind by the nearest buildings (Kontogianni et al., 2011). In contradiction, however, these trees survived the Hurricane Juan in 2003, and have been exposed to strong winds for many years. The main factor that makes them more vulnerable than others is simply the proximity to the coast and the fact that they are much taller than the nearest buildings, exposing the dense crowns to more wind (Niklas, 2002).

The least vulnerable neighbourhood, according to the vulnerability index, is Neighbourhood 5. As shown in the results, this is largely due to the greater distance from the coast (Figure 4), and not having any exposed or stacked roots. While the total shows that the neighbourhood is less vulnerable, the neighbourhood still has tall, wide-crown trees; the averages are just all slightly less than neighbourhood 1. Even though the vulnerability total for Neighbourhood 5 is less than Neighbourhood 1, the individual tree variability within the neighbourhood is still from 2.5 (least vulnerable) to 4.5 (most vulnerable).

A neighbourhood that could be considered an anomaly is Neighbourhood 2. According to the vulnerability index, this neighbourhood ranks 7th based on the index. However, what must be recognized is that this neighbourhood is located within very close proximity to Point Pleasant Park, where the majority of the damage occurred during Hurricane Juan (Halifax Regional Municipality, 2012). The majority of the trees in this area are short, with crowns that are not very wide or dense.

5.3 Individual Tree Vulnerability Index Variability

There is more variability among trees within a neighbourhood (using tree-by-tree indexes) than among neighbourhood, using mean indexes (Table 4). The lowest-index tree scored a 2, and the highest a 7. These two trees are located in the same neighbourhood, which demonstrates that there is much variability of trees' vulnerabilities within each neighbourhood (Table 4). This variation within neighbourhoods lowers the overall vulnerability of the neighbourhoods, as there is such great diversity of vulnerabilities within each neighbourhood (Saebo et al., 2003). This should mean that a storm capable of blowing trees over should not decimate all the trees in a neighbourhood.

As a generalization, those trees scoring 2-3 on the vulnerability index are the least vulnerable, those scoring 3.5-4.5 are at medium risk, and those above 5 are the most at risk to being windthrown. The trees calculated to have the highest vulnerabilities are located across the Peninsula, and not concentrated in any one neighbourhood. Therefore, it seems safe to assume that all neighbourhoods are more or less equally vulnerable, but there are certain trees within each one that are of most concern.

5.4 Variability Within Individual Tree Characteristics

Based on data from the one hundred trees, it is clear that some characteristics contributed more to the vulnerability index outcomes than others. Pruning, for example, was the highest overall contributor to the index, while distance to nearest building was the lowest contributor (Figure 5). However, because factors are measure in different ways, for example, pruning as a categorical measure of three options and distance to building as a continuous ratio measurement, factor contribution to the index will remain elusive as long as the index continues to be an amalgamation of different measures. In this regard, a full factor analysis may be needed here to gain further insights, for such analysis was beyond the scope of this study. A bigger sample size may also be needed to undertake this.

While the root system was not examined, the roots play a large part in trees' windfirmness. As trees grow in response to their changing environment, stems and roots may thicken in proportion to the additional winds or gravity that they must withstand (Shaw et al., 2003). Root systems were not measured on the Peninsula, as no underground measurements were made.

5.5 Topography

Topography affects the risk of windthrow, as the higher the tree, the more there is a chance of being exposed to strong winds (Kane, 2008). Trees on rounded hills are more susceptible to increased velocity and turbulence. However, it depends on the direction of the prevailing winds, as those on the lee side slopes are more at risk (Stathers et al., 1994). As the direction of the prevailing winds changes between seasons, the regions most at risk would change with the different wind directions. Generally, Neighbourhoods 4 and 9, which include the highest points on the Peninsula, would be most at risk to turbulent winds. These neighbourhoods are also at risk of having trees susceptible to windthrow. However, based on the results of the Neighbourhood totals, neither Neighbourhood 4 nor 9 had significant vulnerability totals than the other regions on the Peninsula. The 'elevation' characteristic did not contribute much to the final vulnerability index totals.

5.6 Crown area

The crown area determines the amount of drag force that the tree is exposed to, and taller, individual trees are exposed to more wind and therefore are more susceptible to windthrow (Stathers et al., 1994). The literature states that taller and denser crowns are more vulnerable to windthrow than smaller, open-grown crowns. As a result, pruning a tree can greatly diminish the windthrow vulnerability of a tree by reducing the density of the crown (Kane & Smiley, 2006).

5.7 Genus

The genus characteristic did not contribute as much to the final vulnerability index as other characteristics such as pruning, tree height minus building height, average crown width, and distance to coast. This is because the dominant tree on the Halifax Peninsula was found to be maples and lindens (HRM UFMP, 2012), which are rated at 0.5 and 0 respectively on the vulnerability index scale. However, based on the notion that tall, more cylindrical trees sway more in the wind than shorter, conical trees (Stathers et al., 1994), the elms, which are taller, and have wide, branching crowns, will be the individual trees most at risk to windthrow. The elm trees, which have wide, branching crowns, are the most susceptible to windthrow according the vulnerability index (Figure 6).

5. 8 Relationships with Findings of Previous Works

As shown in the literature review, no work has been reported on pre-storm data collection of urban street trees. The vulnerability index was created based on a compilation of scholarly works, predominantly post-storm data analysis from across the globe. While some works based their findings primarily on specific characteristics, such as height, genus, canopy position, and amount of damage (Foster, 1988), this study analyzed nine such characteristics.

The most vulnerable neighbourhoods were determined, but the average indexes ranged from 3.75 to 4.35 out of a potential 9.0, suggesting that none of the neighbourhoods was significantly more vulnerable than others. The results show that individual trees may pose more of a threat than specific neighbourhoods, as the variability within the neighbourhoods was greater than the variation among neighbourhoods (Table 4). While this study only provided an analytical response to possible future storminess, the implications for many other fields of study could propel further work to be done on the vulnerability of urban forests to windthrow.

5.9 Significance

While it was determined that there are few differences among the neighbourhoods, there is great variability in the vulnerability of trees on the Halifax Peninsula. At the individual tree level, it can be concluded that the majority of wide crowned, tall, non-pruned, elm trees with stacked and exposed roots are the most susceptible to windthrow. Those located at higher elevation and nearer to the coast are also at greater risk. While there were no pre-storm data collected for the Halifax Peninsula previously, this study provides a general idea on the state of the urban street trees on the Peninsula. While the future storms are impossible to predict, there is now a beginning to a reasonably comprehensive account of the threatened zones/trees.

The point of this study was to develop a vulnerability index that was informed by field information. Thus, little inference can be made about the total street tree population in the HRM. Sample significance and effect was not the focus of this study. The focus was to explore a population that would contribute to the vulnerability index; not referring to a hypothesis based statistical analysis of the representativeness of the sample to the population as a whole. Nonetheless, I believe that the index can be applied to a more significant sample in the future and thus try and approach the vulnerability to windthrow of the total population of street trees of HRM.

6.0 Conclusion

6.1 What was Researched

The study set out to determine the susceptibility of trees on the Halifax Peninsula to windthrow, and potentially increasing storminess in Atlantic Canada. The Peninsula's street trees were measured to get a general idea of the relative windfirmness of the urban forest in Halifax's urban core. The study sought to provide a base set of information on the condition of the trees, and which neighbourhoods/zones were most at risk to windthrow in the future. The research questions that were answered are:

1. What are the urban forest sites on the Halifax Peninsula that are the most vulnerable to damage in higher winds?

a. What are the specific tree characteristics that make them the most vulnerable to windthrow (using a vulnerability index), as collected through expert opinion and a literature review?

b. Based on the characteristics that make them more vulnerable (above), what genus of tree is the most vulnerable?

c. How are these vulnerable trees distributed, and therefore what are the most vulnerable neighbourhoods?

6.2 Main Findings of the Study

The results suggest that the characteristic that contributed the greatest number of points to individual tree vulnerabilities was whether the tree was pruned, the distance to the coast, average crown area, and tree height minus building height. While these characteristics were not weighted any differently, the results show that a large number of the trees were pruned, were relatively close to the coast, had larger than average crown areas, and were taller than the nearest buildings (and therefore had less protection from the buildings).

The most vulnerable trees on the Peninsula (with a vulnerability index score of 5+) were located all across the Peninsula, and were not restricted to certain zones. These trees were found to have height/diameter at breast height proportions that suggest that they have grown tall, without the DBH growing accordingly. In addition, they are taller than the nearest building, are relatively close to the coast, and at higher elevation – these trees received the highest scores on the vulnerability index, identifying them as most susceptible to windthrow.

While predictions stated that the most vulnerable neighbourhoods would be elevated and on the coast, there was not a significant variability within the neighbourhood vulnerabilities. The most vulnerable Neighbourhood was 1, and the least vulnerable Neighbourhood was 5, with scores of 4.35

and 3.75 respectively. The variability among neighbourhoods was not as great as the variability among the individual trees (Table 4). There was no previous documentation on the windthrow vulnerability of trees on the Halifax Peninsula; therefore, no comparisons can be drawn between previous findings and these results. However, the notion that Neighbourhood 1 is the most vulnerable aligns with previous work, as it is a coastal region, the trees are relatively large, and the buildings are shorter than the tree crowns (Escobedo et al., 2009; Kane., 2008; Kontogianni et al., 2011; Moore & Maguire, 2004).

Based on the statistical ANOVA test (Figure 4), it was determined that the variability within a neighbourhood was greater than between neighbourhoods. This suggests that the most vulnerable trees are not located in one specific region on the Peninsula, but scattered throughout.

6.3 Limitations and Assumptions

Notably, as the study was conducted throughout the fall and winter, the crowns of the deciduous trees did not have any leaves. This made it difficult to make accurate assessments of crown density and area. Only one hundred trees were sampled. The goal of this study was to develop an exploratory approach in creating the vulnerability index, and not proving the statistical significance for the HRM as a whole. It was assumed throughout the project that the root system would not be analyzed for the final vulnerability index. The assumption was also made that the hundred trees that were analyzed were representative of the entire urban street tree population, but not the HRM as a whole as the Peninsula's urban forest only represents a fraction of the total (HRM UFMP, 2012).

6.4 Implications

This study was limited to data collection on the trees to determine the susceptibility to windthrow. However, future studies could analyze the more vulnerable trees and neighbourhoods, to determine what the specific locations are throughout the Peninsula where trees are more vulnerable to windthrow. In the event of a severe storm in the future, there is now a general knowledge on the state of the street trees on the Peninsula. Debris analysis could be cross-referenced with the pre-storm data, and compare what trees and neighbourhoods were more susceptible than others. The vulnerability index used on the Peninsula can be applied to other regions, and draw comparisons with the Halifax Peninsula, and other areas throughout Canada (particularly coastal regions).

References

Barry, P. J., C. Doggett, R. L. Anderson, & K. M. Swain Sr. (1993). *How to evaluate and manage storm-damaged forest areas*. Atlanta, GA: Management Bulletin R8-MB 63 of the USDA Forest Service, Southern Region. Retrieved December 2012.

Carreiro,M.M. (2008). Introduction: The growth of cities and urban forestry. In: Carreiro,M.M.; Song,Y.C.; Wu,J. (Ed). *Ecology, planning, and management of urban forests: International perspectives,* Springer: New York, pp 2-9.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr & P. Whetton. (2007). Regional climate projections. In Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Ed.), *Climate change 2007: The physical science basis. contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change* (pp. 887-892). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. Retrieved December 2012 from (www.ipcc.ch).

Coder, K. (2007). *Storm Wind Loads on Trees*. Georgia: Outreach Publication.

Duryea, M. L., Blakeslee, G. M., Hubbard, W. G., & Vasquez, R. A. (1996). Wind and trees: A survey of homeowners after hurricane Andrew. *Journal of Arboriculture. 22*(1), 44.

Duryea, M. L., Kampf, E., & Littell, R. C. (2007). Hurricanes and the urban forest: I. Effects on southeastern United States coastal plain tree genus. *Arboriculture and Urban Forestry, 33*(2), 83-97..

Dwyer, John. F., E. McPherson, H. W. Schroeder & R. A. Rowntree. (1992). Assessing the benefits and costs of the urban forest. *Journal of Arboriculture, 18*(5), 227-234..

Escobedo, F. J., Luley, C. J., Bond, J., Staudhammer, C., & Bartel, C. (2009). Hurricane debris and damage assessment for Florida urban forests. *Arboriculture and Urban Forestry, 35*(2), 100-106.

Everham, E. M., & Brokaw, N. V. L. (1996). Forest damage and recovery from catastrophic wind. *The Botanical Review, 62*(2), 114-149..

Farrar, J. (1995). *Trees in Canada* (13th ed.). Ottawa: Canadian Forest Service.

Forestry Suppliers, I. (2011). *How to use a Clinometer.* Retrieved December, 2012, from http://www.gaaged.org/Browseable_Folders/Power_Points/Forestry%20Natural%20Resources%20and%20Wildlife/How_to_Use_a_Clinometer.pdf

Foster, D. R. (1988). Genus and stand response to catastrophic wind in central New England, U.S.A. *British Ecological Society, 76*(1), 135-151..

Francis, J. K., & Gillespie, A. J. R. (1993). Relating gust speed to tree damage in Hurricane Hugo, 1989. *Journal of Arboriculture, 19*(6), 368-373..

Grace, J. (1977). Plant Response to Wind. *Department of Forestry and Natural Resources*. (22). 71-88. Retrieved December 2012.

Halifax Regional Municipality. (2012). *Urban Forest Master Plan (UMFP).* 2-13. Retrieved December 2012.

Hauer, R. J. (1992). *Urban Tree Risk Management: A Community Guide to Program Design and Implementation.* St Paul: USDA Forest Service (5).

Jim, C. Y. (2004). Evaluation of heritage trees for conservation and management in Guangzhou City (china). *Environmental Management, 33*(1), 74-86..

Kane B. (2008). Tree failure following a windstorm in Brewster, Massachusetts, USA. *Urban Greening Urban Forestry and Urban Greening, 7*(1), 15-23. Retrieved December 2012.

Kane, B. & Smiley, E. T. (2006). Drag coefficients and crown area estimation of red maple. *Canadian Journal of Forest Research*. 36(8). Retreived March 2013 from http://web.ebscohost.com /ehost/detail?sid=be177207-113d-4f1b-b2cf-230beb90c6ee%40sessionmgr112&vid=1& hid=113&bdata= JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=eih&AN=22486308

Kontogianni, A., Tsitsoni, T., & Goudelis, G. (2011). An index based on silvicultural knowledge for tree stability assessment and improved ecological function in urban ecosystems. *Ecological Engineering, 37*(6), 914-919. Retrieved December 2012.

Moore, J. R., & Maguire, D. A. (2004). Natural sway frequencies and damping ratios of trees: Concepts, review and synthesis of previous studies. *Trees - Structure and Function, 18*(2), 195-203. Retrieved December 2012.

Moser, A. & Stuart, A. (1953). An Experimental Study of Quota Sampling. *Journal of the Royal Statistical Society*. 4(116). 349-405. Retrieved March 2013. Retrieved December 2012.

Moser, W. K., & Nelson, M. D. (1992). Windstorm damage in boundary water canoe area wilderness (Minnesota, USA): Evaluating landscape-level risk factors. *Baltic Forestry, 15*(2), 248-254. Retrieved December 2012.

Nova Scotia Museum of Natural History. (1996). T5.2 Nova Scotia's Climate. *Natural History of Nova Scotia*. 1. 97-103. Retrieved December 2012 from http://museum.gov.ns.ca/mnh/nature/nhns/t5/t5-2.pdf.

Niklas, K. J. (2002). Wind, size, and tree safety. *Journal of Arboriculture, 28*(2), 84-93.

Nilsson, K., Randrup, T. B., & Wandall, B. M. (2000). Trees in the urban environment. *The Forest Handbook, 1*, 347-361..

Perrings, C., Folke, C., & Maler, K. (1992). The ecology and ecnomics of biodiversity loss: The research agenda. *Ambio, 21*(3), 201-211..

Rice, J., & Rice, J. S. (2012). Debt and the built urban environment: Examining the growth of urban slums in the less developed countries, 1990-2010. *Sociological Spectrum, 32*(2), 114-137. Retrieved December 2012.

Ruel, J. (1995). Understanding windthrow: Silvicultural implications. *The Forestry Chronicle, 71*(4), 434. Retrieved December 2012.

Sæbø, A., Benedikz, T., & Randrup, T. B. (2003). Selection of trees for urban forestry in the nordic countries. *Urban Forestry & Urban Greening, 2*(2), 101-114. Retrieved December 2012.

Sani, L., Lisci, R., Moschi, M., Sarri, D., Rimediotti, M., Vieri, M., & Tofanelli, S. (2012). Preliminary experiments and verification of controlled pulling tests for tree stability assessments in mediterranean urban areas. *Biosystems Engineering, 112*(3), 218-226. Retrieved December 2012.

Shaw, J., R.B. Taylor, D.L. Forbes, S. Solomon, D. Frobel, G. Parkes, & C.T. O'Reilly. (2003). Climate change and the canadian coast. *Fisheries and Oceans Canada*. Retrieved December 2012.

Smith, J.H.G. (1964). Root spread can be estimated from crown width of Douglas fir, Lodgepole pine, and other British Columbia tree genus. *The Forestry Chronicle, 40*(4), 456-473. Retrieved December 2012.

Stathers, R. J., Rollerson, T. P., & Mitchell, S. J. (1994). *Windthrow handbook for British Columbia forests*. Victoria, B.C.: British Columbia Ministry of Forestry. Retrieved December 2012.

Thompson, B. K., Escobedo, F. J., Staudhammer, C. L., Matyas, C. J., & Qiu, Y. (2011). Modeling hurricane-caused urban forest debris in Houston, Texas. *Landscape and Urban Planning, 101*(3), 286-297. Retrieved December 2012.

Thompson, K. R., Bernier, N. B., & Chan, P. (2009). Extreme sea levels, coastal flooding and climate change with a focus on Atlantic Canada. *Natural Hazards, 51*(1), 139-150. Retrieved December 2012.

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Appendix I Data Collection Sheet

Data Collection Sheet Date Name		Data Collection Sheet Date Name	
ID Number		ID Number	
Tree (Common Name)		Tree (Common Name)	
Location 1. Street		Location 1. Street	
Location 2. (N-S intersection)		Location 2. (N-S intersection)	
Location 3. (Side of the road)		Location 3. (Side of the road)	
Location 4. (Tree # N-S)		Location 4. (Tree # N-S)	
DBH (cm)		DBH (cm)	
Site Conditions (1-5)		Site Conditions (1-5)	
Crown Size (N/S) in m		Crown Size (N/S) in m	
Crown Size (W/E) in m		Crown Size (W/E) in m	
Crown shape (R/T and S/A)		Crown shape (R/T and S/A)	
Distance to nearest building (m)		Distance to nearest building (m)	
Height of nearest building (m)		Height of nearest building (m)	
General Condition (healthy, dead/dying)		General Condition (healthy, dead/dying)	

Power Line conflict? (Y/N)		Power Line conflict? (Y/N)	
Height of tree (m)		Height of tree (m)	

Appendix II Field Protocol

1. Arrive at site.
2. Orient on map (have rough street layout on map to mark location/tree identification).
3. [Individual tree data collection]
    a. Tree identification and location (on map, as well label with number)
    b. Genus, by common name (genus will be added later)
    c. Diameter at breast height (using a measuring tape)
    d. Height (using a clinometer)
    e. Site conditions (visual assessment): 5 categories
        i. All grass
        ii. Mostly grass, some concrete/pavement
        iii. Mostly grass, some gravel
        iv. Mostly grass, some concrete/pavement and some gravel
        v. Half grass, half concrete/pavement
        vi. Half grass, half gravel
        vii. Some grass, mostly concrete/pavement
        viii. Some grass, mostly gravel
        ix. Some grass, some pavement/concrete and mostly gravel
        x. Some grass, some gravel, and mostly pavement/concrete
        xi. All concrete/pavement
        xii. All gravel
        xiii. Half gravel, half concrete/pavement
    f. Crown size (the distance (in m) that the crown would cover if vertical lines were traced to the ground)
    g. Crown shape
        i. Round vs. Triangular
        ii. Symmetric vs. Asymmetric
    h. Distance (in m) to nearest building
    i. Height difference between the tree and the nearest building, using a clinometer.
    j. Notes on any particular deformities/decay?
4. Each measurement should take approximately 5-7 minutes.
5. Will be repeated for all randomly selected neighbourhoods (approximately 25 trees multiplied by 10 regions = 250 trees sampled).

Appendix III Vulnerability Index for Characteristics from Sampling

ID Number	Genus	Distance to Coast	Elevation	Height/DBH (trees >10m)	Tree Height – Building Height	Average Crown Width (Trees above building)	Distance to Nearest Building	Pruning	Root Structure	FINAL
1	1	1	0.5	0.5	1	1		1	0.5	6.5
2	0.5	1	0.5	0.5	0.5	1		1	0	5
3	0	1	0.5	0.5	0.5	0.5		1	0	4
4	0	1	0	0.5	1	0.5		0.5	0	3.5
5	0	1	0		0		0.5	0.5	0	2
6	1	1	0.5	0.5	1	1		1	0	6
7	0.5	1	0.5	0	0.5	1		0.5	0	4
8	0.5	1	0.5	0	0.5	0.5		0	0.5	3.5
9	0.5	1	0	0	0.5	0.5		1	0.5	4
10	0.5	1	0	0.5	0.5	1		1	0.5	5
11	1	0.5	0	0.5	0.5	0.5		1	0	4
12	1	0.5	0	0.5	0		0.5	0	0	2.5
13	1	0.5	0	0.5	1	1		1	0	5
14	0	0.5	0		0		0.5	1	0	2
15	0.5	0.5	0	0	0.5	1		1	0.5	4
16	0.5	1	0		0.5	0.5		1	1	4.5
17	0.5	1	0	0	0.5	0.5		0	1	3.5
18	0	1	0	0.5	1	1		1	0	4.5
19	0.5	1	0		0.5	0.5		1	1	4.5
20	0.5	1	0	0.5	0		1	1	0	4
21	0	0.5	0.5	0.5	0.5	1		1	1	5
22	0.5	0.5	0.5	0.5	0.5	0.5		0.5	0	3.5
23	0	0.5	0.5	0.5	1	0.5		1	1	5
24	0	1	0.5	0	0	0.5	0.5	1	0	3.5
25	0.5	1	0	1	0.5	0.5		1	0	4.5
26	0	1	0.5	0.5	1	1		0.5	0	4.5
27	0.5	1	0.5	0.5	0.5	0.5		0.5	0	4
28	0.5	1	0.5	0.5	0		0.5	1	0	4
29	0.5	1	0.5		0		0.5	1	0	3.5
30	0	0.5	0.5	0.5	0.5	1		1	0	4
31	0.5	0.5	1	0.5	0.5	0.5		0.5	0	4
32	0	0.5	1	1	0.5	0.5		0.5	0	4
33	0	0.5	1	0.5	0.5	0		0.5	0	3
34	0.5	0.5	1	0.5	0.5	0.5		1	0.5	5
35	0.5	0.5	1	0.5	0.5	0.5		1	0	4.5
36	0.5	1	0.5	0.5	0.5	0.5		0.5	0	4
37	1	1	0	0.5	1	0.5		0	0	4
38	0	1	0	1	0.5	0		1	0	3.5
39	0.5	1	0	0.5	1	0.5		1	0.5	5
40	0	1	0.5	0.5	1	0.5		1	0	4.5
41	0.5	0.5	0.5	0.5	1	0.5		0.5	0	4
42	0	0.5	0.5	0.5	1	0.5		1	0	4
43	0.5	0	0.5	0.5	1	1		1	0	4.5
44	0	0.5	0.5	0.5	0.5	0.5		1	0	3.5

45	0.5	0.5	0.5	0.5	0.5	0.5		1	0	4
46	0.5	0.5	0.5	0	0.5	0.5		1	0	3.5
47	0	0.5	0.5		0		0.5	1	0	2.5
48	0	0.5	0.5	0.5	0.5	0.5		1	0	3.5
49	0	0.5	0.5	0.5	1	0.5		1	0	4
50	0.5	0.5	0.5	0.5	1	0.5		0.5	0	4
51	0.5	0	0.5		0		0.5	1	0	2.5
52	1	0.5	0.5	0.5	1	0.5		0.5	0.5	5
53	0	0	0.5	1	1	0.5		0.5	0	3.5
54	1	0	0.5	0.5	1	1		1	0	5
55	1	0	0.5	0.5	1	1		0.5	0	4.5
56	0	0	1	0.5	1	0.5		0.5	0	3.5
57	0.5	0	1	0.5	1	1		1	0	5
58	0	0	0.5	0.5	1	0.5		0.5	0.5	3.5
59	0.5	0.5	0.5	0.5	1	1		1	0	5
60	0.5	0	0.5	0.5	0.5	0.5		1	0.5	4
61	0.5	0.5	0.5	0.5	0.5	0.5		1	0	4
62	0	0.5	0.5	0.5	0.5	0.5		1	0.5	4
63	0.5	0.5	0	0.5	0.5	1		1	0.5	4.5
64	0.5	0	0	0.5	0.5	0.5		0.5	0	2.5
65	0	0.5	0	0.5	1	1		1	0	4
66	0.5	0.5	0	0.5	1	1		1	0	4.5
67	0	0	0	0.5	0.5	1		1	0	3
68	1	0.5	0	0.5	0.5	0.5		1	0.5	4.5
69	0.5	0.5	0	0.5	0		0.5	1	0.5	3.5
70	0.5	0.5	0	0.5	0		1	1	0	3.5
71	0.5	0	0	0	0.5	0.5		0.5	0	2
72	0	0	0	0.5	1	1		1	0	3.5
73	0	0	0.5	0.5	0.5	0.5		1	0	3
74	0.5	0	0.5	0.5	0.5	0.5		1	0.5	4
75	0.5	0	0.5	0.5	0.5	1		1	0.5	4.5
76	0.5	0	0.5	0.5	0.5	1		1	0	4
77	1	0.5	0.5	0.5	0.5	1		1	0	5
78	0.5	0	0.5	0.5	0.5	0.5		1	0	3.5
79	0.5	0.5	0.5	1	0		1	1	0	4.5
80	0	0.5	0.5	0.5	1	1		1	0	4.5
81	1	0.5	0.5	1	0		1	1	0.5	5.5
82	0.5	0.5	0	0.5	1	0.5		0.5	0	3.5
83	0.5	0.5	0	0.5	1	1		1	0	4.5
84	0.5	0.5	0.5	0.5	0		1	0.5	0	3.5
85	0	1	0.5	0.5	0		0.5	1	0	3.5
86	0	0.5	0.5	0.5	0.5	0.5		1	0	3.5
87	0.5	0.5	0.5	0.5	0.5	1		1	0	4.5
88	0.5	0.5	0.5	0.5	1	1		1	0	5
89	0	0	0.5	0.5	0		1	0.5	0	2.5
90	0	0.5	0.5	0.5	0		0.5	1	0	3
91	0.5	1	0	1	0.5	0.5		0.5	0	4
92	0	1	0	0.5	0		1	1	0	3.5
93	0.5	1	0	0.5	0		1	0.5	0	3.5

94	0	1	0	1	0		1	1	0	4
95	0.5	1	0	1	0		0.5	1	0	4
96	0.5	1	0		0		0.5	1	0	3
97	0	1	0	1	0		0.5	1	0	3.5
98	0.5	1	0	1	0		0.5	0.5	0	3.5
99	0.5	1	0	1	0.5	1		1	0	5
100	1	1	0	1	0.5	1		1	0.5	6

Appendix IV Categorical Raw Data Collection

ID Number	Tree Genus (Common Name)	General Condition	Power Line conflict? (Y/N)
1 (E)	Elm	stacked roots	Y
2 (F)	Maple	healthy	Y
3 (G)	Linden	healthy	N
4 (H)	Linden	trimmed at base	N
5 (I)	Linden	large branch cut	Y
6 (J)	Elm	healthy	Y
7 (K)	Maple	dead branches	Y, trimmed
8 (L)	Maple	stacked roots	Y, heavily pruned
9 (M)	Maple	roots stacked	Y
10 (N)	Maple	stacked roots	Y
11 (O)	Elm	healthy	N
12 (P)	Elm	heavily pruned	Y
13 (Q)	Elm	metal nailed in	Y
14 (R)	Linden	leaning towards st.	Y
15 (S)	Maple	stacked roots	N
16 (T)	Maple	exposed and stacked	N
17 (U)	Maple	stacked & exposed	Y, very pruned
18 (V)	Oak	barely any grass	N
19 (W)	Maple	stacked & exposed	Y, pruned
20 (X)	Maple	young	N
21 (a)	Linden	exposed	N
22 (b)	Maple	pruned	Y
23 (c)	Linden	stacked & no grass	Y
24 (d)	Linden	small bran. @ base	Y
25 (e)	Maple	healthy	Y
26 (f)	Linden	pruned	Y
27 (g)	Maple	pruned, young	N
28 (h)	Maple	healthy	Y
29 (i)	Maple	Young	N (but close)
30 (j)	Linden	some brn. Missing	N
31 (k)	Maple	pruned & young	Y
32 (l)	Oak	top R pruned	Y

33 (m)	Linden	branches cut	N
34 (n)	Maple	stacked&missing branches	Y
35 (o)	Maple	healthy	N
36 (p)	Maple	pruned	Y
37 (q)	Elm	many limbs cut	N
38 (r)	Linden	young	Y
39 (s)	Maple	trunk rot, stacked roots	Y
40 (t)	Linden	small maple grow. Beside	N
41 (i-)	Maple	half of side is pruned	Y
42 (ii)	Linden	healthy	Y
43 (iii)	Maple	healthy	Y
44 (iv)	Linden	leaning towards st.	Y
45 (v)	Maple	missing large branch	N, but close
46 (vi)	Maple	young	Y
47 (vii)	Oak	young	N
48 (viii)	Linden	slight lean towards street	N, but close
49 (ix)	Linden	healthy	Y
50 (x)	Maple	pruned	Y
51 (1)	Maple	young	Y (when taller)
52 (2)	Elm	pruned, stacked roots	Y
53 (3)	Linden	pruned on E side	Y
54 (4)	Elm	large growth above BH	N
55 (5)	Elm	pruned, missing lg. branch	N
56 (6)	Linden	branches pruned over road	N
57 (7)	Beech	healthy	N
58 (8)	Linden	stacked roots, pruned	Y
59 (9)	Maple	heathly	N
60 (10)	Maple	stacked roots	Y
61 (11)	Maple	large crack/gap	N
62 (12)	Oak	healthy, stacked roots	N
63 (13)	Maple	stacked roots	Y
64 (14)	Maple	pruned on sidewalk side	Y
65 (15)	Linden	healthy	N
66 (16)	Maple	healthy - branch missing	N
67 (17)	Oak	healthy	N
68 (18)	Elm	some fungus, stacked roots	N
69 (19)	Maple	missing brnch, stacked roots	Y
70 (20)	Maple	healthy	N
71 (21)	Maple	branches dying	Y, pruned
72 (22)	Linden	healthy	Y
73 (23)	Oak	few branches missing	N
74 (24)	Maple	stacked, some dead brnch	N
75 (25)	Maples	stacked, healthy	N
76 (26)	Maple	healthy	N
77 (27)	Elm	branches missing, many near bottom	Y
78 (28)	Maple	healthy	N
79 (29)	Maple	healthy	Y
80 (30)	Linden	healthy	Y

81 (31)	Elm	stacked, healthy	Y
82 (32)	Beech	dead branches	Y, pruned on S side
83 (33)	Beech	dead branches	Y
84 (34)	Maple	many branches missing	Y, pruned
85 (35)	Linden	healthy	N, lamp post
86 (36)	Linden	healthy	Y
87 (37)	Maple	branches growing low	Y
88 (38)	Maple	growths at base	N
89 (39)	Linden	pruned/dead branches	N
90 (40)	Linden	healthy	N
91 (41)	Maple	pruned	Y
92 (42)	Oak	healthy	N
93 (43)	Maple	pruned/healthy	N
94 (44)	Linden	young	N
95 (45)	Maple	young, healthy	N
96 (46)	Maple	dead branches, unhealthy	N
97 (47)	Oak	young, healthy	N
98 (48)	Beech	pruned	Y
99 (49)	Maple	dead branches	Y pruned
100 (50)	Elm	stacked roots, dying branches	N

Appendix V Numerical Raw Data Collection

ID	Tree Genus (Common Name)	Circumfe rece (cm)	Circumfe rence/3. 14	Height of tree (m)	Height /DBH	Site Conditions (i-xiii)	Average Crown Width in m	Crown width (N/S) in m	Crown width (W/E) in m	Crown shape (R/T and S/A)	Distance to Nearest Building (m)	Height of Nearest Building (m)	Height of Tree above Nearest Bldg (m)
1 (E)	Elm	270	86	23	0.27	vii	20.8	20.7	20.9	R & S	12.1	11	12.0
2 (F)	Maple	203	65	21	0.32	ii	18.2	17.3	19	R & S	14.1	15	6.0
3 (G)	Linden	232	74	17	0.23	v	12.4	14.1	10.7	T & S	14	8	9.0
4 (H)	Linden	244	78	19	0.24	x	11.1	10.5	11.6	T & S	28.4	5	14.0
5 (I)	Linden	108	34	9	0.26	v	10.3	8.9	11.6	R & S	10.5	10	-1.0
6 (J)	Elm	244	78	24	0.31	vii	18.0	19.2	16.8	T & S	12.2	9	15.0
7 (K)	Maple	320	102	15	0.15	vii	16.0	17.9	14	R & S	13.1	7	8.0
8 (L)	Maple	224	71	12	0.17	vii	12.0	9.3	14.7	R & A	13.2	5	7.0
9 (M)	Maple	210	67	12	0.18	vii	14.4	14.7	14.1	R & S	5.9	9	3.0
10 (N)	Maple	261	83	19	0.23	vii	16.8	18.4	15.2	R & S	8.6	10	9.0
11 (O)	Elm	133	42	14	0.33	v	10.7	10.3	11	R & S	5.2	13.5	0.5
12 (P)	Elm	213	68	23	0.34	v	15.4	13.3	17.5	T & S	6.4	36	-13.0
13 (Q)	Elm	312	99	28	0.28	v	20.1	18.8	21.3	T & S	2.8	16	12.0
14 (R)	Linden	192	61	9	0.15	x	10.4	12	8.7	R & S	7.2	24	-15.0
15 (S)	Maple	260	83	16	0.19	vii	18.5	17.9	19	R & S	11.4	10	6.0
16 (T)	Maple	120	38	9	0.24	v	9.0	10.4	7.6	R & S	13.2	6	3.0
17 (U)	Maple	290	92	16	0.17	vii	14.2	17.4	10.9	R & A	16.2	7	9.0
18 (V)	Oak	217	69	21	0.30	vii	20.8	19.5	22.1	R & S	5.4	7	14.0
19 (W)	Maple	187	60	9.5	0.16	v	14.3	13.6	15	R & S	8.9	7	2.5
20 (X)	Maple	39	12	4.5	0.36	vii	4.5	4.4	4.5	R & S	35	7	-2.5
21 (a)	Linden	221	70	17	0.24	ii	15.2	16.7	13.7	R & S	24.6	8	9.0
22 (b)	Maple	124	39	14	0.35	v	9.9	9.2	10.6	R & S	4.2	10	4.0
23 (c)	Linden	212	68	19	0.28	xi	10.8	10.9	10.6	R & S	4.6	7	12.0
24 (d)	Linden	236	75	12	0.16	x	11.6	10.7	12.5	T & A	18.6	14	-2.0
25 (e)	Maple	94	30	15	0.50	vi	12.3	12.4	12.1	R & S	6.3	9	6.0

26 (f)	Linden	258	82	19	0.23	vi	15.3	15	15.6	R & S	5.6	9	10.0
27 (g)	Maple	112	36	11	0.31	vii	7.7	8.2	7.1	R & S	2.4	10	1.0
28 (h)	Maple	122	39	12	0.31	vii	9.6	10.4	8.7	R & S	5.4	13	-1.0
29 (i)	Maple	80	25	8	0.31	vi	6.2	6.6	5.7	R & S	2.7	18	-10.0
30 (j)	Linden	262	83	18.5	0.22	vii	17.8	18.7	16.8	R & S	26.3	9	9.5
31 (k)	Maple	97	31	11	0.36	vii	8.8	9.2	8.4	R & S	10.7	9	2.0
32 (l)	Oak	101	32	14	0.44	v	8.1	8.1	8.1	T & S	7.5	11	3.0
33 (m)	Linden	122	39	13	0.33	vii	7.3	7.9	6.6	R & A	7.4	7	6.0
34 (n)	Maple	170	54	13	0.24	v	10.2	9.6	10.8	R & A	7.8	10	3.0
35 (o)	Maple	191	61	12	0.20	vii	11.3	12.8	9.8	R & S	8.6	8	4.0
36 (p)	Maple	154	49	11	0.22	v	11.5	10.7	12.2	R & T	10.5	7	4.0
37 (q)	Elm	228	73	20	0.28	vii	13.4	12.8	14	T & A	17.8	10	10.0
38 (r)	Linden	94	30	15	0.50	vii	7.2	6.8	7.5	T & S	8.8	10	5.0
39 (s)	Maple	205	65	20	0.31	vii	13.3	13	13.6	R & A	5.9	10	10.0
40 (t)	Linden	292	93	27	0.29	vii	14.5	14.8	14.1	T & S	15	11	16.0
41 (i-)	Maple	263	84	22	0.26	vii	15.2	17.8	12.5	R & A	4.8	9	13.0
42 (ii)	Linden	213	68	18	0.27	xiii	12.0	13.4	10.5	T & S	7.2	6	12.0
43 (iii)	Maple	344	110	25	0.23	vii	20.7	19.5	21.9	R & S	3.4	9	16.0
44 (iv)	Linden	172	55	15	0.27	vii	10.4	10.2	10.5	T & S	6.5	11	4.0
45 (v)	Maple	176	56	14	0.25	vii	11.5	11.5	11.5	R & S	8.2	11	3.0
46 (vi)	Maple	231	74	13	0.18	vii	10.0	10.6	9.3	R & S	6.8	9	4.0
47 (vii)	Oak	28	9	6	0.67	v	3.8	3.4	4.1	T & S	6.9	7	-1.0
48 (viii)	Linden	168	54	16	0.30	vii	12.4	12.5	12.3	R & S	11.3	8	8.0
49 (ix)	Linden	223	71	23	0.32	v	13.2	11.1	15.3	T & S	10.7	11	12.0
50 (x)	Maple	210	67	19	0.28	vii	13.5	14.5	12.5	R & S	6.3	9	10.0
51 (1)	Maple	33	11	4	0.38	vii	3.0	2.5	3.5	R & S	4.7	8	-4.0
52 (2)	Elm	237	75	22	0.29	v	12.8	13	12.5	T & S	5.6	8	14.0
53 (3)	Linden	198	63	27	0.43	vii	14.5	16.6	12.3	T & A	5	16	11.0
54 (4)	Elm	332	106	29	0.27	vii	17.8	17.2	18.4	T & S	5.8	7	22.0
55 (5)	Elm	256	82	31	0.38	vii	16.6	15.4	17.8	T & S	8.7	9	22.0
56 (6)	Linden	261	83	26	0.31	vii	12.3	13.4	11.2	R & S	7.5	7	19.0
57 (7)	Beech	183	58	19	0.33	vii	15.3	14.4	16.2	R & S	8.5	9	10.0
58 (8)	Linden	202	64	23	0.36	vii	12.4	13.5	11.2	T & S	4.1	7	16.0
59 (9)	Maple	272	87	18	0.21	vii	15.6	16.3	14.8	R & S	10.3	8	10.0
60 (10)	Maple	184	59	17	0.29	vii	11.9	13.5	10.3	R & S	4	10	7.0

61 (11)	Maple	156	50	14	0.28	vii	10.1	10.3	9.8	R & S	8.5	9	5.0
62 (12)	Oak	158	50	16	0.32	vii	14.3	14.6	13.9	R & S	9.3	10	6.0
63 (13)	Maple	177	56	16	0.28	vii	15.3	14.7	15.9	R & S	8.4	10	6.0
64 (14)	Maple	129	41	14	0.34	vii	10.7	9.3	12.1	R & A	21.2	10	4.0
65 (15)	Linden	175	56	18	0.32	vii	16.9	16.7	17	R & S	19.7	5	13.0
66 (16)	Maple	207	66	19	0.29	vii	21.5	22.2	20.8	R & S	8.9	8	11.0
67 (17)	Oak	140	45	17	0.38	vii	20.3	21.1	19.5	R & S	7.5	8	9.0
68 (18)	Elm	158	50	14	0.28	vii	13.6	11.8	15.3	R & S	7.6	12	2.0
69 (19)	Maple	194	62	18	0.29	vii	19.1	20	18.2	R & S	11.8	20	-2.0
70 (20)	Maple	165	53	16	0.30	vii	17.6	18.5	16.7	R & S	>50m	23	-7.0
71 (21)	Maple	230	73	10.5	0.14	vii	12.8	12.6	13	R & S	7.4	7	3.5
72 (22)	Linden	212	68	22	0.33	vii	25.8	24.9	26.7	R & S	8.8	12	10.0
73 (23)	Oak	174	55	11	0.20	vii	11.1	9.8	12.3	R & S	5	10	1.0
74 (24)	Maple	160	51	16	0.31	vii	12.1	13.4	10.7	R & S	13.5	14	2.0
75 (25)	Maples	179	57	15	0.26	vii	16.4	15.6	17.1	R & S	14	12	3.0
76 (26)	Maple	149	47	16	0.34	vii	16.1	15	17.2	R & S	9.6	13	3.0
77 (27)	Elm	180	57	22	0.38	v	16.7	14.5	18.9	T & A	6.6	18	4.0
78 (28)	Maple	80	25	11	0.43	vii	8.1	7.2	8.9	R & S	20.1	8	3.0
79 (29)	Maple	110	35	14	0.40	v	11.6	11.2	11.9	R & S	26	15	-1.0
80 (30)	Linden	200	64	20	0.31	v	21.8	22.4	21.1	R & S	15	10	10.0
81 (31)	Elm	95	30	14	0.46	v	12	12	11.9	R & S	24	34	-20.0
82 (32)	Beech	310	99	26	0.26	vii	10.5	12	9	T & A	32	8	18.0
83 (33)	Beech	297	95	22	0.23	vii	18.2	17	19.3	T & S	3	12	10.0
84 (34)	Maple	163	52	16	0.31	v	8.1	7.2	9	R & A	23	19	-3.0
85 (35)	Linden	188	60	18	0.30	xi	19.8	11.1	10.4	R & S	7	20	-2.0
86 (36)	Linden	155	49	17	0.34	vii	14.4	15.2	13.6	R & S	100 +	9	8.0
87 (37)	Maple	267	85	23	0.27	v	20.3	19	21.6	R & S	21	20	3.0
88 (38)	Maple	252	80	21.5	0.27	v	17.8	17.6	17.9	R & S	100 +	11	10.5
89 (39)	Linden	141	45	17	0.38	vii	11.1	9	13.1	R & A	100 +	19	-2.0
90 (40)	Linden	162	52	19	0.37	v	11.4	11.5	11.2	T & S	11	23	-4.0
91 (41)	Maple	134	43	19	0.45	v	9.8	11	8.5	R & A	4	15	4.0
92 (42)	Oak	157	50	15	0.30	v	16.8	17	16.5	R & S	50 +	50 +	-50.0
93 (43)	Maple	255	81	21	0.26	v	19	19.7	18.2	R & S	100 +	50 +	-50.0
94 (44)	Linden	49	16	13	0.83	vii	6.7	7.4	5.9	T & S	50 +	22	-9.0
95 (45)	Maple	47	15	11	0.73	vii	8.8	8.2	9.3	R & S	12.8	40 +	-40.0

96 (46)	Maple	25	8	6	0.75	xi	3.6	3.1	4	R & S	4.5	30	-24.0
97 (47)	Oak	32	10	12	1.18	xi	7.5	8.1	6.8	R & S	1.5	15	-3.0
98 (48)	Beech	162	52	21	0.41	xi	15.6	14.7	16.4	R & A	17	40 +	-40.0
99 (49)	Maple	99	32	18	0.57	vii	16.4	16.9	15.8	R & S	6.2	16	2.0
100 (50)	Elm	125	40	26	0.65	vii	17.4	18.6	16.1	R & A	23	18	8.0

Appendix VI   Vulnerability Index and Raw Data for Characteristics from GIS

Tree Number	Distance to coast	Vulnerability INDEX	Elevation (Raster Value)	Vulnerability Index
1	554.854982	1	38.706649	0.5
2	519.313863	1	41.173648	0.5
3	360.976799	1	35.205966	0.5
4	221.006053	1	23.559999	0
5	53.243083	1	8.569999	0
6	552.377264	1	42.32912	0.5
7	487.193461	1	42.862537	0.5
8	327.726509	1	37.980773	0.5
9	162.618687	1	29.969999	0
10	336.870365	1	28.809999	0
11	882.918537	0.5	24.363115	0
12	906.912031	0.5	24.857891	0
13	771.820023	0.5	24.27	0
14	686.734888	0.5	23.53	0
15	640.859524	0.5	18.390083	0
16	359.354852	1	13.075289	0
17	555.106181	1	24.599548	0
18	590.184411	1	23.360013	0
19	348.911671	1	31.939159	0
20	269.388878	1	29.393651	0
21	1007.048768	0.5	47.830001	0.5
22	756.885215	0.5	50.032176	0.5
23	820.700217	0.5	56.93	0.5
24	527.195965	1	53.069999	0.5
25	205.732155	1	27.219999	0
26	547.704253	1	53.040546	0.5
27	548.991677	1	50.551971	0.5
28	518.057912	1	40.509998	0.5
29	502.327053	1	42.409999	0.5
30	808.150316	0.5	47.082691	0.5
31	912.83377	0.5	65.440002	1
32	967.503445	0.5	72.089347	1
33	842.540503	0.5	65.25756	1
34	702.553961	0.5	64.473373	1
35	532.620611	0.5	65.110168	1
36	253.799563	1	42.7	0.5
37	261.349155	1	29.829999	0
38	207.958692	1	16.549999	0
39	275.669676	1	27.156373	0
40	341.258529	1	40.948726	0.5
41	757.386832	0.5	49.114379	0.5
42	1091.730381	0.5	57.068397	0.5

43	1306.445082	0	55.900199	0.5
44	1194.332645	0.5	50.727291	0.5
45	1051.435195	0.5	50.645534	0.5
46	1020.281689	0.5	49.672222	0.5
47	874.357017	0.5	48.887615	0.5
48	759.70492	0.5	54.18	0.5
49	610.067441	0.5	42.968601	0.5
50	818.318483	0.5	51.729999	0.5
51	1223.324286	0	58.45	0.5
52	1133.058157	0.5	54.099998	0.5
53	1220.215323	0	49.21685	0.5
54	1443.565368	0	55.830001	0.5
55	1621.176982	0	61.47549	0.5
56	1475.148104	0	65.400001	1
57	1516.211637	0	65.5	1
58	1399.918877	0	62.729999	0.5
59	1195.528731	0.5	61.935359	0.5
60	1268.043974	0	58.746879	0.5
61	649.685112	0.5	41.130569	0.5
62	924.011483	0.5	42.939998	0.5
63	904.178936	0.5	23.051162	0
64	1345.393049	0	21.77	0
65	1027.056771	0.5	18.916603	0
66	1008.762564	0.5	18.773344	0
67	1319.980566	0	25.494146	0
68	1071.361773	0.5	24.379999	0
69	832.647218	0.5	16.626178	0
70	719.803705	0.5	27.001201	0
71	1287.182206	0	32.213321	0
72	1520.90421	0	31.762292	0
73	1663.054646	0	40.045639	0.5
74	1577.28137	0	50.835063	0.5
75	1384.994762	0	45.369998	0.5
76	1450.691058	0	50.77	0.5
77	1133.643393	0.5	49.729999	0.5
78	1272.70156	0	39.616203	0.5
79	866.692159	0.5	34.582347	0.5
80	1088.607747	0.5	55.179531	0.5
81	931.82782	0.5	36.330001	0.5
82	859.023196	0.5	24.419752	0
83	807.544729	0.5	28.85	0
84	923.794116	0.5	41.669998	0.5
85	495.344989	1	42.36	0.5
86	643.373758	0.5	51.942737	0.5
87	914.637196	0.5	44.445259	0.5
88	1141.334826	0.5	46.639999	0.5

89	1221.17172	0	44.369998	0.5
90	1034.884811	0.5	40.619998	0.5
91	537.612768	1	28.173313	0
92	276.467485	1	9.43	0
93	123.596134	1	6.624563	0
94	122.36604	1	3.4	0
95	72.795509	1	2.509999	0
96	336.903918	1	23.44	0
97	396.392874	1	30.220071	0
98	287.844433	1	18.994775	0
99	506.079276	1	27.452581	0
100	400.455002	1	30.51	0