TREE SPECIES SELECTION FOR THE HALIFAX URBAN FOREST UNDER A CHANGING CLIMATE

by

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Submitted in partial fulfillment of the requirements
for the degree of Master of Environmental Studies

at

Dalhousie University
Halifax, Nova Scotia
August 2011

DALHOUSIE UNIVERSITY

SCHOOL FOR RESOURCE AND ENVIRONMENTAL STUDIES

The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled “Tree Species Selection for the Halifax Urban Forest under a Changing Climate” by Maliheh Rostami in partial fulfilment of the requirements for the degree of Master of Environmental Studies.

Dated: August 17th, 2011

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DALHOUSIE UNIVERSITY

DATE: August 17th, 2011

AUTHOR: Maliheh Rostami

TITLE: Tree Species Selection for the Halifax Urban Forest under a Changing Climate

DEPARTMENT OR SCHOOL: School for Resource and Environmental Studies

DEGREE: MES CONVOCATION: October YEAR: 2011

Signature of Author

Dedicated
To my beloved husband, Ali
And my dearest mother, Malak
For all their love and support

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ABSTRACT

Tree selection is critical to ensuring that urban forests are diverse, healthy, and adapted to the urban environment. Climate is one of the main controllers of plant distribution around the world, so tree species are expected to redistribute as a result of climate change. This research aimed to identify which eastern North American tree species should be most suited for planting in urban areas in Halifax given impending climate change. A database was developed for 57 tree species and 95 tree characteristics to enable analysis of tree species native to eastern North America. The results of previous climate envelope research and the database were used to identify the tree species most suitable for planting in Halifax. Of the 57 tree species examined, 16 were identified as most suited for the Halifax urban forest of the 21st century.

LIST OF ABBREVIATIONS USED

C	Celsius
dbh	diameter at breast height
GDD	Growing Degree Days
GHG	Green House Gasses
HRM	Halifax Regional Municipality
IPCC	Intergovernmental Panel on Climate Change
km	kilometres
l/m/h	low/medium/high
m	meters
N	North
NB	New Brunswick
NS	Nova Scotia
ppm	parts per million
USA	United States of America
USDA	United States Department of Agriculture
W	West
yr	year

ACKNOWLEDGEMENTS

I would like to thank and acknowledge my Supervisor, Dr. Peter Duinker, for all his support and guidance throughout this research. I have learned a lot from his knowledge, ideas, and thoughts. I could not have wished for a better supervisor than him.

I would also like to thank my committee member, Dr. Eric Rapaport, for his inputs and suggestions and guidance that helped me on the road to completing this thesis. I thank Dr. Andy Kenney for acting as my external examiner and for his valuable feedback.

I would also like to thank the faculty and staff at SRES for helping me have an unforgettable educational experience and creating an atmosphere that felt like home, although I was away and far from my country. A special thanks to my friends and classmates, Alison, James, Camilo, and Heather, for their friendship and help. I appreciate the help of John Simmons, John Charles, and Peter Bigelow for their comments and feedback on my thesis.

And many thanks to my Husband, Ali, who gave me strength at times when I felt I was failing and for all his support every step of the way in this journey. I appreciate the support of my family and in-laws, Malak, Marzieh, Sina, Hedayatollah, Shahnaz, Meghdad, and Mohammad, for encouraging me from kilometres away.

Finally, I would like to acknowledge my father, Mohammad Ali, who I lost very early in life but his thoughts and memory always guide me through life.

CHAPTER 1: INTRODUCTION

Urban forests are frequently defined as all the trees that grow within city limits, on private or public lands (Freedman *et al.* 1996, Cushing 2009). They are one of the most important elements of the urban landscape and are vital in maintaining urban ecosystem biodiversity. Urban forests have many environmental, economic, and aesthetic values for the urban population. They reduce urban noise, absorb and sequester carbon, help cleanse the air, shade and cool the city, reduce strong winds, reduce energy usage, fight soil erosion, conserve rain water, attract wildlife, and increase real estate values (Plotnik 2000, USDA 2008, Nowak and Dwyer 2007).

Most of the population of the world, including Canada, lives in urban areas and the urban forests will be the closest experience of nature offered to some people (Tree Canada, 2011). Therefore awareness about conserving urban forest is increasing. However, trees and stands within and at the fringe of cities and suburbs are vulnerable to urban development pressures. As cities grow, taking over new and remnant green areas, trees are displaced or damaged (Plotnik 2000). Exposure to excessive pollutants, heavy pruning, limited root space, soil compactions and other stresses are causes of deterioration (Saebo *et al.* 2003). Some tree species will become maladapted and some cannot survive the various stresses. Therefore, planning and caring for the trees is important so that they will be able to provide cities with their many benefits.

Climate plays an important role in tree growth and distribution around the world. Each tree species will have the ability to persist without assistance in a specific range of climatic conditions. However, human activities and those actions that increase the amount of greenhouse gases in the atmosphere are causing the climate of the earth to change (IPCC 2001, Nowak 2002). The changing climate may have negative effects on some tree species. In Atlantic Canada, the future climate is predicted to bring warmer and more humid weather. It is predicted that the surface air temperature over Canada will increase by 2-5°C by the end of the century and there will be an overall increase in the amount of precipitation (McKenney *et al.* 2007a). Importantly, there will also be an increase in the amount of hurricanes and high winds which can significantly affect and alter the shape and health of the urban forest (Environment Canada 2002 and 2003).

Yang (2009) states this change may not be to the benefit of trees because of their long life span and their slow adaptation rate of tree species to environmental change.

The effects of the changing climate combined with ongoing effects of urban development will have some undesirable effects on urban forests. Fortunately there have been movements around the world as well as in Canada to protect, preserve, and restore this resource (Hightshoe 1988). One such effort is to select the right tree species for every different location to be planted. Urban foresters have understood that in order for trees to thrive in urban setting, they should be well adapted to their surrounding environment. This means that urban foresters should understand tree physiology, the urban ecosystem, and the effects of the urban ecosystem on trees before making tree selections. Planting new trees in urban areas can cost hundreds of dollars per tree, and trees are expected to live for many decades. Comprehensive, reliable and relevant information is vital for selecting the right species.

Recent research on the relation of tree growth with the climate has shown that the changes in the climate will likely lead to circumstances where many tree species will experience northerly movements of both their southern and northern range limits (Iverson *et al.* 2004, McKenney *et al.* 2007b, Pearson *et al.* 2002). In other words, climate change is forcing tree species to migrate into regions where the changing climate is better suited for them. The main issue is that many become maladapted in the southern reaches of their ranges and vulnerable to other environmental disruptions such as pests, windstorms, and fires. Yet, tree-species migration is a difficult process; trees should be in great numbers near their range boundaries in order for them to be able to produce enough seeds and disperse them far enough to survive the changing climate. In reality, their numbers are reduced near their climatic ranges (Scheller and Mladenoff 2008). Trees near or in urban areas also have to cope with fragmentation and disturbances caused by human development, which reduces the number of mature trees that produce seeds, consequently reducing the rate of successful migration (Iverson *et al.* 2004). Therefore there is a possibility of a decrease in the population and biodiversity of tree species in urban areas. The generally northerly range shifts should be included while selecting tree species. Climate change effects on tree species should be examined in the long term.

My review of the literature shows that previous tree species selection methods have focused either on making sure that the selected trees species are adapted to the urban environment and can tolerate urban stress (*e.g.* Saebo *et al*. 2003) or on ensuring that the selected tree species are adapted to the changing climate (*e.g.* Yang 2009). These studies have failed to incorporate both climate change and urban ecosystem adaptation.

1.1 Research Goals

The goal of this research is therefore to develop and test an approach to tree selection that combines consideration of adaptation to both climate change and urban settings. To reach this goal the following objectives were set:

1.2 Research Objectives

- To develop a tree-species database to supports tree-species selection under a changing climate
- To develop an easy-to-use decision-making approach that supports tree-species selection
- To examine tree species under various scenarios representing unique combinations of selection criteria
- To develop and recommend a list of tree species for planting in Halifax that will be best suited to the changing climate up to the year 2100

1.3 Study Area and scope

The tree selection approach developed in this work was structured for general applicability to urban centres Atlantic Canada. The test case for this project is centered in Halifax, Nova Scotia. Considerations of tree species and characteristics to be examined were made with the urban core of Halifax Regional Municipality (HRM) in mind. In broad terms, the HRM urban core consists mostly of the former municipalities of Halifax, Dartmouth, Bedford, and Sackville (Halifax Regional Municipality 2006). While the tool could be used by private interests (*e.g.* nurseries, landscapers, and property owners), its construction was meant to assist tree selection by municipal authorities. However it should be mentioned that tree selection is not only a matter of plantation. In naturally planted areas of the urban forest, where trees were not assisted for plantation, thinning could help the tree selection process. Meaning that during thinning, those species that were selected and noticed as suitable for the urban forest of a specific region could remain and those that were considered not suitable could be removed from the area. For the purpose of simplicity, the HRM urban core will be referred throughout this document as Halifax.

1.4 Research Overview

Chapter 2 examines the literature on urban forests and their definition. It explains why urban forests are important to the urban ecosystem. It recounts several urban stresses imposed on trees and the effects of those stresses on trees in the urban forest. It also examines literature related to climate change and the effects of the change on trees. Finally, this chapter examines previous tree-species selection methods.

Chapter 3 explains the process of developing a tree-species database that will support tree-species selection. It covers the data collection phase and challenges encountered and decisions made during data collection. Later I explain the development of a decision-making tool for analyzing the assembled data. It also documents the decisions I made during the data analysis phase.

Chapter 4 examines the results of two analytical methods. Chapter 5 discusses published selection methods and their strengths and weaknesses, and compares my approach with previous tree-species selection studies. A discussion is provided on why my research is more complete than previous work and explains the approaches that this research has taken differently to previous tree-species selection studies. It explains the limitations and the benefits of using the new tool. It also compares the results of the alternative analytical methods and examines the differences in the results. The chapter concludes by recommending a tree species list that should be robust for the future climate of Halifax. Chapter 6 concludes the thesis with an overview of the tools and methods developed in this study and ends with recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

This chapter reviews and examines the literature on urban forests, climate change, climate-change effects on urban forests, the importance of tree selection in urban settings, and previous tree-species selection methods. This provides me the background knowledge necessary for the development of a comprehensive selection tool which will enable the selection of tree species that are robust to the changing climate and the multiple stresses imposed on them from the urban environment.

2.1 The Urban Forest

The urban forest has been defined by many researchers, and the definitions are very similar. The first definition of urban forests was proposed by Moeller (1977) as: "The urban forest is a flexible concept that encompasses rows of street trees and clusters of trees in city parks, green belts between cities and eventually forests that are more remote from the inner city. The urban forest occupies that part of the urban ecosystem made up of vegetation and related natural resources found in urban, suburban, and adjacent lands, regardless of ownership". Later researchers such as Freedman *et al.* (1996) defined the urban forest as those trees that are in the vicinity of homes, commercial institutions, and industrial buildings. Burley *et al.* (2007), on the other hand used this definition: "urban forest refers to the tree populations that make up street trees, small woodlots and larger forested areas (often parks) within cities". Despite the small differences in defining the area called the urban forest, it is obvious that trees are the most recognizable and dominant plants in the urban forest (Cushing 2009).

Conserving the urban forest requires knowledge of its structure and how that structure was formed. Urban forests are shaped by both natural and social factors. Urban foresters and city residents mainly alter the shape of the urban forest by introducing new trees native and non-native to the natural ecosystem. The social, economic, and cultural status of residents and how they chose to plant the trees in their properties are all factors that have a role in shaping the urban forest (Cushing 2009). However, the remaining natural vegetation on a site after construction also becomes part of the urban forest. Climate and soils are also important factors that control the distribution of species (Cushing 2009).

Natural disturbances such as storms, fires and pest invasions play a role in building forests (Mosseler *et al.* 2003); and urban forests are not excluded from that. Self-seeded trees could help shape the urban forest as well (Freedman *et al.* 1996).

Urban forests have many benefits for the urban environment which have been recognized by many urban foresters and forest researchers. These include: changing microclimatic conditions, decreasing air pollution, sequestering carbon dioxide, saving energy, providing habitat for wildlife, and making the urban structure more pleasing to residents (Chen and Jim 2003, Heisler 1986, Rowntree and Nowak 1991, McPherson 1994). Further research on the benefits of urban forests include the following to the list above: reducing stormwater runoff by trapping water among leaves and stems, altering wind speed and direction, removing chemicals and pollutants from landfills and other polluted soils, and reducing noise levels in cities (Bartens *et al.* 2009, Nowak and Dwyer 2007). Urban forests not only have structural and economic benefits, they also have many positive psychological effects on the residents of cities (Burley *et al.* 2007). Martens *et al.* (2011) found that human activity increases in forested areas (both tended and natural forest). Trees also help reduce fear, violence, and aggressive behaviour in cities (Kuo 2003). Wolf (2005) explains that research on different retail consumers showed that they were willing to pay more money in areas with more trees.

Recognizing the values of urban forests makes it necessary to take the right steps in taking care of them. Urban forest management plans should aim at sustaining the benefits of the urban forest for urban environments and societies. Measures should be taken to improve the health of the urban forest and to keep it at its optimum condition.

2.2 Urban Forest Stresses

There are several disturbances that both natural and urban forests face, such as fires hurricanes, and pest outbreaks that tend to be of a large magnitude (Burley *et al.* 2007). Unfortunately, urban forests face other types of disturbances such as branch breakage, soil compaction, and pollution that tend to be small in magnitude but have a noticeable impact on the urban forest. These disturbances happen frequently and therefore can prevent many trees from reaching maturity and providing urban environments with their many benefits (Rudnicky and McDonnell 1989). To minimize the amount of stress on urban trees, it is important to know the causes of stress. Some examples of a combined human-induced and natural stress are as follows.

- Below- and above-ground space is very limited which is caused by bedrocks, paving, pipelines, buildings, electrical lines, etc. (Cushing 2009).
- Trees in cities use more water because of higher temperatures but yet they receive less water because of the high amount of impervious surfaces (Saebo *et al*. 2003). Warmer temperatures in the absence of water will make the trees undergo heat and moisture stress (Johnston 2004).
- Trees in the urban forests of cold climates need to be able to tolerate salt. Sodium chloride (NaCl), which is commonly used to treat winter ice in streets, is highly soluble in water and can harm trees by the water that is taken up by the roots, or by salt spray (Cushing 2009).
- Trees in cities not only grow under the shade of each other but they also have to grow under the shade of buildings (Saebo *et al.* 2003).
- Trees are seldom cared for sufficiently after being planted to improve their chances of survival (Ligeti *et al.* 2007).
- Several studies have shown that windstorms affect the forest by altering forest structure (tree fall) and disturbing the soil (Foster and Boose 1992, Catovsky and Bazzaz 2000, Roberts 2004). This is the case in Atlantic Canada where wind and insect disturbances are the two most important factors that alter forests (Mosseler *et al.* 2003).

Usually the life span of trees is shorter under the combined natural and human stress in cities than what it is generally expected to be in their natural environment (Nilson *et al.* 2000). However, the degree and type of stresses will be different depending on the location of the tree. For instance, park trees face fewer stresses compared to street trees (Saebo *et al.* 2003). This indicates how important it is to select the right tree for each planting place.

Since the urban forest requires planning and management as a land use amongst all other urban land uses, to reap the benefits it requires the investment of human and economic resources. Knowing how the urban forest is shaped, what values it brings to the urban environment, and what is causing it to undergo stress can help in developing knowledge for tree selection. A good tree selection protocol can optimize the benefits of the urban forest while reducing stress on trees, which will then lead to a healthier urban forest. Planning for the urban forest requires knowledge of historical and recent background information as well as the inclusion of future variables such as the changing environment. The last issue is of particular importance of my research.

2.3 Climate and Climate Change Effects on Trees

As noted above, climate has been the main controller of plant distribution around the world (Forman 1964, Box 1981). Trees will therefore redistribute as a result of climate change. Thus it is necessary to be familiar with the predicted changes.

According to the IPCC (2007b), there will be an increase of 2.4 to 6.4 degrees Celsius in the world average temperature as a result of climate change by the end of the 21st century. Temperature increase in Canada will be greater than the global average which is consistent with regional projections for Atlantic Canada (Environment Canada, 2002 & 2003). This means hotter summers, more-variable winter temperatures, and longer growing seasons (Ligeti *et al.* 2007).

The temperature increase will also result in significant changes in the hydrological cycle (Trenberth *et al.* 2003). These changes have led to a 2% increase in global average precipitation during the past century (IPCC 2007a). There has been an increasing trend in the number of hurricanes in the past one hundred years, becoming a threat to forests (Environment Canada 2003). Also there will be an increase in the events of strong winds, storms, droughts, etc. High winds can damage trees by branch breakage, crown loss, windthrow and trunk breakage (Kirilenko and Sedjo 2007). In the Maritimes and Atlantic Canada, an increase in extreme weather events and biotic disturbances is what will be expected (Johnston *et al.* 2009).

The general effect of climate change on tree species, according to Johnston *et al.* (2009) are changes in:

- regeneration success
- forest health (*e.g.* reduced vigour, maladaptation, and increased mortality)
- forest productivity (positive in some places; negative in other places)
- and the amount of growing stock (as a result of increased frequency, intensity, duration, and location of disturbances)

All the changes in the climate are forcing tree species to migrate northward where the climate is more preferable for them (Morse *et al.* 1993, Opdam and Wascher 2004, Walther *et al.* 2002). This is not the first time that migration has happened as a result of climate change. Research has shown that tree species have faced many environmental changes which may have lasted as long as 100,000 years or as short as a decade. These changes could have happened suddenly or gradually during the years (Davis and Shaw 2001). There is evidence showing tree species migration of 50 km per century in the past as a result of climate change. However, the rate of the change was not as rapid as the change happening now (Schwartz 1992, Noss 2001, Parmesan and Yohe 2003).

Tree-species migration is a difficult process. The degree of climate change may be so big that trees may not have the genetic variations to adapt to the change. The changes may happen so fast that trees could not adapt during their long life spans (Davis and Shaw 2001, Kirilenko *et al.* 2000, Overpeck *et al.* 1991, Schwartz 1992). In the cases where trees do have the genetic variations to cope with the change, they may not have the ability to disperse fast enough for species survival (Clark 1998). Also, tree species have to be in large numbers near their boundaries in order for them to migrate long distances. In reality, most species decrease in density towards their range boundaries. Moreover, trees that are on the edge of their climatic ranges are the ones that are mostly affected by environmental changes and therefore are under a lot of stress (Hamrick 2004). Tree species migration in the next 100 years will be mostly focused on the first 10 km beyond the range boundary. This probably cannot keep up with the rate of climate change (Iverson *et al.* 2004). In order for the trees in North America to be able to survive the changing climate, they should be able to migrate 100-1000 m/yr (McLachlan *et al.* 2005).

2.4 Climate-Change Effects on Forest Pests and Pathogens

Climate change will not only change the ranges of tree species, the warmer temperature has also changed the climatic ranges of forest insects and has shifted them northwards. The concern is that this shift in insect and pest ranges may affect trees that do not have the mechanisms to defend themselves in pest outbreaks (Dukes *et al.* 2009, Kirilenko and Sedjo 2007). Insects can migrate into new regions faster than the migration capacity of trees (Logan *et al.* 2003). In addition, when trees migrate into new regions, they may introduce new pests and pathogens along with themselves, exposing the remaining natural vegetation to pests and diseases that they have not been exposed to before (Coakley *et al.* 1999).

In simple words as Ayers (2000) explains, climate change will affect forest herbivores and pathogens by: (1) the direct effects on the development and survival of herbivores and pathogens; (2) the physiological changes in tree defences; and (3) the indirect effects from changes in the abundance of natural enemies (*e.g.* parasitoids of insect herbivores), mutualists (*e.g.* insect vectors of tree pathogens), and competitors.

Some researchers, such as Dukes *et al.* (2009), are also concerned that there are possibilities of an increase in insect infestation on trees as a result of the warming temperatures. This is because Insect metabolism is highly related to temperature and that with a 10°C increase in the temperature, their metabolism doubles (Dukes *et al.* 2009).

Moreover, the increase in winter temperatures will probably result in unnatural insect and pest survivals (Coakley *et al.* 1999, Volney and Fleming 2000). Increased precipitation will benefit pathogens by spreading their spores by rain splash (Dukes *et al.* 2009). Damages from storms and frost will provide openings for pathogens to find their way inside the trees (Dukes *et al.* 2009).

It seems that the changing climate to some extent will be benefiting forest pest and pathogens. This will certainly not be in the interests of trees, especially those in the urban forests, resulting in additional stress on the trees.

2.5 Other Climate-Change Effects on Trees

Pests and pathogens are not the only ones benefiting from climate change. The ability of long-distance dispersals of invasive plants will give them an advantage to adapt to the changing climate faster than native plants (Dukes *et al.* 2009).

Periods with less snow or no snow and increased drought which have resulted from warmer temperatures can increase the possibility of forest fires (Kirilenko and Sedjo 2007). Forest pest and pathogens will also contribute to this matter by increasing the abundance of dead trees (Logan *et al.* 2003).

2.6 Adaptation to the Changes

Although there is uncertainty in the extent of the change on tree species, it is better to take precautionary steps and adaptive strategies in dealing with the changes than not doing anything at all. According to the IPCC (2007b), "Adaptation is broadly defined as adjustment in human or natural systems, including structures, processes, and practices". If adaptation happens early in the process of dealing with climate change, then there will be a potential to minimize the negative effects of the change and maximize the benefits of the impacts (Johnston *et al.* 2009). Adaptation is not for the future, it is needed now.

As seen in history, generally, forests would be able to adapt autonomously to changes in the climate. However, because of the slow adaptation rate of tree populations as opposed to the rapid change in the climate, there may be a desire to influence the direction and timing of the adaptation at some locations (Spittlehouse and Stewart, 2003). Assisting forest migration has been previously seen in tree plantations (Woodall *et al.* 2010). For instance, Van der veken *et al.* (2008) explain how trees in nurseries already exist in the most northern limits of their ranges.

According to Johnston *et al.* (2009) there are many adaptation efforts that could help reduce tree species vulnerability, including:

- Ensuring that the next generation of trees is better suited to the climatic environment within which they will be growing (*i.e.* facilitating migration, managing gene pools, and taking account of the potential range of future conditions when selecting species for stand regeneration)

- Minimizing losses to the current inventory from climate-change-induced disturbances
- Modifying management of the current generation of trees such that the risks of maladaptation of some species are taken into account
- Adopting climate-sensitive sustainable forest management best practices and implementing no-regret options (*i.e.* actions that are beneficial today and very likely to be beneficial in the future regardless of what form climate change takes)

Adaptation can ensure a healthy forest and a healthy urban forest alternatively reduces management costs (Saebo *et al.* 2003). Planting trees is not free and requires financial investment. Yet the right plantations can also help reduce costs in other venues. For example, an urban ecosystem analysis of the Washington, DC, metropolitan area describes how tree cover has helped reduce stormwater storage costs by $4.7 billion per year (Zhu and Zhang 2008). It is not untrue to say that a healthy urban forest may become a good seed source during periods of climate change (Woodall *et al.* 2010). Some theories even propose that during past periods of climate change, colonization was achieved by the species which survived in microclimates and were in isolated populations (Pearson, 2006).

A well-adapted urban forest can also help mitigate climate change (Litegi *et al.* 2007). Urban trees mitigate climate-change effects by absorbing pollutants, cooling the air, shading and reducing energy usage (Ligeti *et al.* 2007). The increase in atmospheric $CO_{2,}$ which has been known as the primary cause of climate change, is still proceeding, and according to the IPCC (2001) the concentration of CO_2 will still keep on increasing possibly from 525 to 750 ppm until the end of this century. In the past, reducing GHG emissions was the only approach governments took to mitigate climate change (Heller and Zavaleta 2009). However, protecting the forest from deforestation and planting trees can also decrease CO_2 levels in the atmosphere (Jakson *et al.* 2008). Urban trees store, on average, approximately three metric tonnes of CO_2 each during their life span (Nowak and Dwyer 2007).

As described above making sure that tree species are well suited to the environment which they are planted in, is part of the adaptation efforts that urban foresters can take. For this purpose extracting data from databases, books and publications that have previously studied tree species and consolidating them could help build and extend on the knowledge of tree species (Day *et al.* 2011). As the Urban Forest Management Toolkit (Day *et al.* 2011) outlines, a step to ensuring that urban forests are healthy is to connect the data gathered from databases on tree species to the characteristics of the site and the climate, and eventually selecting the right tree for the right place. These are steps in most tree species selection methods that urban foresters take in the path of selecting tree species.

2.7 Tree Selection and Tree Selection Methods

Tree species selection is an important step to ensure that trees will respond well to the many stressors they will face and that they are well adapted to the future situations. Trees that are not well adapted can be adversely affected by the least aggressive pests and pathogens (Konijnendijk *et al.* 2005, Saebo *et al.* 2003). Tree species selection is especially important in urban forests where the amount of stress that trees are facing is more than what naturally occurs. Knowing tree physiology will help one understand what influences tree growth the most and how trees respond to urban conditions (Cushing 2009). Selecting heat-tolerant species, pollution-resistant trees and pest-resistant trees are only few examples of what a good tree selection can offer (Ligeti *et al.* 2007). Plants that are appropriately planted and have the optimum growth will be able to provide the many benefits that urban forests have in cities (Roloff *et al.* 2009). A healthy urban forest depends on healthy tree species (Cushing 2009). Tree species selection can also help diversify the urban forest. The more diverse an urban forest is, the more resistant it is to invasions (Rejmanek 1996) and that diversity ensures the stability of the urban forest under environmental changes (Peterson *et al*. 1998). Tilman (1996) explains that those ecosystems that have low species diversity are the most sensitive to climatic extremes.

Following is a review of previous tree species selection methods. This is to understand their benefits and to improve areas where there was a lack of attention.

The USDA (2004) suggests the plantation of tree species that become large at maturity. Bigger trees have more impact on energy conservation, urban heat-island mitigation, and cooling the city when compared to small-stature trees. They are better at reducing stormwater runoff, extending the life of asphalt pavements, improving local air quality, improving the water and soil, reducing CO_2, providing wildlife habitat, increasing property values, enhancing the attractiveness of the community, and promoting human health and wellbeing (USDA 2004). The USDA (2004) has calculated the benefits of larger trees compared to smaller trees and concludes that the benefits of planting larger trees are almost eight times the cost that is expended for taking care of them. In the USA, it is estimated that the cost of caring for a large tree is \$13 per year per tree, while in total it nets \$65 in energy saving, cleaner air, better-managed storm water, extended life of street pavements, and higher property values (USDA 2004).

Another example of tree selection studies is Cushing's (2009) research, which examines tree species selection for the city of Toronto. In his research, Cushing (2009) took a mixed-methods approach. He collected data for the tree species studied in his research from the literature and also interviews with tree experts. Then, by combining his findings with previous success and failure experiences gathered from other cities in different countries, he developed a tree selection guide for urban foresters and landscape architects.

Saebo *et al.* (2003) explore previous tree selection methods that have been used in Europe, and also look at developing a method for tree selection for the Nordic countries. Saebo and his colleagues find that among all the tree-species selection methods used in different countries in Europe, Miller's (1997) selection model has been the most common model that has been used. This model takes into account environmental constraints, cultural constraints, economic factors and social factors when selecting trees. Cultural constraints are those limitations caused by human structures and activities to trees. Environmental constraints are those caused by pests, pathogens, soils and microclimates. Social factors are those values of the community in which the tree is planted. Economic factors are those concerns of management, establishment and removal (Saebo *et al.* 2003). Yet, Saebo *et al.* (2003) take a different approach in tree selection. They believe that the criteria for selecting street trees should be different from those used to select park trees and woodland trees because of the different environment that the tree grows in, the different stresses the tree faces, and the different usage of the tree. However, some basic characteristics should be repeated in all three selection types: climate adaptation, resistance to diseases, and large plasticity.

The selection criteria that Saebo *et al.* (2003) use, aside from the basic characteristics for selecting street trees, are aesthetic characteristics, social factors, root quality, growth potential and form, wind resistance, drought resistance, resistance to limb breakage, and tolerance of air pollution. The criteria they use for park trees are similar to the criteria they use for street trees which include aesthetic characteristics, social factors, root quality, growth potential and form, wind resistance, and resistance to limb breakage. The criteria they choose for urban woodlands include timber quality and growth rate (Saebo *et al.* 2003).

A key tool in approaching tree-species selection in relation to climate is studying the climate envelopes of species. Climate envelopes account for annual mean, maximum and minimum temperature and precipitation data in regions where plants and animals live, and they are extensively used to examine the relation of plant and animal distribution to climate and finding where each species fits (Bartlein *et al.* 1996, Busby 1998, Brereton *et al.* 1995). Researchers such as McKenney *et al.* (2007a & b) and Iverson *et al.* (2004) use climatic envelopes and the results from general circulation models that predict the future climate, compare them, and make predictions of the possible future climatic ranges of species.

Some researchers such as Yang (2009) used the results of predicted climate ranges with other tree characteristics and made tree selections. In his study, Yang made a climate-related tree-species selection for Philadelphia. He used the results of the McKenney *et al.* (2007a & b) climate envelope research on 130 tree species of the eastern United States. Current and future climate envelopes for 60 tree species in Philadelphia were studied. He then examined the main pests and diseases of those trees in Philadelphia. The climate-change effects on the pests and diseases were also examined. He concluded his research with a list of tree species suitable to Philadelphia with the least pest and disease hazards.

2.8 The Selected Climate Envelope Study for this Research

The use of McKenney *et al.* (2007a & b) in my research is the means for including climate envelope information and requires explanation. In their study, McKenney and colleagues use climate envelopes to study the current distribution of 130 North American tree species and to predict their responses to possible climate change. A climate envelope was generated for each tree species. The ANUCLIM software was used to estimate the value of each climatic variable at the location in which the tree species were observed. After that, general circulation models were used to find future climatic ranges for three periods of time including 2011-2040, 2041-2070 and 2071-2100.

McKenney *et al.* (2007a & b) then examined the migration of trees species into their future climate ranges in two scenarios. The two extreme scenarios which are previously used in other studies (Peterson *et al.* 2002, Thuiller *et al.* 2006) are: a full-dispersal situation in which tree species are able to migrate fully into their future climatic ranges; and a no-dispersal situation in which tree species are unable to migrate into their future climatic ranges and therefore survive only in areas where there is an overlap between their current and future climatic regions. McKenney *et al.* (2007a & b) believe that the actual distribution of tree species would be somewhere between these two scenarios.

All the methods above explain the importance of climatic fitness for tree species selection. However, (except for Yang, 2009) they do not examine tree species selection in the face of climate change and what is needed to be done to be prepared and adapt to sudden changes. In the case of Yang (2009) study, he does examine climate change effects on tree species distribution but does not consider other characteristics needed in a tree that will make it well suited to the urban environment. The following chapter will examine the development of a tool that will, hopefully, fill the gaps required to make a suitable tree species selection for the urban environment under a changing climate for the city of Halifax.

The tree selection method developed in this research uses the knowledge gained on tree species from the tree-species database, which this research has integrated from other sources that have previously studied tree species, combined with the results of climatic envelope studies as a basis for examining tree species in a variety of scenarios.

CHAPTER 3: METHODS

This chapter describes the methods and procedures taken in the path to develop a tree-species selection method that enables the selection of trees that are robust to the changing climate and the urban environment of Halifax. I start this chapter by explaining how the tree species database was developed and the decisions that were made along the way in completing the database. I then describe the first method of analysis used in this research and the scenarios developed to analyse tree-species data. The scenarios and the characteristics that are examined in each are explained and also the decisions made during the analysis phase are explored. The chapter ends by describing the second method used to analyse tree-species data.

3.1 Halifax

Halifax is the capital of the Nova Scotia province, Canada and is located at a Latitude of 45°51'16" N and Longitude of 63°11'57" W (Halifax Regional Municipality 2011). It has a temperate maritime climate regime, the soils are primarily shallow loams, and the forests in this region are part of the Acadian forest (Freedman *et al.* 1996). According to the census metropolitan area (Statistics Canada 2011) the population of the urban core in 2010 was 282,924.

3.2 Method of Data Collection

Tree species can be studied in a variety of ways and also in great number of characteristics, therefore it was necessary to begin this research by deciding on which tree characteristics needed to be examined and analyzed. A group of four people from Dalhousie university faculty and students currently researching on urban forests and urban forest issues, including me, met to discuss the suitability of the many characteristics of trees in Halifax's urban forest. After several meetings, a list of the important characteristics and the ways that the data should be presented in the database were decided upon and codified in a digital spreadsheet. For example, one characteristic is the ability of trees to tolerate shade, and the data for this trait would be represented in numbers from 1 to 5, with 1 representing the least shade-tolerant and 5 representing the most shade-tolerant of trees (see Table 3.2 for the list of tree characteristics studied in this research).

It was decided to study trees native to Nova Scotia, New Brunswick, and the eastern seaboard of the United States of America (USA). In addition to these groups of trees, six trees native to Europe and Asia and which are widely planted in North American cities were included. This decision was based partly on the continuity of climate characteristics along the Atlantic coast of North America. Also, if tree migration happens as a result of climate change according to several climatic envelope studies (McKenney *et al.* 2007a & b and Iverson *et al.* 2004), these would be the regions from which tree species would most probably have the ability to migrate to Nova Scotia. In this research I chose to use the results of the full-dispersal scenario of the McKenney *et al.* (2007a & b) because urban forestry is mostly based on human-assisted tree plantations, and therefore there is no need to wait for tree species to migrate into their new climatic regions. Farrar's (1995) book *Trees in Canada* was used to identify the indigenous species from these regions.

Three tree species were chosen out of 57 species selected for this research for a pilot test to check data availability for the selected tree characteristics. The three trees species were selected from three different categories:

Category 1: this category includes tree species that are non-native to Nova Scotia but have been widely planted in Halifax's urban settings; the selected tree from this category was *Acer platanoides*.

Category 2: this category includes tree species that are native to Nova Scotia and that are currently performing well in Halifax's urban forest; the selected tree from this category was *Ulmus americana*.

Category 3: this category includes tree species native to Nova Scotia which are known for their weak performance in street settings in the current climate; the selected tree from this category was *Pinus resinosa*.

The pilot test was done in June 2009. After collecting the data for the three tree species, another team meeting was held to validate the data. As an outcome of the meeting, some tree characteristics were deleted from the database and some were added (table 3.2 shows the final list of characteristics). For example, the database contained a characteristic on the propensity for a tree to sprout branches when pruned. Since the data for this characteristic were impossible to find from published sources, it was eventually deleted from the database. Also there were some changes made to how the data for some of the tree characteristic was represented.

As soon as the pilot test was finished, data were collected first for trees native to Nova Scotia and New Brunswick. Data were obtained from 13 main published sources which were gradually collected during the pilot test and the actual data collection phase. These sources were chosen based on the opinion of credibility among tree experts or if they were recommended by other sources. The sources consisted of books, published research on tree species, and online databases such as follow:

1- Trees in Canada (Farrar 1995)
2- The urban tree book (Plotnik 2000)
3- Trees of Ontario (Kershaw 2001)
4- North American trees (Preston and Braham 2002)
5- Trees for urban and suburban landscapes (Gilman 1997)
6- Silvics of North America (Burns and Honkala 1990)
7- Native plants of the Northeast: a guide for gardening and conservation (Leopold 2005)
8- Trees of the Carolinian forest: A guide to species, their ecology and uses (Waldron 2003)
9- The complete plant selection guide for landscape design (Stoecklein 2001)
10- Native trees, shrubs and vines for urban and rural America (Hightshoe 1988)
11- Plants Database (USDA 2010)
12- Fire Effects Information System (USDA 2010)
13- SelecTree (Urban Forest ecosystem institute 2010)

To track the provenance of the data in the digital spreadsheet, each source of data was given a specific colour, and data were entered into the database with the colour associated with its source. In cases where there were inconsistent data found in different sources, the inconsistencies were entered in the database based on their descending order to show conflicting ideas among experts. For instance, according to one of the sources, *A. platanoides* is highly tolerant of fire, but according to another source it has a medium tolerance of fire. Both data were inserted in the database in descending order: high/medium.

The 13 main sources did not provide all the data needed for the characteristics. Therefore, an online search was conducted through Google and other online search engines for the missing data. All the data collected this way were entered in a light green colour and the source of data for each tree species was saved in an individual folder for better referencing. These data were mostly collected from experienced gardeners and tree nurseries. If data were not available in my entire data search, a dash was inserted in place of the required data.

When the data collection was finished for the native species of Nova Scotia and New Brunswick, the group met again to review the data and address issues associated with data collection. At times when data seemed to be questionable, it was decided to add an option of consulting with local experts and correcting the data. The corrected data were entered in a light blue colour. For a second time, a few characteristics were deleted and some others added to the database. The final step was collecting data for species native to the eastern seaboard of the USA and the six Eurasian species that are widely planted through North America.

In the end, a total of 57 tree species and 92 characteristics were included in the database. At the beginning of the research, it was decided to also study cultivars and hybrids of tree species but due to the extent of the study, it was later decided to study only the original species. Therefore, this research excludes the study of all tree cultivars and hybrids. Table 3.1 shows the list of tree species studied in this research. For more information on the database and the link to downloading it, see Appendices 2 and 3.

Table 3.1. Scientific and common names of tree species studied in this research.

Scientific Name	Common Name	Scientific Name	Common Name
Acer rubrum□	Red Maple	*Tilia americana*■	Basswood
Acer saccharum□	Sugar Maple	*Acer nigrum*	Black Maple
Betula alleghaniensis□	Yellow Birch	*Acer platanoides*	Norway Maple
Betula papyrifera□	White Birch	*Acer pseudoplatanus*	Sycamore Maple
Betula populifolia□	Gray Birch	*Aesculus hippocastanum*	Horsechestnut
Fagus grandifolia□	American Beech	*Carpinus caroliniana*	Blue-Beech
Fraxinus americana□	White Ash	*Carya cordiformis*	Bitternut Hickory
Fraxinus nigra□	Black Ash	*Carya ovata*	Shagbark Hickory
Fraxinus pennsylvanica□	Red Ash	*Castanea dentata*	American Chestnut
Larix laricina□	Tamarack	*Catalpa bignonioides*	Southern Catalpa
Ostrya virginiana□	Ironwood	*Catalpa speciosa*	Northern Catalpa
Picea glauca□	White Spruce	*Fagus sylvatica*	European Beech
Picea mariana□	Black Spruce	*Ginkgo biloba*	Ginkgo
Picea rubens□	Red Spruce	*Gleditsia triacanthos*	Honey Locust
Pinus resinosa□	Red Pine	*Gymnocladus dioicus*	Kentucky Coffee-Tree
Pinus strobus□	Eastern White Pine	*Juglans nigra*	Black Walnut
Populus balsamifera□	Balsam Poplar	*Liriodendron tulipifera*	Tulip-Tree
Populus grandidentata□	Largetooth Aspen	*Magnolia acuminata*	Cucumber-Tree
Populus tremuloides□	Trembling Aspen	*Nyssa sylvatica*	Black-Gum
Prunus serotina□	Black Cherry	*Picea abies*	Norway Spruce
Quercus rubra□	Red Oak	*Platanus occidentalis*	Sycamore
Thuja occidentalis□	Eastern White Cedar	*Quercus alba*	White Oak
Tsuga canadensis□	Eastern Hemlock	*Quercus bicolor*	Swamp White Oak
Ulmus americana□	White Elm	*Quercus velutina*	Black Oak
Acer saccharinum■	Silver Maple	*Robinia pseudoacacia*	Black Locust
Juglans cinerea■	Butternut	*Salix nigra*	Black Willow
Pinus banksiana■	Jack Pine	*Sassafras albidum*	Sassafras
Prunus nigra■	Canada Plum	*Ulmus rubra*	Slippery Elm
Quercus macrocarpa■	Bur Oak		

□: indicates trees native to NS ■: indicates tree native to NB in addition to those native to NS

Table 3.2. The characteristics of trees studied in this research.

Characteristic		**Data Format**	**Characteristic definition**[1]
Genus		Name	A taxonomic category that is ranked below family and above species in the taxonomic list, written in Latin
Species		Name	The principle taxonomic category ranked below genus, written in Latin
Authority		Name	The scientist credited with the scientific name of a species
Most common name		Name	The non-scientific name of the species that occurs more than any other name
Other common names		Name	Other popular non-scientific names of the species
Other common names 2		Name	Other popular non-scientific names of the species
Other common names 3		Name	Other popular non-scientific names of the species
Broad-leafed		1 or 0	A tree species with wide, flat leaves
Deciduous		1 or 0	A tree species that sheds its leaves annually
Mature height		Metres	Tree height at maturity
Mature stem diameter		centimetres	Tree diameter at maturity. The measurement is taken 137 cm above ground
Longevity		Years	The time span that a tree species normally lives
Growth rate		l/m/h	Speed of growth
Maximum height growth rate		centimetres in one year	Maximum annual vertical growth of tree species
Fruit ripening		Month	The month during which the fruit of the tree ripen
Monopodium		1 or 0	A character in tree species that grow with a single trunk
Monoecious		1 or 0	A tree species that has both male and female reproductive organs
Maximum seed dispersal by wind		Metres	The maximum distance that a tree species seed can travel by wind
Natural hybridization	Amount	l/m/h	The amount of hybridization that naturally occurs with other species
	Binomial	Name	The scientific name of the most popular tree species that hybridization naturally occurs with
Self-pruning		1 or 0	An ability of trees that shed their branches naturally
Degree of shade		l/m/h	The degree of darkness of the shade that a tree casts
Tap root		1 or 0	A characteristic in trees with roots that grow straight deep into the ground
Toxic parts		1 or 0	The toxic parts of tree species
Allelopathy		1 or 0	An ability of a tree to release chemicals that inhibits the growth of other species around it
Wood strength		l/m/h	The strength of the wood before breaking
Degree of debris produced		l/m/h	The amount of litter produced by the tree
Water-use efficiency		l/m/h	The amount of biomass produced per unit of water consumed

1. The definitions were partly retrieved from oxford dictionaries online at http://oxforddictionaries.com

Table 3.2. (Continued).

Characteristic	**Data format**	**Characteristic Definition**
Crown shape	Word	The shape that the crown of a tree naturally holds at maturity
Coppice potential	1 or 0	The ability of a tree to survive and produce new stem after being cut down low to the ground
Pollarding potential	1 or 0	An ability of tree to produce various branches once cut at the very top of each existing branch
Unprovoked stump and root sprouting	1 or 0	A characteristic seen in some trees that produce sprout occasionally from the bottom of the tree
Resistant to decay	l/m/h	the ability of the tree species wood to resist decay
Long, East	Degree	the eastern reach of the tree species range limits from the Greenwich median
Long, West	Degree	The western reach of the species range limits from the Greenwich median
Lat, North	Degree	The northern reach of the species range limits from the equator
Lat, South	Degree	The southern reach of the species range limits from the equator
Hardiness zone (USDA)	number/letter	The zone in which the tree species could tolerate the coldest winter temperature
Min growing degree day	Number	The minimum days above 5^0C required in order for a tree to be able to grow
Max growing degree day	Number	The maximum days above 5^0C a in the regions were the tree species grows
Min frost-free days	Number	The minimum amount of days without frost required in a region in order for a tree species to grow
Preferred soil moisture regime	moist/fresh/ dry	The amount of moisture in the soils where the tree species grows best
Preferred soil acidity	l/m/h	The acidity level of the soils where the tree species grows best
Preferred soil texture	Word	The texture of the soil where the tree species grows best
Range of tolerated habitats	l/m/h	The extent of different habitats that a tree species can tolerate
Appropriateness for Halifax in Mckenney's study for year 2100 (full dispersal)	1 or 0	The results of a future climate envelopes study for 130 North American tree species
Abundance change of tree for the State of Maine according to Iverson's study	l/m/h	The results of future climate envelope studies for 134 Eastern United States tree species

Table 3.2. (Continued).

Characteristic		Data format	Characteristic definition
Tolerance to	Salt	l/m/h	The extent that a tree species can tolerate excessive salt
	Drought	l/m/h	The extent that a tree species can tolerate periods without water
	Soil compaction	l/m/h	The extent that a tree species can tolerate compacted soils
	Urban Pollution	l/m/h	The extent that a tree species can tolerate urban pollution
	Ozone	l/m/h	The extent that a tree species can tolerate excessive ozone
	Wind	l/m/h	The extent that a tree species can tolerate extreme winds
	Low nutrients	l/m/h	The extent that a tree species can tolerate the lack of nutrients in soils
	Freezing rain / icing	l/m/h	The extent that a tree species can tolerate freezing rain or ice
	Pruning	l/m/h	The extent that a tree species can tolerate excessive pruning
	Fire	l/m/h	The extent that a tree species can survive a fire
	Flooding	l/m/h	The extent that a tree species can survive long periods of extreme moisture
Shade tolerance		1 to 5	The extent that a tree species can grow under the shade of other tree species, with 1 the least shade tolerance
Flammability		l/m/h	The speed of a tree catching fire and burning entirely
Main disease	Binomial	Name	The scientific name of the main disease of the tree species
	Effect	Word	The effect the disease has on the tree
	Binomial	Name	The scientific name of the main disease of the tree species
	Effect	Word	The effect the disease has on the tree
Main insect pest	Binomial	Word	The scientific name of the main pest of the tree species
	Effect	Name	The effect the pest has on the tree
	Binomial	Word	The scientific name of the main pest of the tree species
	Effect	Name	The effect the pest has on the tree
Main vertebrate pest	Binomial	Word	The scientific name of the main vertebrate pest of the tree species
	Effect	Name	The effect the vertebrate pest has on the tree
	Binomial	Word	The scientific name of the main vertebrate pest of the tree species
	Effect	Word	The effect the vertebrate pest has on the tree
Importance of the fruit to wildlife		l/m/h	The reliance of wildlife on the tree to provide food
Invasive		l/m/h	The degree to which a tree species can invade a region

Table 3.2. (Continued).

Characteristic		Data format	Characteristic definition
Utility of wood	Lumber	l/m/h	The extent of the wood of the tree to be used for lumber
	Paper	l/m/h	The extent of the wood of the tree to be used for paper
	Panel	l/m/h	The extent of the wood of the tree to be used for panels
	Firewood	l/m/h	The extent of the wood of the tree to be used for firewood
	fine wood work	l/m/h	The extent of the wood of the tree to be used for fine wood work
	Post	l/m/h	The extent of the wood of the tree to be used for posts
Factor of attractiveness 1		Word	Factors that people consider attractive in the tree
Factor of attractiveness 2		Word	Factors that people consider attractive in the tree
Factor of attractiveness 3		Word	Factors that people consider attractive in the tree
Factor of unattractiveness 1		Word	Factors that people consider unattractive in the tree
Factor of unattractiveness 2		Word	Factors that people consider unattractive in the tree
Factor of unattractiveness 3		Word	Factors that people consider unattractive in the tree
Pollen irritation to humans		1 or 0	Is the pollens of the tree considered irritative to humans
Hazard dead branches		1 or 0	The degree of falling dead branches of the tree
Root hazard to infrastructure		l/m/h	The ability of a tree to lift or ruin infrastructure
Edible		1 or 0	Fruits or parts of the tree that are safe to be eaten
Culturally important		1 or 0	The degree of importance to local populations
Degree of maintenance		l/m/h	The amount of work required to maintain the tree

While entering the raw data into the database, many unique decisions had to be made. All such decisions were inserted into the database using the software's comment function. These decisions are as follows:

While studying the overall growth rates and annual height growth of trees (the data are not specific to Nova Scotia; the data were collected from databases that had cited them based on what the authors have generally seen in tree species), conflicting data were seen. Therefore, the general growth rates were changed to match the annual growth rates of trees. For example, young *A. platanoides* has an average annual height-growth rate of 100 cm; on the other hand, its general growth rate is mentioned to be medium. Usually fast growing trees have annual growth rates as much as *A. platanoides.* Therefore *A. platanoides'* general growth rate was changed to a fast-growing tree so that it would match its annual growth rate.

For some of the tree species, depending on the source of the data, growth rate numbers were noted as centimetres in duration of years. In these cases, the amount of growth was divided by the number of years the data were collected to determine its annual growth rate.

Accounting for the pollarding potentials of trees was another part of the study. For this trait, several references mentioned the same list of trees with pollarding potential. On the other hand, finding trees with explicit mention of no pollarding potential was difficult. Sources usually did not mention if a tree did not have pollarding potential. The team decided to assign pollarding potentials to all species noted as having it, whereas lack of mention would mean no pollarding potential.

Minimum and maximum growing-degree days for all the trees (excluding the Eurasian trees) were obtained from a combination of two sources: *The National Atlas of Canada* (Natural Resources Canada 1995*), 5th edition,* the map entitled *Growing Degree Days*, and *Index to Degree Day Data and Maps of USA* (Coop 2009). The Index to Growing Degree Day Data of USA calculates growing degree days in any selected year. The calculated Growing Degree Days (GDD) of the year 2005 was used to represent GDDs for the USA because 2005 was the first time that growing degree days were calculated on a national basis in the USA. Because tree-species climatic ranges usually extend into both Canada and the USA, for most tree species the minimum GDDs were obtained from the Canadian atlas and the maximum GDDs were collected from the American maps.

Tree species often share characteristics with their nearest relatives (species in the same genus). Therefore when data were hard to find for a tree species, the same characteristics were examined in its closest relatives and were used to fill the missing data. For example, data on the ozone tolerance of *P. grandidentata* could not be found. However, the other aspens *P. balsamifera* and *P. tremuloides* are both of low tolerance to ozone. It was decided that *P. grandidentata* was also of low ozone tolerance.

Some species of trees studied have two scientific names which are synonymous. The synonyms of the scientific names were also inserted in the database using the comment function. The scientific name for Norway spruce is *P. abies*. It also goes by the name *P. excelsa*. Both names were inserted in the database.

As part of the research, the most common pests and diseases of the tree species were also examined. For better understanding, the common names of the pests are also inserted in the database using the comment function.

3.3 Ensuring the Reliability of the Database

Once the data collection was finished, to ensure the reliability of the database, it was reviewed by a group of urban forest experts from the HRM which consisted of an arborist, a landscape architect, and a city planner. The database was printed as posters and the experts were invited to review the data and write their comments and also identify data which they thought were inaccurate. Each person was given a different colour marker to better track the reference of the comment. Once all the concerns of the experts were considered, the database was ready for analysis.

3.4 Method of Data Analysis

Data analysis started with developing a range of scenarios defined thematically for differentiation. Each scenario examined different concerns, interests, and arguments that urban foresters and planners have towards tree species in urban setting. Also the robustness of each scenario was examined in relation to climate change. The characteristics included in the database were used to examine tree species within the definition of each scenario. In each scenario, the results of the McKenney *et al.* (2007a & b) climate envelope research for tree species and their future distribution were applied, along with other characteristics associated with the relation of trees with different urban conditions. For easier reading, the results of McKenney *et al.* (2007a & b) climate envelope research will be referred to as McKenney's study from now on. Before the analysis started, the research group rated the characteristics in the database based on what they believed were important for trees to have in the urban environment. This rating was also repeated in the database review session with HRM urban forest experts. The two ratings were combined and the characteristics that received medium and high ratings were used to assign tree species in each scenario.

The developed scenarios are as follows:

Scenario 1: The robustness of the tree species planted on municipal lands in Halifax during the past decade to climate change. A list of tree species that the HRM has been planting during the past ten years was obtained and then compared to McKenney's study.

Scenario 2: The robustness of all tree species studied in the database to climate change. The results of McKenney's study were examined for all 57 species from the database. This is a one-characteristic scenario.

Scenario 3: The robustness of tree species which are better at sequestering carbon dioxide to climate change. The tree characteristics associated with this scenario include McKenney's study, tree longevity, mature height, mature diameter, and growth rate.

Scenario 4: The robustness of tree species that have low carbon footprints to climate change. This scenario is associated mainly with low maintenance needs. The characteristics associated with this scenario include McKenney's study, self-pruning, resistance to decay, degree of maintenance, and water use efficiency.

Scenario 5: The robustness of the large tree argument to climate change. This argument discusses the many benefits of larger trees compared to smaller trees within city limits. The supporters of this argument insist on planting species with large mature trees in urban areas (USDA 2004). The characteristics associated with this scenario include McKenney's study, broad-leafed trees, mature height, and longevity.

Scenario 6: The robustness of tree species with the least negative effects (hazards) in urban environments to climate change. The characteristics associated with this scenario include McKenney's study, toxic elements of trees, pollen irritation to humans, hazard dead branches, unprovoked stump/root sprouting, allelopathy, flammability, root hazard to infrastructure, resistance to decay, and invasiveness.

Scenario 7: The robustness of tree species with desired tolerances to urban conditions to climate change. The characteristics associated with this scenario include McKenney's study, tree tolerances to wind, freezing rain, salt, soil compaction, urban pollution, ozone, shade, low nutrients, pruning, drought, and fire in addition to other characteristics such as flammability, resistance to decay, preferred soil moisture regime, preferred soil acidity, preferred soil texture, range of tolerated habitat, and pollarding potential. This scenario contains the most number of characteristics: 19.

Scenario 8a: The robustness of commonly attractive broad-leafed tree species to climate change. The characteristics associated with this scenario include McKenney's study, broad-leafed trees (zero meaning needle-leaved), factor of attractiveness, and factor of unattractiveness.

Scenario 8b: The robustness of commonly attractive needle-leafed tree species to climate change. The characteristics associated with this scenario include McKenney's study, broad-leafed trees, factor of attractiveness, and factor of unattractiveness.

Scenario 9: The robustness of Nova Scotia native tree species to climate change. This scenario mainly examines characteristics that are specifically needed in tree species in order for them to be able to tolerate the climate of Halifax. The characteristics associated with this scenario include McKenney's study, mature height,, wind tolerance, salt tolerance, tolerance to freezing rain, tolerance to ozone, tolerance to low nutrients, and if the tree has a tap root or not.

Scenario 10: The robustness of other Acadian native tree species to climate change. Again the characteristics studied in this scenario and Scenario 11 are associated with the climate of Halifax. The characteristics associated with this scenario include McKenney's study, mature height, tap root, wind tolerance, salt tolerance, tolerance to freezing rain, tolerance to ozone, and tolerance to low nutrients.

Scenario 11: The robustness of tree species native to the eastern seaboard of the USA to climate change. The six Eurasian trees are also included in this scenario. The characteristics associated with this scenario include McKenney's study, mature height, tap root, wind tolerance, salt tolerance, tolerance to freezing rain, tolerance to ozone, and tolerance to low nutrients.

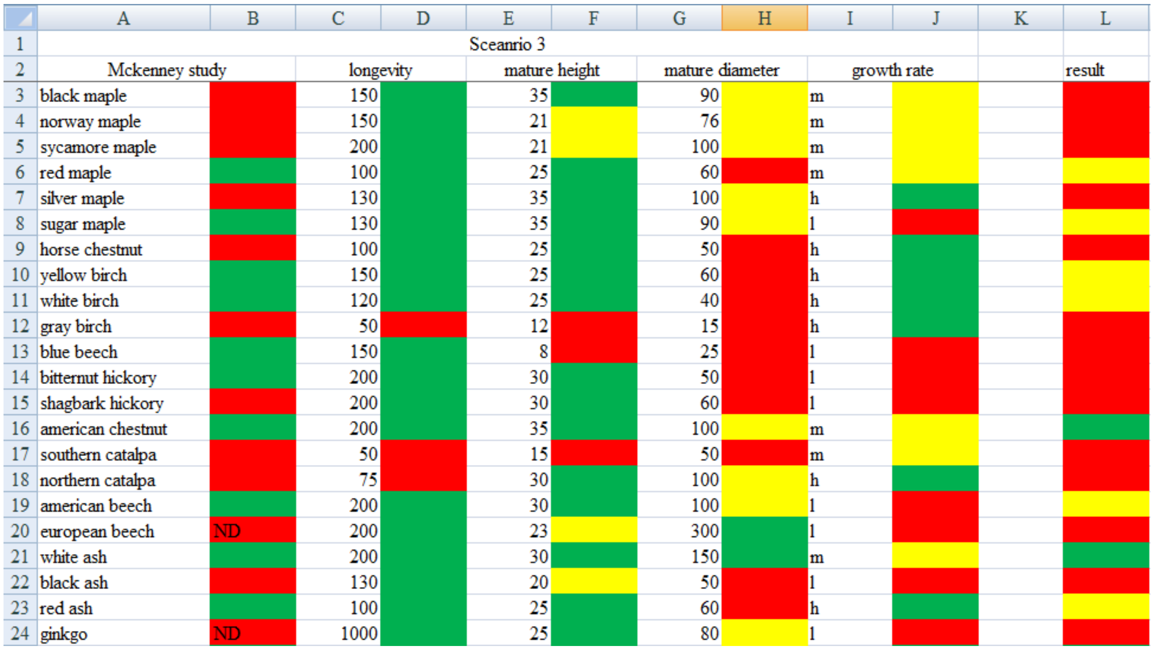
All scenarios were processed using digital spreadsheets. Data were imported for each characteristic into each scenario from the database. Once all the data were entered into each scenario, there was a need to develop a decision-making tool. The variety of data forms made it necessary for the development of a tool that could help analyze the different forms (*e.g.* nominal, ordinal, and ratio) and render them commensurable. In addition, in the database there are two types of characteristics; categorical data that define categories for their related data (*e.g.* tolerance to drought which is represented in low, medium and high categories) and continual data that do not define categories for their related data (*e.g.* tree height at maturity which is represented in single numbers such as 25 m, 30 m, 8 m). There was a need to develop categories for the latter type of characteristics in order to give uniformity to all the data in the database and to put data on the same scale for tradeoffs between characteristics. This makes it easier to find suitable tree species for Halifax because sometimes a specific word or number is not an appropriate means of showing how good or bad a tree species could be for planting in an urban environment. For example, it is arbitrary to say that only trees 25 m high are considered tall trees and trees under 25 m height are considered short trees. In these cases the data from these types of characteristics were displayed in scatter plots, and then by searching the charts natural breakpoints in data, suitable categories were developed (see Appendix 1).

Once categories were defined, a tool was developed that allowed the data of different measures (as described above) to be related to each other; this tool was called the *Analytical Tool*. With this tool, Data were translated into colours. The suitable and preferred data of a characteristic of a tree were coloured green, the medium-ranged data were coloured yellow, and the unsuitable and undesired data were coloured red. Binary characteristics (characteristics with data of zero and one), depending on the outcome, if the number one had a positive outcome it was coloured green; if it had a negative outcome it was coloured red.

In the spreadsheet that was used to analyse each scenario, two cells were assigned to each characteristic of each tree. The first cell was for inserting data and the second cell was for colouring based on the analytical tool. This was done for all the characteristics in the scenarios. At times when there were data inconsistencies in the database, the highest or the most positive datum was selected for the scenario. When there was a lack of data for some of the characteristics, an ND (no data) was inserted in the scenario spreadsheet and these characteristics received a red colour.

Every scenario had a result column at the very end that documented the results for each tree species after accounting for the relevant characteristics. The results were also represented with the analytical tool. Once the entire set of relevant characteristics was coloured, every tree species was then studied individually in each scenario, and the results were documented in the result column.

The scenarios used included several characteristics. Some characteristics could have been red while others could have been green or yellow. Decision rules needs to be established to determine if a tree species was suitable or not under a specific scenario. If all the characteristics of a tree species were coloured green or mixtures of greens and yellows, the tree species was determined to be a suitable tree species in the scenario and would get a green colour in the result column. If the tree species had only one red characteristic and the rest of the characteristics were greens and yellows, it meant that the tree species would be included in the scenario but may not be the most suitable tree for planting in Halifax according to that scenario, and that there is a need to take precautionary measures while planting it. These tree species were given a yellow colour in the result column. If a tree species had more than one characteristic coloured red, it would fail the scenario with a red colour inserted in the result column. An example of the analytical tool is shown in Figure 3.1. This figure is a demonstration of the analytical tool utility.



	A	B	C	D	E	F	G	H	I	J	K	L
1					Sceanrio 3							
2	Mckenney study		longevity		mature height		mature diameter		growth rate			result
3	black maple	🟥	150	🟩	35	🟩	90	🟨	m	🟨		🟥
4	norway maple	🟥	150	🟩	21	🟨	76	🟨	m	🟨		🟥
5	sycamore maple	🟥	200	🟩	21	🟨	100	🟨	m	🟨		🟥
6	red maple	🟩	100	🟩	25	🟩	60	🟥	m	🟨		🟨
7	silver maple	🟥	130	🟩	35	🟩	100	🟨	h	🟩		🟥
8	sugar maple	🟩	130	🟩	35	🟩	90	🟨	l	🟥		🟨
9	horse chestnut	🟥	100	🟩	25	🟩	50	🟥	h	🟩		🟥
10	yellow birch	🟩	150	🟩	25	🟩	60	🟥	h	🟩		🟨
11	white birch	🟩	120	🟩	25	🟩	40	🟥	h	🟩		🟨
12	gray birch	🟥	50	🟥	12	🟥	15	🟥	h	🟩		🟥
13	blue beech	🟩	150	🟩	8	🟥	25	🟥	l	🟥		🟥
14	bitternut hickory	🟩	200	🟩	30	🟩	50	🟥	l	🟥		🟥
15	shagbark hickory	🟥	200	🟩	30	🟩	60	🟥	l	🟥		🟥
16	american chestnut	🟩	200	🟩	35	🟩	100	🟨	m	🟨		🟩
17	southern catalpa	🟥	50	🟥	15	🟥	50	🟥	m	🟨		🟥
18	northern catalpa	🟥	75	🟥	30	🟩	100	🟨	h	🟩		🟥
19	american beech	🟩	200	🟩	30	🟩	100	🟨	l	🟥		🟨
20	european beech	🟥 ND	200	🟩	23	🟨	300	🟩	l	🟥		🟥
21	white ash	🟩	200	🟩	30	🟩	150	🟩	m	🟨		🟩
22	black ash	🟥	130	🟩	20	🟨	50	🟥	l	🟥		🟥
23	red ash	🟩	100	🟩	25	🟩	60	🟥	h	🟩		🟨
24	ginkgo	🟥 ND	1000	🟩	25	🟩	80	🟨	l	🟥		🟥

Figure 3.1. The analytical tool where greens represent suitable data, yellows represent medium suitability, and reds represent unsuitable data.

All 57 tree species included in the database were examined in scenarios 1 to 8b and the remaining three scenarios examined fewer species based on the definition of the scenario. In each scenario, the binary characteristics (meaning that there were only green and red outcomes) were examined prior to the other characteristics. McKenney's study is a characteristic repeated in all scenarios and it was a binary characteristic. This repetition was because this research is focusing on climate change, and therefore if a tree species in our research has already failed the future climatic scenario of the McKenney *et al.* (2007a & b) research, the tree species would automatically fail in our research too. No matter what the other characteristics of the tree species were, if the tree species will not have a future climatic range in Halifax, then there was no need to study that species to find its suitability for planting in Halifax (*e.g.* silver maple in Figure 3.1)

3.5 Scenario Analysis

In the following section, the decisions that were made in each scenario are described.

Scenario 1: The robustness of tree species planted on municipal lands in Halifax during the past decade to climate change. The list of the 57 tree species from the database was compared with the list of trees obtained from HRM. Using the analytical tool, I coloured those trees that have been available for plantation in HRM in the past decade with green; those trees that are only planted in specific places and cannot be planted in every location throughout the city with yellow; and those trees that were not planted at all with red. For example, according to the HRM list, *A. nigrum* has been planted in Halifax during the past ten years. Therefore, it would get a green colour. However, *A. pseudoplatanus* had not been planted in the past ten years so it got a red colour. The next step was to compare the list with McKenney's study. The results column was coloured as follows: if a tree species had greens or a mix of green and yellow, it survived inclusion in this scenario. If it had a red characteristic, the tree failed this scenario.

Scenario 2: The robustness of all tree species studied in the database to climate change. This scenario is just a representation of the results of McKenney's study for the 57 tree species in the database. It is a binary characteristic with only green and red colours for tree species that have future climatic ranges in Halifax or do not, respectively.

Scenario 3: The robustness of tree species which are better at sequestering carbon dioxide to climate change. This scenario has two binary characteristics - McKenney's study, and tree longevity at maturity. Tree longevity data were among those that required the development of scatter charts and by examining the charts, ranges were defined in places where there were gaps or noticeable differences among data. It was decided that tree species living 100 years and over were considered long-lived trees and trees living for less than 100 years were considered short-lived trees. The longer a tree lives, the longer it sequesters carbon, and therefore it is a suitable characteristic and was coloured green. On the other hand, shorter-lived trees were coloured red. Scatter charts were also used for both mature heights and mature diameters of trees, and the examination of the charts helped develop ranges of suitability and unsuitability for the characteristics. Tree species 25 m and taller were classified as tall trees with a green colour. Tree species between 20 to 24 m tall were considered as medium height trees and were coloured yellow. Tree species with a height less than 20 m tall were considered short trees, and were coloured red. Some may disagree with this division stating that trees in the urban forest do not grow to get this tall and therefore would like to use other ranges to define short, medium, and tall trees in urban settings. In response I should say that given the right amount of space and environment tree species would grow to their fullest potential; trees do not choose to grow shorter in urban environments.

Tree species with a mature diameter at breast height (dbh) of 120 centimeters and over were coloured green. Tree species with a dbh between 75 to 120 centimeters were coloured yellow. Tree species with a dbh less than 75 centimeters were coloured red. Growth-rate data were already in low, medium and high categories which were coloured red, yellow and green respectively.

In this scenario, if a tree species was coloured green in all its characteristics, it was coloured green with a star inserted in the result column. If it had a combination of greens and yellows, it was only coloured green. If it had only one red characteristic, it was coloured yellow. And more than one red characteristic resulted in the tree failing the scenario, in which case it was coloured red.

Scenario 4: The robustness of tree species that have lower carbon footprints to climate change. In this scenario, there are two binary characteristics. Aside from McKenney's study, the other binary characteristic is self-pruning (Self pruning can be a good characteristic for trees indicating that they require less maintenance, or it could be a bad characteristic for trees because it indicates its hazards in dropping branches. However in this scenario I have examined this characteristic from the less maintenance requirements point of view). A tree is either a self-pruner, a green colour, or not a self-pruner, a red colour. The other characteristics studied in this scenario were already in ranges of low, medium, and high values. The result column was coloured in the same way as in Scenario 3.

Scenario 5: The robustness of the large tree argument to climate change. In this scenario, in addition to McKenney's study, there are two other binary characteristics, broad-leafed and tree longevity. The decisions on tree longevity are the same as in scenario 3. In the big-tree argument, bigger trees are preferred for their overarching ability (their ability to create cover). This is a characteristic that is usually not seen in needle-leafed trees. Therefore, if a tree species is a broad-leafed tree, it was coloured green, and if it is a needle-leafed tree, it was coloured red. The fourth characteristic is mature height and the decisions made on this characteristic are the same as in scenario 3. Although a characteristic such as crown width could have been useful to support the large tree argument, trees with wide crowns with short heights would have not given the desired results this argument is seeking. Therefore tree height at maturity was chosen to be studied in this scenario. The result column was filled out in the same manner as in the two previous scenarios.

Scenario 6: The robustness of tree species with the least negative effects (hazards) in urban environments to climate change. There are six binary characteristics in this scenario: McKenney's study, toxic parts, pollen irritation to humans, hazardous dead branches, unprovoked stump/root sprouting, and allelopathy. The other characteristics have low, medium, and high ranges. In this scenario, after colouring all the characteristics and filling the result column, it was noticed that none of the trees had made it through the scenario without failing at least one characteristic. In this case, it was decided to count the number of red characteristics for each tree, and then writing the number in the result column. A scatter chart was made from the failure count and it was examined. If a tree species only failed one or two characteristics, it was coloured green. If it failed three characteristics, it was coloured yellow. Finally, if it failed more than three characteristics it was coloured red, meaning that the tree species failed the scenario.

Scenario 7: The robustness of tree species with desired tolerances to urban conditions to climate change. There are three binary characteristics in this scenario: McKenney's study, preferred soil moisture regime, and pollarding potential (tolerance to pollarding was examined if urban foresters would want to prioritize trees with pollarding potentials in their plantations). The other characteristics are in ranges of low, medium and high values. Similar to Scenario 6, there were no tree species that had not failed at least one characteristic. The number of failures was counted and written in the result column. Again for this scenario, a scatter chart was developed to define the ranges of acceptability in the number of times a tree species failed the characteristic. A failure of one to four characteristics was coloured green, five to nine failures were coloured yellow, and more than nine failures were coloured red in the result column.

Scenario 8a: The robustness of common attractive broad-leafed tree species to climate change. This scenario has two binary characteristics: McKenneys study and broad-leafed. In this scenario, broad-leafed trees received a green colour and needle-leafed trees received a red colour. Factors of attractiveness and unattractiveness were different in each tree species. In the database, three cells were given to each of these characteristics (three factors of attractiveness and three factor of unattractiveness could have been written in the database). For these sets of data, it was decided to count the number of ways a tree was attractive or unattractive. If the tree species had no factor of attractiveness, a red colour was given to the characteristic. If only one factor of attractiveness was found, a yellow colour was given to the characteristic. Two or three factors of attractiveness received a green colour. The opposite happened for the factor of unattractiveness. If there were no factors of unattractiveness mentioned for the tree species, a green colour was inserted in the result column. One factor of unattractiveness resulted in a yellow colour. Two or three factors of unattractiveness resulted in a red colour. The result column in this scenario was filled the same as were the other scenarios.

Scenario 8b: The robustness of common attractive needle-leafed tree species to climate change. This scenario is similar to scenario 8a. The only difference is in the broad-leafed characteristic. For this scenario if a tree species were broad-leafed, it would be coloured red and if it was a needle-leafed tree, it was coloured green.

Scenario 9: The robustness of Nova Scotia native tree species to climate change. This scenario has two binary characteristics: McKenney's study and tap root. The other characteristics were in ranges of low, medium and high. Unlike the previous scenarios in which mature height was studied and the taller the tree species was, the better it would have been, in this scenario the shorter the tree the better it was. Shorter tree species are usually more wind-firm. Therefore tree species less than 20 m tall were coloured green. Tree species between 20 to 25 m tall were coloured yellow. Tree species 25 m and taller were coloured red. Once again in this scenario, all tree species failed at least one characteristic. The number of failures was counted and a scatter chart was made. It was decided that tree species that fail once or twice were coloured green; tree species that fail three or four times were coloured yellow; and failures of five or more were coloured red in the result column.

Scenario 10: The robustness of Acadian native tree species to climate change. This scenario is the same as the previous scenario with a slight difference. This scenario has five trees in addition to scenario number 9. The result column was filled just as in Scenario 9.

Scenario 11: The robustness of tree species native to the eastern seaboard of USA to climate change. This scenario is similar to the previous two scenarios. It has 27 trees in addition to Scenario 10. The result column was filled out just as in the other two scenarios.

After all the scenarios were filled and the results were achieved for each scenario, the result columns of all the scenarios were put together in three separate digital spreadsheets to enable the comparison of trees. Three sheets are used because of the uneven number of tree species in scenario 9, 10, and 11, which means they cannot be compared together. Spreadsheet 1 examines the results of Scenario 2 first, and then it examines the results of Scenario 9. Following them are the results of Scenarios 3 to 8. The result of Scenario 1 was just used to explore whether tree species surviving different or all the scenarios have been planted in Halifax. Spreadsheets 2 and 3 take the same procedure except for examining Scenarios 10 and 11 instead of Scenario 9 respectively.

3.6 The Characteristic Count Analysis

Aside from the scenario analysis, another approach was taken in which all the characteristics that were previously studied in the scenarios were put together and the number of green, yellow and red characteristics was counted in total for each tree species. There are two characteristics that were examined in different scenarios with different results: mature height and broad-leafed. For example: mature height had two outcomes: in one scenario the taller the tree, the better it was, and in another scenario the shorter the tree, the better it was. In the cases above the tree species would have received a green colour based on the first outcome, and a red colour based on the second outcome. Both outcomes were used in the count of characteristics.

The characteristic count approach was taken because some of the characteristics were repeated in various scenarios. If a tree failed some of these repetitive characteristics, it could have possibly caused the tree to fail several of the scenarios. So the count was made to tabulate in total how many good, medium, and bad characteristics (green, yellow and red respectively) each tree species had. Once the count was done, to be able to compare the trees and find suitable tree species for Halifax using this approach, each colour was given a value; the characteristics were counted and multiplied by their values to achieve a final result. Red characteristics had a zero value, yellow characteristics had a value of one, and green characteristics were given a value of two. To clarify, a tree species may have had 12 red coloured characteristics, 11 yellow coloured characteristics, and 17 green coloured characteristics. These numbers were multiplied by their values (explained above) and added together to achieve a final result of 44. This number was then used to rate the tree species in comparison to the other species. Again a scatter chart was used here to examine the average calculated value for the tree species. Any tree with a result above 40 was considered to be an acceptable tree. To answer the question of those who might ask why I did not use the assignment of values in my scenario analysis instead of using the analytical tool, I should say, that I did not want the audience of this research to start summing up numbers, calculating, and finally categorizing the tree species in first, second, third… places.

In the end the results of the scenario analysis and the characteristic count were compared to examine the extent of similarities in the results achieved from both methods.

CHAPTER 4: RESULTS

This chapter will examine the results of each scenario that has been analysed using the analytical tool (a method of analysis developed in this research as described in Chapter 3). Later the results of all the scenarios are also compared together and described herein. Once the results of the scenario analysis are described, I will then conclude this chapter by explaining the results of the second procedure (the characteristic count).

4.1 Results of the Scenario Analysis

The results of Scenario 2 will be explored prior to the results of Scenario 1. This is because Scenario 2 (as described in the methods chapter) will then itself act as a characteristic in other scenarios; representing the results of the McKenney *et al.* (2007a & b) study.

It is necessary to say that all of the tree species native to Nova Scotia (NS) and New Brunswick (NB) are also native to the eastern shore of the United States of America (USA). All tree species native to NS are also native to NB. Throughout this chapter, whenever it is said that a tree species is native to NS it means that it is also native to NB, and eastern USA, and whenever it is said that a tree species is native to NB, it is also native to eastern USA.

Scenario 2 (The robustness of all tree species studied in the database to climate change)

Examining the results of the McKenney *et al.* (2007a & b) climate envelope research and applying it to this study, of the 57 trees species studied in the database, 32 will have a future climatic range in Halifax by the year 2100 (Table 4.1). Of the 32 species, 17 are native to NS, two of the 32 species are native to NB, and 13 are native only to the eastern shore of USA. None of the Eurasian species made it to the list because either they do not have a future climatic range in Halifax or they were not included in the McKenney *et al.* (2007a & b) study. It can be concluded from this scenario that eight of the 25 native species in Nova Scotia will not do well in the changing climate.

Table 4.1. The robustness of 57 tree species to climate change using the *Analytical Tool.*

Scientific Name	McKenney's Study	Scientific Name	McKenney's Study
Acer rubrum□	🟩	*Tilia americana*■	🟥
Acer saccharum□	🟩	*Acer nigrum*	🟥
Betula alleghaniensis□	🟩	*Acer platanoides*	🟥
Betula papyrifera□	🟩	*Acer pseudoplatanus*	🟥
Betula populifolia□	🟥	*Aesculus hippocastanum*	🟥
Fagus grandifolia□	🟩	*Carpinus caroliniana*	🟩
Fraxinus americana□	🟩	*Carya cordiformis*	🟩
Fraxinus nigra□	🟥	*Carya ovata*	🟥
Fraxinus pennsylvanica□	🟩	*Castanea dentata*	🟩
Larix laricina□	🟥	*Catalpa bignonioides*	🟥
Ostrya virginiana□	🟥	*Catalpa speciosa*	🟥
Picea glauca□	🟩	*Fagus sylvatica*	🟥
Picea mariana□	🟥	*Ginkgo biloba*	🟥
Picea rubens□	🟩	*Gleditsia triacanthos*	🟩
Pinus resinosa□	🟥	*Gymnocladus dioicus*	🟥
Pinus strobus□	🟩	*Juglans nigra*	🟩
Populus balsamifera□	🟩	*Liriodendron tulipifera*	🟩
Populus grandidentata□	🟥	*Magnolia acuminata*	🟩
Populus tremuloides□	🟩	*Nyssa sylvatica*	🟩
Prunus serotina□	🟩	*Picea abies*	🟥
Quercus rubra□	🟩	*Platanus occidentalis*	🟩
Thuja occidentalis□	🟩	*Quercus alba*	🟩
Tsuga canadensis□	🟩	*Quercus bicolor*	🟥
Ulmus americana□	🟩	*Quercus velutina*	🟩
Acer saccharinum■	🟥	*Robinia pseudoacacia*	🟩
Juglans cinerea■	🟩	*Salix nigra*	🟥
Pinus banksiana■	🟥	*Sassafras albidum*	🟩
Prunus nigra■	🟥	*Ulmus rubra*	🟥
Quercus macrocarpa■	🟩		

□: indicates trees native to NS ■: indicates tree native to NB in addition to those native to NS

Scenario 1 (The robustness of the tree species planted on municipal lands in Halifax during the past decade to climate change)

The list obtained from HRM shows that during the past decade, urban foresters have been planting 32 tree species of which 18 are native to Nova Scotia and the other 14 are not native to the area. By comparing the list with the results of Scenario 2, it shows that 18 of the 32 tree species HRM plants today will have a future climatic range in Halifax and 12 are native to NS (Table 4.2).

Table 4.2. Evaluation of 57 tree species in relation to Scenario 1 (The robustness of the trees planted on municipal lands in Halifax during the past decade to climate change) using the *Analytical Tool*.

Scientific Name	HRM Tree Species List	McKenney's Study	Scenario outcome	Scientific Name	HRM Tree Species List	McKenney's Study	Scenario outcome
Acer rubrum□	🟩	🟩	🟩	*Tilia americana*■	🟩	🟥	🟥
Acer saccharum□	🟩	🟩	🟩	*Acer nigrum*	🟩	🟥	🟥
Betula alleghaniensis□	🟩	🟩	🟩	*Acer platanoides*	🟥	🟥	🟥
Betula papyrifera□	🟥	🟩	🟥	*Acer pseudoplatanus*	🟥	🟥	🟥
Betula populifolia□	🟥	🟥	🟥	*Aesculus hippocastanum*	🟥	🟥	🟥
Fagus grandifolia□	🟥	🟩	🟥	*Carpinus caroliniana*	🟥	🟩	🟥
Fraxinus americana□	🟩	🟩	🟩	*Carya cordiformis*	🟥	🟩	🟥
Fraxinus nigra□	🟩	🟥	🟥	*Carya ovata*	🟥	🟥	🟥
Fraxinus pennsylvanica□	🟥	🟩	🟥	*Castanea dentata*	🟥	🟩	🟥
Larix laricina□	🟨	🟥	🟥	*Catalpa bignonioides*	🟥	🟥	🟥
Ostrya virginiana□	🟩	🟥	🟥	*Catalpa speciosa*	🟥	🟥	🟥
Picea glauca□	🟩	🟩	🟩	*Fagus sylvatica*	🟩	🟥	🟥
Picea mariana□	🟥	🟥	🟥	*Ginkgo biloba*	🟩	🟥	🟥
Picea rubens□	🟥	🟩	🟥	*Gleditsia triacanthos*	🟥	🟩	🟥
Pinus resinosa□	🟨	🟥	🟥	*Gymnocladus dioicus*	🟩	🟥	🟥
Pinus strobus□	🟩	🟩	🟩	*Juglans nigra*	🟩	🟩	🟩
Populus balsamifera□	🟥	🟩	🟥	*Liriodendron tulipifera*	🟩	🟩	🟩
Populus grandidentata□	🟨	🟥	🟥	*Magnolia acuminata*	🟥	🟩	🟥
Populus tremuloides□	🟨	🟩	🟩	*Nyssa sylvatica*	🟩	🟩	🟩
Prunus serotina□	🟥	🟥	🟥	*Picea abies*	🟥	🟥	🟥
Quercus rubra□	🟩	🟩	🟩	*Platanus occidentalis*	🟥	🟩	🟥
Thuja occidentalis□	🟨	🟩	🟩	*Quercus alba*	🟩	🟩	🟩
Tsuga canadensis□	🟨	🟩	🟩	*Quercus bicolor*	🟥	🟥	🟥
Ulmus americana□	🟩	🟩	🟩	*Quercus velutina*	🟥	🟩	🟥
Acer saccharinum■	🟥	🟥	🟥	*Robinia pseudoacacia*	🟩	🟩	🟩
Juglans cinerea■	🟥	🟩	🟥	*Salix nigra*	🟥	🟥	🟥
Pinus banksiana■	🟨	🟥	🟥	*Sassafras albidum*	🟥	🟩	🟥
Prunus nigra■	🟥	🟥	🟥	*Ulmus rubra*	🟥	🟥	🟥
Quercus macrocarpa■	🟩	🟩	🟩				

□: indicates trees native to NS ■: indicates tree native to NB in addition to those native to NS

Scenario 3 (The robustness of tree species which are better at sequestering carbon dioxide to climate change)

As shown in Table 4.3, *J. nigra* and *U. americana* are the two tree species that are green coloured in all their characteristics and therefore they received a star in addition to the green colour in the result column, showing the superiority of these two tree species in this scenario. Aside from the green-star tree species, there are nine other tree species coloured green, meaning that they sequester carbon dioxide faster and (or) for a longer period of time than other tree species. Five of these tree species are native to NS and the rest are only native to eastern USA.

Table 4.3 also shows that 11 tree species are medium ranked and are yellow coloured. This indicates that these tree species may not be as good at sequestering carbon as those mentioned above. Seven of these species are native to NS, one is native to NB, and three are only native to the eastern USA.

Table 4.3. Evaluation of 57 tree species in relation to Scenario 3 (The robustness of tree species which are better at sequestering carbon dioxide to climate change) using the *Analytical Tool*.

Scientific Name	McKenney's Study	Longevity	Mature Height	Mature Diameter	Growth Rate	Scenario outcomes
Acer rubrum□	🟩	🟩	🟩	🟥	🟨	🟨
Acer saccharum□	🟩	🟩	🟩	🟨	🟥	🟨
Betula alleghaniensis□	🟩	🟩	🟩	🟥	🟩	🟨
Betula papyrifera□	🟩	🟩	🟩	🟥	🟩	🟨
Betula populifolia□	🟥	🟥	🟥	🟥	🟨	🟥
Fagus grandifolia□	🟩	🟩	🟩	🟨	🟥	🟨
Fraxinus americana□	🟩	🟩	🟩	🟩	🟨	🟩
Fraxinus nigra□	🟥	🟩	🟨	🟥	🟥	🟥
Fraxinus pennsylvanica□	🟩	🟩	🟩	🟥	🟩	🟨
Larix laricina□	🟥	🟩	🟩	🟥	🟨	🟥
Ostrya virginiana□	🟥	🟩	🟥	🟥	🟥	🟥
Picea glauca□	🟩	🟩	🟩	🟥	🟥	🟥
Picea mariana□	🟥	🟩	🟨	🟥	🟥	🟥
Picea rubens□	🟩	🟩	🟩	🟥	🟥	🟥
Pinus resinosa□	🟥	🟩	🟩	🟨	🟨	🟥
Pinus strobus□	🟩	🟩	🟩	🟨	🟨	🟩
Populus balsamifera□	🟩	🟥	🟩	🟥	🟩	🟥
Populus grandidentata□	🟥	🟥	🟨	🟥	🟩	🟥
Populus tremuloides□	🟩	🟥	🟩	🟥	🟩	🟥
Prunus serotina□	🟩	🟩	🟩	🟥	🟨	🟨
Quercus rubra□	🟩	🟩	🟩	🟨	🟨	🟩
Thuja occidentalis□	🟩	🟩	🟥	🟥	🟨	🟥
Tsuga canadensis□	🟩	🟩	🟩	🟨	🟨	🟩
Ulmus americana□	🟩	🟩	🟩	🟩	🟩	🟩 *
Acer saccharinum■	🟥	🟩	🟩	🟨	🟩	🟥
Juglans cinerea■	🟩	🟥	🟩	🟨	🟩	🟨
Pinus banksiana■	🟥	🟩	🟨	🟥	🟩	🟥
Prunus nigra■	🟥	🟥	🟥	🟥	🟨	🟥
Quercus macrocarpa■	🟩	🟩	🟥	🟥	🟥	🟥

□: tree species native to NS   ■: tree species native to NB in addition to those native to NS

*: tree species that have received the green colour in all their characteristics

Table 4.3. (Continued).

Scientific Name	McKenney's Study	Longevity	Mature Height	Mature Diameter	Growth Rate	Scenario outcome
Tilia americana■	🟥	🟩	🟩	🟨	🟨	🟥
Acer nigrum	🟥	🟩	🟩	🟨	🟨	🟥
Acer platanoides	🟥	🟩	🟨	🟨	🟩	🟥
Acer pseudoplatanus	🟥	🟩	🟨	🟨	🟨	🟥
Aesculus hippocastanum	🟥	🟩	🟩	🟥	🟩	🟥
Carpinus caroliniana	🟩	🟩	🟥	🟥	🟥	🟥
Carya cordiformis	🟩	🟩	🟩	🟥	🟥	🟥
Carya ovata	🟥	🟩	🟩	🟥	🟥	🟥
Castanea dentata	🟩	🟩	🟩	🟨	🟨	🟩
Catalpa bignonioides	🟥	🟥	🟥	🟥	🟨	🟥
Catalpa speciosa	🟥	🟥	🟩	🟨	🟨	🟥
Fagus sylvatica	🟥	🟩	🟨	🟩	🟩	🟥
Ginkgo biloba	🟥	🟩	🟩	🟨	🟥	🟥
Gleditsia triacanthos	🟩	🟩	🟩	🟨	🟨	🟩
Gymnocladus dioicus	🟥	🟩	🟩	🟥	🟥	🟥
Juglans nigra	🟩	🟩	🟩	🟩	🟩	🟩 *
Liriodendron tulipifera	🟩	🟩	🟩	🟨	🟨	🟩
Magnolia acuminata	🟩	🟩	🟩	🟨	🟩	🟩
Nyssa sylvatica	🟩	🟩	🟨	🟥	🟥	🟥
Picea abies	🟥	🟩	🟩	🟩	🟨	🟥
Platanus occidentalis	🟩	🟩	🟩	🟩	🟨	🟩
Quercus alba	🟩	🟩	🟩	🟩	🟥	🟨
Quercus bicolor	🟥	🟩	🟨	🟨	🟨	🟥
Quercus velutina	🟩	🟩	🟨	🟨	🟨	🟩
Robinia pseudoacacia	🟩	🟩	🟨	🟥	🟩	🟨
Salix nigra	🟥	🟥	🟥	🟥	🟩	🟥
Sassafras albidum	🟩	🟥	🟨	🟥	🟨	🟥
Ulmus rubra	🟥	🟩	🟩	🟥	🟨	🟥

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

*: tree species that have received the green colour in all their characteristics

Scenario 4 (The robustness of tree species that have low carbon footprints to climate change)

The results of this scenario (Table 4.4) indicate that three tree species have a very low carbon footprint. These green-coloured tree species are: *C. cordiformis*, *Q. rubra*, and *R. pseudoacacia*. Only *Q. rubra* is native to NS. On the other hand, there are 19 tree species that are medium ranged and are yellow coloured; 12 of them are native to NS, two are native to NB, and five are native to eastern USA.

Table 4.4. The evaluation of 57 tree species in relation to Scenario 4 (The robustness of trees that have low carbon footprints to climate change) using the *Analytical Tool.*

Scientific Name	**Mckenney's Study**	**Self Pruning**	**Degree of Maintenance**	**Resistance to Decay**	**Water Use Efficiency**	**Scenario outcomes**
Acer rubrum□	🟩	🟩	🟩	🟨	🟥	🟨
Acer saccharum□	🟩	🟩	🟨	🟥	🟨	🟨
Betula alleghaniensis□	🟩	🟩	🟨	🟥	🟨	🟨
Betula papyrifera□	🟩	🟩	🟨	🟥	🟥	🟥
Betula populifolia□	🟩	🟩	🟩	🟥	🟩	🟥
Fagus grandifolia□	🟩	🟥	🟨	🟩	🟨	🟨
Fraxinus americana□	🟩	🟩	🟨	🟨	🟥	🟨
Fraxinus nigra□	🟥	🟥	🟩	🟥	🟥	🟥
Fraxinus pennsylvanica□	🟩	🟩	🟩	🟥	🟨	🟨
Larix laricina□	🟥	🟩	🟩	🟩	🟨	🟥
Ostrya virginiana□	🟥	🟥	🟩	🟥	🟩	🟥
Picea glauca□	🟩	🟥	🟨	🟨	🟨	🟨
Picea mariana□	🟥	🟥	🟨	🟥	🟥	🟥
Picea rubens□	🟩	🟥	🟨	🟥	🟨	🟥
Pinus resinosa□	🟥	🟩	🟩	🟥	🟥	🟥
Pinus strobus□	🟩	🟥	🟩	🟩	🟨	🟨
Populus balsamifera□	🟩	🟩	🟥	🟨	🟥	🟥
Populus grandidentata□	🟥	🟩	🟩	🟥	🟥	🟥
Populus tremuloides□	🟩	🟩	🟩	🟨	🟥	🟨
Prunus serotina□	🟩	🟥	🟩	🟥	🟨	🟥
Quercus rubra□	🟩	🟩	🟩	🟨	🟨	🟩
Thuja occidentalis□	🟩	🟥	🟩	🟩	🟨	🟨
Tsuga canadensis□	🟩	🟥	🟩	🟨	🟨	🟨
Ulmus americana□	🟩	🟩	🟨	🟥	🟨	🟨
Acer saccharinum■	🟥	🟥	🟨	🟥	🟨	🟥
Juglans cinerea■	🟩	🟩	🟨	🟥	🟨	🟨
Pinus banksiana■	🟥	🟥	🟩	🟨	🟩	🟥
Prunus nigra■	🟥	🟥	🟥	🟥	🟨	🟥
Quercus macrocarpa■	🟩	🟥	🟩	🟩	🟨	🟨

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

Table 4.4. (Continued).

Scientific Name	Mckenney's Study	Self Pruning	Degree of Maintenance	Resistance to Decay	Water Use Efficiency	Scenario outcome
Tilia americana■	🟥	🟥	🟨	🟥	🟨	🟥
Acer nigrum	🟥	🟥	🟥	🟥	🟨	🟥
Acer platanoides	🟥	🟥	🟥	🟨	🟩	🟥
Acer pseudoplatanus	🟥	🟩	🟥	🟨	🟨	🟥
Aesculus hippocastanum	🟥	🟥	🟥	🟥	🟨	🟥
Carpinus caroliniana	🟩	🟥	🟨	🟥	🟨	🟥
Carya cordiformis	🟩	🟩	🟩	🟩	🟨	🟩
Carya ovata	🟥	🟩	🟨	🟥	🟨	🟥
Castanea dentata	🟩	🟥	🟥	🟩	🟨	🟥
Catalpa bignonioides	🟥	🟩	🟥	🟩	🟩	🟥
Catalpa speciosa	🟥	🟩	🟥	🟩	🟩	🟥
Fagus sylvatica	🟥	🟥	🟩	🟨	🟥	🟥
Ginkgo biloba	🟥	🟥	🟨	🟨	🟨	🟥
Gleditsia triacanthos	🟩	🟥	🟩	🟩	🟨	🟨
Gymnocladus dioicus	🟥	🟩	🟥	🟩	🟨	🟥
Juglans nigra	🟩	🟩	🟨	🟩	🟥	🟨
Liriodendron tulipifera	🟩	🟩	🟨	🟥	🟨	🟨
Magnolia acuminata	🟩	🟩	🟥	🟩	🟥	🟥
Nyssa sylvatica	🟩	🟥	🟥	🟥	🟨	🟥
Picea abies	🟥	🟩	🟨	🟥	🟨	🟥
Platanus occidentalis	🟩	🟩	🟥	🟥	🟥	🟥
Quercus alba	🟩	🟩	🟥	🟨	🟨	🟨
Quercus bicolor	🟥	🟩	🟥	🟨	🟥	🟥
Quercus velutina	🟩	🟥	🟥	🟥	🟨	🟥
Robinia pseudoacacia	🟩	🟩	🟨	🟩	🟨	🟩
Salix nigra	🟥	🟩	🟨	🟥	🟥	🟥
Sassafras albidum	🟩	🟥	🟩	🟩	🟩	🟨
Ulmus rubra	🟥	🟥	🟨	🟥	🟥	🟥

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

Scenario 5 (The robustness of the large-tree argument to climate change)

There are 18 tree species coloured green with a star (Table 4.5), indicating that most of the trees in this scenario are relevant to the large tree argument. Ten are native to NS, and eight are native to eastern USA. In addition, there are three other tree species *(N. sylvatica*, *Q. velutina*, and *R. pseudoacacia)* that have received the green colour only and none are native to NS. Four tree species are in the medium range: *J. cinerea*, *P. balsamifera*, *P. tremuloides*, and *S. albidum*. The aspens are native to NS, *J. cinerea* is native to NB and *S. albidum* is native to eastern USA.

Table 4.5. The evaluation of 57 tree species in relation to Scenario 5 (The robustness of the large-tree argument to climate change) using the *Analytical Tool*.

Scientific Name	**Mckenney's Study**	**Broad Leafed**	**Longevity**	**Mature Height**	**Scenario outcome**
Acer rubrum□	🟩	🟩	🟩	🟩	🟩 *
Acer saccharum□	🟩	🟩	🟩	🟩	🟩 *
Betula alleghaniensis□	🟩	🟩	🟩	🟩	🟩 *
Betula papyrifera□	🟩	🟩	🟩	🟩	🟩 *
Betula populifolia□	🟥	🟩	🟥	🟥	🟥
Fagus grandifolia□	🟩	🟩	🟩	🟩	🟩 *
Fraxinus americana□	🟩	🟩	🟩	🟩	🟩 *
Fraxinus nigra□	🟥	🟩	🟩	🟨	🟥
Fraxinus pennsylvanica□	🟩	🟩	🟩	🟩	🟩 *
Larix laricina□	🟥	🟩	🟩	🟩	🟥
Ostrya virginiana□	🟥	🟩	🟩	🟥	🟥
Picea glauca□	🟩	🟥	🟩	🟩	🟥
Picea mariana□	🟥	🟥	🟩	🟨	🟥
Picea rubens□	🟩	🟥	🟩	🟩	🟥
Pinus resinosa□	🟥	🟥	🟩	🟩	🟥
Pinus strobus□	🟩	🟥	🟩	🟩	🟥
Populus balsamifera□	🟩	🟩	🟥	🟩	🟨
Populus grandidentata□	🟥	🟩	🟥	🟨	🟥
Populus tremuloides□	🟩	🟩	🟥	🟩	🟨
Prunus serotina□	🟩	🟩	🟩	🟩	🟩 *
Quercus rubra□	🟩	🟩	🟩	🟩	🟩 *
Thuja occidentalis□	🟩	🟥	🟩	🟥	🟥
Tsuga canadensis□	🟩	🟥	🟩	🟩	🟥
Ulmus americana□	🟩	🟩	🟩	🟩	🟩 *
Acer saccharinum■	🟥	🟩	🟩	🟩	🟥
Juglans cinerea■	🟩	🟩	🟥	🟩	🟨
Pinus banksiana■	🟥	🟥	🟩	🟨	🟥
Prunus nigra■	🟥	🟩	🟥	🟥	🟥
Quercus macrocarpa■	🟩	🟩	🟩	🟥	🟥

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

*: tree species that have received the green colour in all their characteristics

Table 4.5. (Continued).

Scientific Name	Mckenney's Study	Broad Leafed	Longevity	Mature Height	Scenario outcome
Tilia americana■	🟥	🟩	🟩	🟩	🟥
Acer nigrum	🟥	🟩	🟩	🟩	🟥
Acer platanoides	🟥	🟩	🟩	🟨	🟥
Acer pseudoplatanus	🟥	🟩	🟩	🟨	🟥
Aesculus hippocastanum	🟥	🟩	🟩	🟩	🟥
Carpinus caroliniana	🟩	🟩	🟩	🟩	🟩 *
Carya cordiformis	🟩	🟩	🟩	🟩	🟩 *
Carya ovata	🟥	🟩	🟩	🟩	🟥
Castanea dentata	🟩	🟩	🟩	🟩	🟩 *
Catalpa bignonioides	🟥	🟩	🟥	🟥	🟥
Catalpa speciosa	🟥	🟩	🟥	🟩	🟥
Fagus sylvatica	🟥	🟩	🟩	🟨	🟥
Ginkgo biloba	🟥	🟩	🟩	🟩	🟥
Gleditsia triacanthos	🟥	🟩	🟩	🟩	🟥
Gymnocladus dioicus	🟩	🟩	🟩	🟩	🟩 *
Juglans nigra	🟩	🟩	🟩	🟩	🟩 *
Liriodendron tulipifera	🟩	🟩	🟩	🟩	🟩 *
Magnolia acuminata	🟩	🟩	🟩	🟩	🟩 *
Nyssa sylvatica	🟩	🟩	🟩	🟨	🟩
Picea abies	🟥	🟥	🟩	🟩	🟥
Platanus occidentalis	🟩	🟩	🟩	🟩	🟩 *
Quercus alba	🟩	🟩	🟩	🟩	🟩 *
Quercus bicolor	🟥	🟩	🟩	🟨	🟥
Quercus velutina	🟩	🟩	🟩	🟨	🟩
Robinia pseudoacacia	🟩	🟩	🟩	🟨	🟩
Salix nigra	🟥	🟩	🟥	🟥	🟥
Sassafras albidum	🟩	🟩	🟥	🟨	🟨
Ulmus rubra	🟥	🟩	🟩	🟩	🟥

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

*: tree species that have received the green colour in all their characteristics

Scenario 6 (The robustness of tree species with the least negative effects (Hazards) in urban environments to climate change)

As described in the methods section, none of the tree species met the standard of this scenario without failing at least one characteristic, so it was decided to count the number of the times a tree fails a characteristic. The results (Table 4.6) show that *M. acuminate*, *P. strobus*, *P. balsamifera*, and *T. canadensis* are tree species that have failed one or two characteristics. Aside from *M. acuminata*, the others are native to NS.

C. cordiformis, *C. dentata*, *F. grandifolia*, *G. triacanthos*, *L. tulipifera, N. sylvatica*, *P. glauca*, *P. rubens*, *S. albidum*, and *T. occidentalis* are tree species that have failed three characteristics and received the yellow colour in the result column. Four of the trees are native to NS and the others are native to eastern USA.

Table 4.6. The evaluation of 57 tree species in relation to Scenario 6 (The robustness of trees with the least negative effects (Hazards) in urban environments to climate change) using the *Analytical Tool.*

Scientific Name	**Mckenney's study**	**toxic parts**	**pollen irritation to humans**	**hazard dead branches**	**unprovoked stump/root sprouting**	**allelopathy**	**flammability**	**root hazard to infrastructure**	**resistance to decay**	**invasive**	**Scenario outcome**
Acer rubrum□	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟨	🟩	🟥 6
Acer saccharum□	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟩	🟥	🟩	🟥 6
Betula alleghaniensis□	🟩	🟩	🟥	🟥	🟩	🟥	🟥	🟩	🟥	🟩	🟥 5
Betula papyrifera□	🟩	🟩	🟥	🟥	🟩	🟩	🟥	🟩	🟥	🟩	🟥 4
Betula populifolia□	🟥	🟩	🟥	🟥	🟩	🟩	🟥	🟩	🟥	🟩	🟥
Fagus grandifolia□	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟥	🟩	🟩	🟨 3
Fraxinus americana□	🟩	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟨	🟩	🟥 4
Fraxinus nigra□	🟥	🟩	🟥	🟥	🟥	🟩	🟥	🟨	🟥	🟩	🟥
Fraxinus pennsylvanica□	🟩	🟩	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟩	🟥 6
Larix laricina□	🟥	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟥
Ostrya virginiana□	🟥	🟩	🟥	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟥
Picea glauca□	🟩	🟥	🟩	🟥	🟩	🟩	🟥	🟨	🟨	🟩	🟨 3
Picea mariana□	🟥	🟩	🟩	🟥	🟩	🟩	🟥	🟨	🟥	🟩	🟥
Picea rubens□	🟩	🟩	🟩	🟥	🟩	🟩	🟥	🟨	🟥	🟩	🟨 3
Pinus resinosa□	🟥	🟩	🟩	🟥	🟥	🟩	🟥	🟥	🟥	🟩	🟥
Pinus strobus□	🟩	🟩	🟩	🟥	🟩	🟩	🟥	🟨	🟩	🟩	🟩 2
Populus balsamifera□	🟩	🟩	🟥	🟩	🟥	🟩	🟩	🟩	🟨	🟩	🟩 2
Populus grandidentata□	🟥	🟩	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟩	🟥
Populus tremuloides□	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟥	🟨	🟩	🟥 4
Prunus serotina□	🟩	🟥	🟩	🟩	🟥	🟩	🟥	🟩	🟥	🟩	🟥 4
Quercus rubra□	🟩	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟨	🟩	🟥 4
Thuja occidentalis□	🟩	🟩	🟥	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟨 3
Tsuga canadensis□	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟨	🟨	🟩	🟩 1
Ulmus americana□	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟥	🟥	🟩	🟥 4
Acer saccharinum■	🟥	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟨	🟥
Juglans cinerea■	🟩	🟥	🟥	🟥	🟩	🟥	🟥	🟩	🟥	🟩	🟥 6
Pinus banksiana■	🟥	🟩	🟩	🟥	🟩	🟩	🟥	🟨	🟨	🟨	🟥
Prunus nigra■	🟥	🟥	🟩	🟩	🟥	🟩	🟥	🟩	🟥	🟩	🟥
Quercus macrocarpa■	🟩	🟥	🟥	🟥	🟩	🟩	🟩	🟥	🟩	🟩	🟥 4

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

Table 4.6. (Continued).

Scientific Name	Mckenney's study	toxic parts	pollen irritation to humans	hazard dead branches	unprovoked stump/root sprouting	allelopathy	flammability	root hazard to infrastructure	resistance to decay	invasive	Scenario outcome
Tilia americana■	🟥	🟩	🟥	🟥	🟥	🟩	🟥	🟩	🟥	🟩	🟥
Acer nigrum	🟥	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟩	🟥
Acer platanoides	🟥	🟩	🟥	🟥	🟩	🟩	🟩	🟥	🟨	🟥	🟥
Acer pseudoplatanus	🟥	🟩	🟥	🟩	🟩	🟩	🟥	🟥	🟨	🟨	🟥
Aesculus hippocastanum	🟥	🟥	🟥	🟥	🟩	🟥	🟨	🟥	🟥	🟨	🟥
Carpinus caroliniana	🟩	🟩	🟥	🟩	🟥	🟩	🟥	🟩	🟥	🟨	🟥 4
Carya cordiformis	🟩	🟩	🟥	🟩	🟥	🟩	🟥	🟩	🟩	🟩	🟨 3
Carya ovata	🟥	🟩	🟥	🟩	🟥	🟩	🟥	🟨	🟥	🟨	🟥
Castanea dentata	🟩	🟩	🟥	🟩	🟥	🟩	🟥	🟩	🟩	🟩	🟨 3
Catalpa bignonioides	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟨	🟥
Catalpa speciosa	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟨	🟩	🟥	🟥
Fagus sylvatica	🟥	🟥	🟩	🟩	🟥	🟩	🟨	🟥	🟨	🟩	🟥
Ginkgo biloba	🟥	🟩	🟩	🟥	🟩	🟩	🟥	🟩	🟨	🟩	🟥
Gleditsia triacanthos	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟨	🟩	🟥	🟨 3
Gymnocladus dioicus	🟥	🟥	🟩	🟩	🟥	🟩	🟩	🟨	🟩	🟩	🟥
Juglans nigra	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟨	🟩	🟩	🟥 4
Liriodendron tulipifera	🟩	🟩	🟩	🟥	🟩	🟩	🟥	🟩	🟥	🟩	🟨 3
Magnolia acuminata	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟨	🟩	🟩	🟩 2
Nyssa sylvatica	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟥	🟩	🟨 3
Picea abies	🟥	🟩	🟩	🟥	🟩	🟩	🟥	🟨	🟥	🟨	🟥
Platanus occidentalis	🟩	🟩	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟨	🟥 6
Quercus alba	🟩	🟥	🟥	🟩	🟩	🟩	🟥	🟥	🟨	🟩	🟥 4
Quercus bicolor	🟥	🟩	🟥	🟩	🟩	🟩	🟥	🟥	🟨	🟩	🟥
Quercus velutina	🟩	🟩	🟥	🟩	🟩	🟩	🟥	🟥	🟥	🟩	🟥 4
Robinia pseudoacacia	🟩	🟥	🟩	🟥	🟥	🟩	🟥	🟥	🟩	🟥	🟥 6
Salix nigra	🟥	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥	🟥
Sassafras albidum	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟩	🟥	🟨 3
Ulmus rubra	🟥	🟩	🟥	🟥	🟥	🟩	🟥	🟨	🟥	🟩	🟥

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

Scenario 7 (The robustness of tree species with desired tolerances to urban conditions to climate change)

As in Scenario 6, the number of failing characteristics was also counted for the tree species in this scenario. Despite the fact that almost every tree failed at least one characteristic, *Q. macrocarpa* is the one tree species that did not fail any of the characteristics (Scenario seven is the biggest scenario with 19 characteristics). *A. rubrum*, *C. cordiformis*, *F. grandifolia*, *F. pennsylvanica*, *G. triacanthos*, *J. nigra*, *Q. alba*, and *Q. rubra* are those tree species that fail one to three characteristics (Table 4.7).

There are18 tree species that fail between four to nine characteristics and receive a yellow colour. Of the 18, 12 of these species are native to NS, and the others are native to eastern USA.

Table 4.7. The evaluation of 57 tree species in relation to Scenario 7 (The robustness of trees with desired tolerances to urban conditions to climate change) using the *Analytical Tool*.

Scientific Name	**Mackenney's study**	**preferred soil moisture regime**	**pollarding potential**	**tolerance to wind**	**tolerance to freezing rain**	**tolerance to salt**	**tolerance to soil compaction**	**tolerance to urban pollution**	**tolerance to ozone**	**tolerance of shade**	**tolerance of low nutrients**	**tolerance to pruning**	**tolerance to drought**	**tolerance to fire**	**flammability**	**resistance to decay**	**preferred soil acidity**	**preferred soil texture**	**range of tolerated habitat**	**Scenario outcome**
Acer rubrum□	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟨	🟩	🟨	🟩	🟩	🟨	🟥	🟥	🟨	🟩	🟩	🟨	🟩 4
Acer saccharum□	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟨	🟩	🟩	🟨	🟩	🟨	🟥	🟥	🟥	🟨	🟨	🟥	🟨 6
Betula alleghaniensis□	🟩	🟩	🟥	🟨	🟨	🟨	🟥	🟥	🟩	🟨	🟨	🟨	🟨	🟥	🟥	🟥	🟩	🟨	🟨	🟨 6
Betula papyrifera□	🟩	🟩	🟥	🟩	🟨	🟩	🟥	🟨	🟩	🟥	🟨	🟥	🟥	🟩	🟥	🟥	🟩	🟨	🟩	🟨 7
Betula populifolia□	🟥	🟩	🟥	🟩	🟨	🟩	🟥	🟨	🟩	🟨	🟩	🟨	🟨	🟨	🟥	🟥	🟥	🟩	🟩	🟥
Fagus grandifolia□	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟨	🟥	🟩	🟩	🟨	🟨	🟩 4
Fraxinus americana□	🟩	🟩	🟩	🟩	🟨	🟩	🟥	🟥	🟥	🟨	🟥	🟨	🟥	🟨	🟥	🟨	🟨	🟨	🟨	🟨 6
Fraxinus nigra□	🟥	🟩	🟩	🟥	🟥	🟥	🟩	🟨	🟥	🟥	🟨	🟨	🟥	🟨	🟥	🟥	🟩	🟨	🟥	🟥
Fraxinus pennsylvanica□	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟩	🟨	🟩	🟨	🟩	🟨	🟨	🟥	🟥	🟨	🟩	🟥	🟩 3
Larix laricina□	🟥	🟩	🟥	🟥	🟨	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟥
Ostrya virginiana□	🟥	🟩	🟥	🟨	🟩	🟨	🟥	🟥	🟩	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟩	🟩	🟥	🟥
Picea glauca□	🟩	🟩	🟥	🟥	🟨	🟨	🟨	🟨	🟩	🟨	🟥	🟨	🟩	🟥	🟥	🟨	🟨	🟨	🟨	🟨 5
Picea mariana□	🟥	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟩	🟨	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟥
Picea rubens□	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟨	🟨	🟨	🟩	🟥	🟥	🟩	🟨	🟨	🟨 9
Pinus resinosa□	🟥	🟥	🟥	🟩	🟨	🟥	🟥	🟥	🟥	🟥	🟩	🟨	🟩	🟩	🟥	🟥	🟩	🟥	🟨	🟥
Pinus strobus□	🟩	🟩	🟥	🟨	🟨	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟥	🟩	🟨 9
Populus balsamifera□	🟩	🟩	🟥	🟨	🟥	🟥	🟥	🟨	🟥	🟨	🟨	🟥	🟥	🟩	🟩	🟨	🟥	🟥	🟥	🟥 10
Populus grandidentata□	🟥	🟩	🟥	🟨	🟨	🟨	🟥	🟥	🟥	🟥	🟨	🟨	🟥	🟩	🟥	🟥	🟨	🟥	🟨	🟥
Populus tremuloides□	🟩	🟩	🟥	🟥	🟥	🟨	🟥	🟨	🟥	🟥	🟨	🟨	🟥	🟩	🟩	🟨	🟨	🟩	🟨	🟨 7
Prunus serotina□	🟩	🟩	🟥	🟨	🟨	🟨	🟥	🟨	🟥	🟥	🟨	🟩	🟨	🟥	🟥	🟥	🟩	🟨	🟩	🟨 7
Quercus rubra□	🟩	🟩	🟩	🟩	🟩	🟨	🟥	🟩	🟩	🟨	🟩	🟩	🟥	🟩	🟥	🟨	🟩	🟨	🟨	🟩 3
Thuja occidentalis□	🟩	🟩	🟥	🟨	🟥	🟨	🟩	🟨	🟩	🟨	🟨	🟥	🟥	🟥	🟥	🟩	🟨	🟨	🟩	🟨 6
Tsuga canadensis□	🟩	🟩	🟥	🟥	🟩	🟥	🟥	🟨	🟥	🟩	🟨	🟩	🟥	🟨	🟥	🟨	🟩	🟨	🟨	🟨 7
Ulmus americana□	🟩	🟩	🟩	🟩	🟥	🟩	🟨	🟥	🟩	🟨	🟥	🟩	🟨	🟥	🟩	🟥	🟩	🟩	🟩	🟨 5
Acer saccharinum■	🟥	🟩	🟩	🟥	🟥	🟩	🟨	🟥	🟩	🟨	🟥	🟥	🟩	🟥	🟥	🟥	🟨	🟨	🟥	🟥
Juglans cinerea■	🟩	🟥	🟥	🟨	🟥	🟥	🟥	🟩	🟩	🟥	🟨	🟨	🟥	🟥	🟥	🟥	🟨	🟨	🟥	🟥 11
Pinus banksiana■	🟥	🟩	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟩	🟩	🟨	🟥	🟥	🟥	🟨	🟩	🟥	🟨	🟥
Prunus nigra■	🟥	🟩	🟥	🟥	🟥	🟥	🟨	🟩	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟨	🟨	🟥	🟥
Quercus macrocarpa■	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩 0

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

Table 4.7. (Continued).

Scientific Name	Mackenney's study	preferred soil moisture regime	pollarding potential	tolerance to wind	tolerance to freezing rain	tolerance to salt	tolerance to soil compaction	tolerance to urban pollution	tolerance to ozone	tolerance of shade	tolerance of low nutrients	tolerance to pruning	tolerance to drought	tolerance to fire	flammability	resistance to decay	preferred soil acidity	preferred soil texture	range of tolerated habitat	Scenario outcome
Tilia americana■	🟥	🟩	🟩	🟨	🟥	🟥	🟥	🟨	🟩	🟩	🟨	🟩	🟥	🟨	🟥	🟥	🟨	🟨	🟨	🟥
Acer nigrum	🟥	🟩	🟩	🟥	🟨	🟥	🟥	🟨	🟩	🟩	🟨	🟨	🟥	🟥	🟥	🟥	🟨	🟨	🟥	🟥
Acer platanoides	🟥	🟩	🟩	🟥	🟩	🟨	🟥	🟨	🟨	🟨	🟩	🟨	🟨	🟩	🟩	🟨	🟩	🟨	🟨	🟥
Acer pseudoplatanus	🟥	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟥	🟨	🟨	🟨	🟨	🟥	🟨	🟨	🟩	🟨	🟥
Aesculus hippocastanum	🟥	🟩	🟩	🟥	🟨	🟨	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟨	🟨	🟥	🟨	🟨	🟨	🟥
Carpinus caroliniana	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟨	🟩	🟥	🟥	🟥	🟥	🟨	🟩	🟨	🟨 8
Carya cordiformis	🟩	🟩	🟥	🟩	🟩	🟥	🟨	🟨	🟩	🟨	🟨	🟨	🟩	🟨	🟥	🟩	🟨	🟨	🟩	🟩 3
Carya ovata	🟥	🟩	🟥	🟩	🟩	🟥	🟨	🟨	🟩	🟨	🟨	🟨	🟩	🟨	🟥	🟥	🟨	🟩	🟥	🟥
Castanea dentata	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟨	🟩	🟨	🟥	🟥	🟩	🟨	🟥	🟥	🟥 11
Catalpa bignonioides	🟥	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟥	🟨	🟨	🟥	🟩	🟥	🟥	🟩	🟨	🟩	🟨	🟥
Catalpa speciosa	🟥	🟩	🟩	🟥	🟥	🟨	🟩	🟩	🟥	🟨	🟨	🟥	🟩	🟥	🟥	🟩	🟥	🟨	🟥	🟥
Fagus sylvatica	🟥	🟩	🟥	🟨	🟥	🟥	🟥	🟨	🟩	🟨	🟥	🟨	🟨	🟥	🟨	🟨	🟩	🟨	🟩	🟥
Ginkgo biloba	🟥	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟥	🟨	🟨	🟥	🟥	🟥	🟨	🟨	🟨	🟩	🟥
Gleditsia triacanthos	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟨	🟨	🟨	🟩	🟨	🟥	🟩	🟥	🟩	🟨	🟩 3
Gymnocladus dioicus	🟥	🟩	🟥	🟩	🟩	🟩	🟨	🟨	🟥	🟨	🟩	🟩	🟩	🟥	🟩	🟩	🟥	🟨	🟥	🟥
Juglans nigra	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟨	🟩	🟨	🟩	🟩	🟥	🟩	🟥	🟨	🟨	🟩 2
Liriodendron tulipifera	🟩	🟩	🟥	🟩	🟥	🟥	🟥	🟩	🟥	🟨	🟥	🟨	🟥	🟥	🟥	🟥	🟨	🟥	🟥	🟥 12
Magnolia acuminata	🟩	🟩	🟥	🟩	🟩	🟥	🟥	🟥	🟩	🟨	🟥	🟨	🟥	🟥	🟥	🟩	🟩	🟨	🟥	🟨 9
Nyssa sylvatica	🟩	🟩	🟥	🟩	🟩	🟩	🟨	🟥	🟩	🟩	🟨	🟩	🟩	🟥	🟥	🟥	🟩	🟨	🟩	🟨 5
Picea abies	🟥	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟨	🟨	🟩	🟨	🟥	🟥	🟥	🟩	🟨	🟥	🟥
Platanus occidentalis	🟩	🟩	🟥	🟩	🟩	🟥	🟩	🟩	🟥	🟨	🟨	🟩	🟥	🟨	🟥	🟥	🟥	🟨	🟥	🟨 8
Quercus alba	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟨	🟩	🟨	🟨	🟨	🟥	🟨	🟨	🟩	🟥	🟩 4
Quercus bicolor	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟨	🟥	🟨	🟨	🟥	🟥	🟥
Quercus velutina	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟨	🟨	🟨	🟨	🟩	🟨	🟥	🟥	🟨	🟩	🟥	🟨 5
Robinia pseudoacacia	🟩	🟥	🟩	🟥	🟥	🟩	🟨	🟩	🟥	🟨	🟩	🟩	🟩	🟩	🟥	🟩	🟨	🟨	🟥	🟨 7
Salix nigra	🟥	🟩	🟩	🟥	🟥	🟨	🟩	🟥	🟥	🟥	🟨	🟨	🟥	🟥	🟥	🟥	🟨	🟩	🟥	🟥
Sassafras albidum	🟩	🟥	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟨	🟩	🟨	🟩	🟥	🟥	🟩	🟨	🟨	🟥	🟥 10
Ulmus rubra	🟥	🟩	🟩	🟩	🟥	🟥	🟨	🟨	🟩	🟩	🟨	🟨	🟩	🟥	🟥	🟥	🟨	🟩	🟨	🟥

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

Scenario 8a (The robustness of attractive broad-leafed tree species to climate change)

Examining the results for Scenario 8 (Table 4.8) shows that nine tree species are green star coloured, 17 are green coloured only, and *U. americana* is the only medium-range tree species in this scenario. Out of the list of tree species mentioned above, 11 are native to NS, two are native to NB, and the others are native to eastern USA. All of the broad-leafed trees in our research if they have future climatic ranges in Halifax survived this scenario. *U. americana* has lost part of its attractiveness to the urban residents because of the Dutch elm disease but yet does not fail this scenario.

Table 4.8. The evaluation of 57 tree species in relation to Scenario 8a (The robustness of attractive broad-leafed trees to climate change) using the *Analytical Tool*.

Scientific Name	**Mckenney's study**	**broadleafed**	**number of factor of attractiveness**	**number of factor of unattractiveness**	**Scenario outcome**
Acer rubrum□	🟩	🟩	🟩	🟨	🟩
Acer saccharum□	🟩	🟩	🟩	🟨	🟩
Betula alleghaniensis□	🟩	🟩	🟩	🟨	🟩
Betula papyrifera□	🟩	🟩	🟩	🟨	🟩
Betula populifolia□	🟥	🟩	🟩	🟩	🟥
Fagus grandifolia□	🟩	🟩	🟩	🟨	🟩
Fraxinus americana□	🟩	🟩	🟩	🟨	🟩
Fraxinus nigra□	🟥	🟩	🟥	🟨	🟥
Fraxinus pennsylvanica□	🟩	🟩	🟩	🟨	🟩
Larix laricina□	🟥	🟥	🟩	🟩	🟥
Ostrya virginiana□	🟥	🟩	🟩	🟩	🟥
Picea glauca□	🟩	🟥	🟩	🟩	🟥
Picea mariana□	🟥	🟥	🟨	🟩	🟥
Picea rubens□	🟩	🟥	🟩	🟨	🟥
Pinus resinosa□	🟥	🟥	🟨	🟨	🟥
Pinus strobus□	🟩	🟥	🟩	🟩	🟥
Populus balsamifera□	🟩	🟩	🟨	🟨	🟩
Populus grandidentata□	🟥	🟩	🟩	🟩	🟥
Populus tremuloides□	🟩	🟩	🟩	🟨	🟩
Prunus serotina□	🟩	🟩	🟩	🟨	🟩
Quercus rubra□	🟩	🟩	🟩	🟨	🟩
Thuja occidentalis□	🟩	🟥	🟩	🟥	🟥
Tsuga canadensis□	🟩	🟥	🟩	🟨	🟥
Ulmus americana□	🟩	🟩	🟩	🟥	🟨
Acer saccharinum■	🟥	🟩	🟩	🟥	🟥
Juglans cinerea■	🟩	🟩	🟩	🟩	🟩 *
Pinus banksiana■	🟥	🟥	🟨	🟨	🟥
Prunus nigra■	🟥	🟩	🟩	🟩	🟥
Quercus macrocarpa■	🟩	🟩	🟩	🟨	🟩

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

*: tree species that have received the green colour in all their characteristics

Table 4.8. (Continued).

Scientific Name	Mckenney's study	broadleafed	number of factor of attractiveness	number of factor of unattractiveness	Scenario outcome
Tilia americana■	🟥	🟩	🟩	🟨	🟥
Acer nigrum	🟥	🟩	🟩	🟩	🟥
Acer platanoides	🟥	🟩	🟩	🟥	🟥
Acer pseudoplatanus	🟥	🟩	🟨	🟨	🟥
Aesculus hippocastanum	🟥	🟩	🟩	🟩	🟥
Carpinus caroliniana	🟩	🟩	🟩	🟩	🟩 *
Carya cordiformis	🟩	🟩	🟩	🟩	🟩 *
Carya ovata	🟥	🟩	🟩	🟨	🟥
Castanea dentata	🟩	🟩	🟩	🟨	🟩
Catalpa bignonioides	🟥	🟩	🟩	🟩	🟥
Catalpa speciosa	🟥	🟩	🟩	🟩	🟥
Fagus sylvatica	🟥	🟩	🟩	🟩	🟥
Ginkgo biloba	🟥	🟩	🟩	🟨	🟥
Gleditsia triacanthos	🟩	🟩	🟩	🟩	🟩 *
Gymnocladus dioicus	🟥	🟩	🟩	🟨	🟥
Juglans nigra	🟩	🟩	🟩	🟩	🟩 *
Liriodendron tulipifera	🟩	🟩	🟩	🟩	🟩 *
Magnolia acuminata	🟩	🟩	🟩	🟩	🟩 *
Nyssa sylvatica	🟩	🟩	🟩	🟨	🟩
Picea abies	🟥	🟥	🟨	🟩	🟥
Platanus occidentalis	🟩	🟩	🟩	🟨	🟩
Quercus alba	🟩	🟩	🟩	🟩	🟩 *
Quercus bicolor	🟥	🟩	🟩	🟩	🟥
Quercus velutina	🟩	🟩	🟨	🟩	🟩
Robinia pseudoacacia	🟩	🟩	🟩	🟨	🟩
Salix nigra	🟥	🟩	🟩	🟨	🟥
Sassafras albidum	🟩	🟩	🟩	🟩	🟩 *
Ulmus rubra	🟥	🟩	🟩	🟩	🟥

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

*: tree species that have received the green colour in all their characteristics

Scenario 8b (The robustness of attractive needle-leafed tree species to climate change)

This scenario has four green-coloured tree species including *P. glauca*, *P. rubens*, *P. strobus,* and *T. canadensis*. *P. glauca* and *P. strobus* also have a star (Table 4.9). *T. occidentalis* is the only yellow-coloured tree species in this scenario. All of the species are native to NS. All of the needle-leafed trees in this research, if they have future climatic ranges in Halifax survive this scenario.

Table 4.9. The evaluation of 57 tree species in relation to Scenario 8b (The robustness of attractive needle-leafed trees to climate change) using the *Analytical Tool*.

Scientific Name	**Mckenney's study**	**broadleafed**	**number of factor of attractiveness**	**number of factor of unattractiveness**	**Scenario outcome**
Acer rubrum□	🟩	🟥	🟩	🟨	🟥
Acer saccharum□	🟩	🟥	🟩	🟨	🟥
Betula alleghaniensis□	🟩	🟥	🟩	🟨	🟥
Betula papyrifera□	🟩	🟥	🟨	🟨	🟥
Betula populifolia□	🟥	🟥	🟩	🟩	🟥
Fagus grandifolia□	🟩	🟥	🟩	🟨	🟥
Fraxinus americana□	🟩	🟥	🟩	🟨	🟥
Fraxinus nigra□	🟥	🟥	🟥	🟨	🟥
Fraxinus pennsylvanica□	🟩	🟥	🟩	🟨	🟥
Larix laricina□	🟥	🟩	🟩	🟩	🟥
Ostrya virginiana□	🟥	🟥	🟩	🟨	🟥
Picea glauca□	🟩	🟩	🟩	🟩	🟩 *
Picea mariana□	🟥	🟩	🟨	🟩	🟥
Picea rubens□	🟩	🟩	🟩	🟨	🟩
Pinus resinosa□	🟥	🟩	🟨	🟨	🟥
Pinus strobus□	🟩	🟩	🟩	🟩	🟩 *
Populus balsamifera□	🟩	🟥	🟨	🟨	🟥
Populus grandidentata□	🟥	🟥	🟩	🟩	🟥
Populus tremuloides□	🟩	🟥	🟩	🟨	🟥
Prunus serotina□	🟩	🟥	🟩	🟨	🟥
Quercus rubra□	🟩	🟥	🟩	🟨	🟥
Thuja occidentalis□	🟩	🟩	🟩	🟥	🟨
Tsuga canadensis□	🟩	🟩	🟩	🟨	🟩
Ulmus americana□	🟩	🟥	🟩	🟥	🟥
Acer saccharinum■	🟥	🟥	🟩	🟥	🟥
Juglans cinerea■	🟩	🟥	🟩	🟩	🟥
Pinus banksiana■	🟩	🟩	🟨	🟨	🟩
Prunus nigra■	🟥	🟥	🟩	🟩	🟥
Quercus macrocarpa■	🟩	🟥	🟩	🟨	🟥

□: indicates trees native to Nova Scotia ■: indicates tree native to New Brunswick in addition to those native to Nova Scotia

Table 4.9. (Continued).

Scientific Name	**Mckenney's study**	**broadleafed**	**number of factor of attractiveness**	**number of factor of unattractiveness**	**Scenario outcome**
Tilia americana■	🟥	🟥	🟩	🟨	🟥
Acer nigrum	🟥	🟥	🟩	🟩	🟥
Acer platanoides	🟥	🟥	🟩	🟥	🟥
Acer pseudoplatanus	🟥	🟥	🟨	🟨	🟥
Aesculus hippocastanum	🟥	🟥	🟩	🟨	🟥
Carpinus caroliniana	🟩	🟥	🟩	🟩	🟥
Carya cordiformis	🟩	🟥	🟩	🟩	🟥
Carya ovata	🟥	🟥	🟩	🟨	🟥
Castanea dentata	🟩	🟥	🟩	🟨	🟥
Catalpa bignonioides	🟥	🟥	🟩	🟥	🟥
Catalpa speciosa	🟥	🟥	🟩	🟥	🟥
Fagus sylvatica	🟥	🟥	🟩	🟨	🟥
Ginkgo biloba	🟥	🟥	🟩	🟨	🟥
Gleditsia triacanthos	🟩	🟥	🟩	🟩	🟥
Gymnocladus dioicus	🟥	🟥	🟩	🟨	🟥
Juglans nigra	🟩	🟥	🟩	🟩	🟥
Liriodendron tulipifera	🟩	🟥	🟩	🟩	🟥
Magnolia acuminata	🟩	🟥	🟩	🟩	🟥
Nyssa sylvatica	🟩	🟥	🟩	🟨	🟥
Picea abies	🟥	🟩	🟨	🟩	🟩
Platanus occidentalis	🟩	🟥	🟩	🟨	🟥
Quercus alba	🟩	🟥	🟩	🟩	🟥
Quercus bicolor	🟥	🟥	🟩	🟩	🟥
Quercus velutina	🟩	🟥	🟨	🟩	🟥
Robinia pseudoacacia	🟩	🟥	🟩	🟨	🟥
Salix nigra	🟥	🟥	🟩	🟨	🟥
Sassafras albidum	🟩	🟥	🟩	🟩	🟥
Ulmus rubra	🟥	🟥	🟩	🟨	🟥

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

*: tree species that have received the green colour in all their characteristics

Scenario 9 (The robustness of Nova Scotia native tree species to climate change)

As in Scenarios 6 and 7, the number of failing characteristics was counted for the tree species in this scenario. Six of the tree species fail one or two characteristics and are green coloured (Table 4.10). Seven species are yellow-coloured having failed three or four characteristics.

Table 4.10. The evaluation of Nova Scotian native tree species in relation to Scenario 9 (The robustness of Nova Scotia native tree species to climate change) using the *Analytical Tool*.

Scientific Name	Mckenney's study	mature height	tap root	tolerance to wind	tolerance to salt	tolerance to freezing rain/ icing	tolerance to ozone	tolerance to low nutrients	Scenario outcome
Acer rubrum	🟩	🟥	🟩	🟨	🟥	🟨	🟩	🟩	🟩 2
Acer saccharum	🟩	🟥	🟥	🟨	🟥	🟨	🟩	🟨	🟨 3
Betula alleghaniensis	🟩	🟥	🟥	🟨	🟨	🟨	🟩	🟨	🟩 2
Betula papyrifera	🟩	🟥	🟥	🟩	🟩	🟨	🟩	🟨	🟩 2
Betula populifolia	🟥	🟩	🟥	🟩	🟩	🟨	🟩	🟩	🟥
Fagus grandifolia	🟩	🟥	🟥	🟨	🟥	🟨	🟩	🟩	🟨 3
Fraxinus americana	🟩	🟥	🟩	🟩	🟩	🟨	🟥	🟥	🟨 3
Fraxinus nigra	🟥	🟨	🟥	🟥	🟥	🟥	🟥	🟨	🟥
Fraxinus pennsylvanica	🟩	🟥	🟥	🟨	🟨	🟩	🟨	🟨	🟩 2
Larix laricina	🟥	🟥	🟥	🟥	🟩	🟨	🟥	🟩	🟥
Ostrya virginiana	🟥	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟥
Picea glauca	🟩	🟥	🟥	🟥	🟨	🟨	🟩	🟥	🟨 4
Picea mariana	🟥	🟨	🟥	🟥	🟥	🟥	🟥	🟨	🟥
Picea rubens	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟥 6
Pinus banksiana	🟥	🟨	🟩	🟥	🟨	🟥	🟥	🟩	🟥
Pinus resinosa	🟥	🟥	🟩	🟩	🟥	🟨	🟥	🟩	🟥
Pinus strobus	🟩	🟥	🟩	🟨	🟥	🟨	🟥	🟩	🟨 3
Populus balsamifera	🟩	🟥	🟥	🟨	🟥	🟥	🟥	🟨	🟥 5
Populus grandidentata	🟥	🟨	🟥	🟨	🟨	🟨	🟥	🟨	🟥
Populus tremuloides	🟩	🟥	🟥	🟥	🟨	🟥	🟥	🟨	🟥 5
Prunus serotina	🟩	🟥	🟥	🟨	🟨	🟨	🟥	🟨	🟨 3
Quercus rubra	🟩	🟥	🟩	🟩	🟨	🟩	🟩	🟩	🟩 1
Thuja occidentalis	🟩	🟩	🟩	🟨	🟨	🟥	🟩	🟨	🟩 1
Tsuga canadensis	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟨	🟥 5
Ulmus americana	🟩	🟥	🟥	🟩	🟩	🟥	🟩	🟥	🟨 4

Scenario 10 (The robustness of other Acadian native tree species to climate change)

The results of this scenario (Table 4.11) are mostly the same as Scenario 9 with the changes described as follow: *Q. macrocarpa* (a tree failing none of the characteristics in this scenario) is added to the green-coloured tree species list. *J. cinerea* is also added to the yellow-coloured species list.

Table 4.11. The evaluation of Acadian native species in relation to Scenario 10 (The robustness of other Acadian native tree species to climate change) using the *Analytical Tool*.

Scientific Name	Mckenney's study	mature height	tap root	tolerance to wind	tolerance to salt	tolerance to freezing rain/ icing	tolerance to ozone	tolerance to low nutrients	Scenario outcome
Acer rubrum	🟩	🟥	🟩	🟨	🟥	🟨	🟩	🟩	🟩 2
Acer Saccharinum	🟥	🟥	🟥	🟥	🟩	🟥	🟩	🟥	🟥
Acer saccharum	🟩	🟥	🟥	🟨	🟥	🟨	🟩	🟨	🟨 3
Betula alleghaniensis	🟩	🟥	🟥	🟨	🟨	🟨	🟩	🟨	🟩 2
Betula papyrifera	🟩	🟥	🟥	🟩	🟩	🟨	🟩	🟨	🟩 2
Betula populifolia	🟥	🟩	🟥	🟩	🟩	🟨	🟩	🟩	🟥
Fagus grandifolia	🟩	🟥	🟥	🟨	🟥	🟨	🟩	🟩	🟨 3
Fraxinus americana	🟩	🟥	🟩	🟩	🟩	🟨	🟥	🟥	🟨 3
Fraxinus nigra	🟥	🟨	🟥	🟥	🟥	🟥	🟥	🟨	🟥
Fraxinus pennsylvanica	🟩	🟥	🟥	🟨	🟨	🟩	🟨	🟨	🟩 2
Juglans cinerea	🟩	🟥	🟩	🟨	🟥	🟥	🟩	🟨	🟨 3
Larix laricina	🟥	🟥	🟥	🟥	🟩	🟨	🟥	🟩	🟥
Ostrya virginiana	🟥	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟥
Picea glauca	🟩	🟥	🟥	🟥	🟨	🟨	🟩	🟥	🟨 4
Picea mariana	🟥	🟨	🟥	🟥	🟥	🟥	🟥	🟨	🟥
Picea rubens	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟥 6
Pinus banksiana	🟥	🟨	🟩	🟥	🟨	🟥	🟥	🟩	🟥
Pinus resinosa	🟥	🟥	🟩	🟩	🟥	🟨	🟥	🟩	🟥
Pinus strobus	🟩	🟥	🟩	🟨	🟥	🟨	🟥	🟩	🟨 3
Populus balsamifera	🟩	🟥	🟥	🟨	🟥	🟥	🟥	🟨	🟥 5
Populus grandidentata	🟥	🟨	🟥	🟨	🟨	🟨	🟥	🟨	🟥
Populus tremuloides	🟩	🟥	🟥	🟥	🟨	🟥	🟥	🟨	🟥 5
Prunus nigra	🟥	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Prunus serotina	🟩	🟥	🟥	🟨	🟨	🟨	🟥	🟨	🟨 3
Quercus macrocarpa	🟩	🟩	🟩	🟩	🟨	🟩	🟨	🟨	🟩
Quercus rubra	🟩	🟥	🟩	🟩	🟨	🟩	🟩	🟩	🟩 1
Thuja occidentalis	🟩	🟩	🟩	🟨	🟨	🟥	🟩	🟨	🟩 1
Tilia americana	🟥	🟥	🟥	🟨	🟥	🟥	🟩	🟨	🟥
Tsuga aanadensis	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟨	🟥 5
Ulmus americana	🟩	🟥	🟥	🟩	🟩	🟥	🟩	🟥	🟨 4

Scenario 11 (The robustness of tree species native to the eastern seaboard of the USA to climate change)

In this scenario, several tree species are added to the lists from the previous scenario. Six tree species are added to the green coloured list, and four are added to the yellow coloured species (Table 4.12). *Q. macrocarpa* and *N. sylvatica* do not fail any of the characteristics.

Table 4.12. The evaluation of tree species native to the USA in relation to Scenario 11 (The robustness of tree species native to the eastern seaboard of the USA to climate change) using the *Analytical Tool*.

Scientific Name	**Makenney's study**	**tap root**	**mature height**	**tolerance to wind**	**tolerance to salt**	**tolerance to freezing rain**	**tolerance to ozone**	**tolerance of low nutrients**	**Scenario outcome**
Acer nigrum	🟥	🟥	🟥	🟥	🟥	🟨	🟩	🟨	🟥
Acer platanoides	🟥	🟩	🟨	🟥	🟨	🟩	🟨	🟩	🟥
Acer pseudoplatanus	🟥	🟩	🟨	🟩	🟩	🟩	🟩	🟨	🟥
Acer rubrum	🟩	🟩	🟥	🟨	🟥	🟨	🟩	🟩	2
Acer Saccharinum	🟥	🟥	🟥	🟥	🟩	🟥	🟩	🟥	🟥
Acer saccharum	🟩	🟥	🟥	🟨	🟥	🟨	🟩	🟨	3
Aesculus hippocastanum	🟥	🟩	🟥	🟥	🟨	🟨	🟩	🟩	🟥
Betula alleghaniensis	🟩	🟥	🟥	🟨	🟨	🟨	🟩	🟨	2
Betula papyrifera	🟩	🟥	🟥	🟩	🟩	🟨	🟩	🟨	2
Betula populifolia	🟥	🟥	🟩	🟩	🟩	🟨	🟩	🟩	🟥
Carpinus caroliniana	🟩	🟥	🟩	🟩	🟥	🟩	🟥	🟨	3
Carya cordiformis	🟩	🟩	🟥	🟩	🟥	🟩	🟩	🟨	2
Carya ovata	🟥	🟩	🟥	🟩	🟥	🟩	🟩	🟨	🟥
Castanea dentata	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟨	6
Catalpa bignonioides	🟥	🟩	🟩	🟩	🟥	🟩	🟥	🟨	🟥
Catalpa speciosa	🟥	🟩	🟥	🟥	🟨	🟥	🟥	🟨	🟥
Fagus grandifolia	🟩	🟥	🟥	🟨	🟥	🟨	🟩	🟩	3
Fagus sylvatica	🟥	🟥	🟨	🟨	🟥	🟥	🟩	🟥	🟥
Fraxinus americana	🟩	🟩	🟥	🟩	🟩	🟨	🟥	🟥	3
Fraxinus nigra	🟥	🟥	🟨	🟥	🟥	🟥	🟥	🟨	🟥
Fraxinus pennsylvanica	🟩	🟥	🟥	🟨	🟨	🟩	🟨	🟨	2
Ginkgo biloba	🟥	🟩	🟥	🟩	🟨	🟩	🟩	🟨	🟥
Gleditsia triacanthos	🟩	🟩	🟥	🟩	🟩	🟩	🟥	🟨	2
Gymnocladus dioicus	🟥	🟥	🟥	🟩	🟩	🟩	🟥	🟩	🟥
Juglans cinerea	🟩	🟩	🟥	🟨	🟥	🟥	🟩	🟨	3
Juglans nigra	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	1
Larix laricina	🟥	🟥	🟥	🟥	🟩	🟨	🟥	🟩	🟥
Liriodendron tulipifera	🟩	🟥	🟥	🟩	🟥	🟥	🟥	🟥	6
Magnolia acuminata	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟥	4

Table 4.12. (Continued).

Scientific Name	Makenney's study	tap root	mature height	tolerance to wind	tolerance to salt	tolerance to freezing rain	tolerance to ozone	tolerance of low nutrients	Scenario outcome
Nyssa sylvatica	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟨	🟩 0
Ostrya virginiana	🟥	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟥
Picea abies	🟥	🟩	🟥	🟥	🟥	🟥	🟩	🟨	🟥
Picea glauca	🟩	🟥	🟥	🟥	🟨	🟨	🟩	🟥	🟨 4
Picea mariana	🟥	🟥	🟨	🟥	🟥	🟥	🟥	🟨	🟥
Picea rubens	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟥 6
Pinus banksiana	🟥	🟩	🟨	🟥	🟨	🟥	🟥	🟩	🟥
Pinus resinosa	🟥	🟩	🟥	🟩	🟥	🟨	🟥	🟩	🟥
Pinus strobus	🟩	🟩	🟥	🟨	🟥	🟨	🟥	🟩	🟨 3
Platanus occidentalis	🟩	🟥	🟥	🟩	🟥	🟩	🟥	🟨	🟨 4
Populus balsamifera	🟩	🟥	🟥	🟨	🟥	🟥	🟥	🟨	🟥 5
Populus grandidentata	🟥	🟥	🟨	🟨	🟨	🟨	🟥	🟨	🟥
Populus tremuloides	🟩	🟥	🟥	🟥	🟨	🟥	🟥	🟨	🟥 5
Prunus nigra	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟥	🟥
Prunus serotina	🟩	🟥	🟥	🟨	🟨	🟨	🟥	🟨	🟨 3
Quercus alba	🟩	🟩	🟥	🟩	🟩	🟩	🟥	🟩	🟩 2
Quercus bicolour	🟥	🟥	🟨	🟩	🟩	🟩	🟩	🟨	🟥
Quercus macrocarpa	🟩	🟩	🟩	🟩	🟨	🟩	🟨	🟨	🟩 0
Quercus rubra	🟩	🟩	🟥	🟩	🟨	🟩	🟩	🟩	🟩 1
Quercus velutina	🟩	🟩	🟨	🟩	🟥	🟩	🟨	🟨	🟩 1
Robinia pseudoacacia	🟩	🟥	🟨	🟥	🟩	🟥	🟥	🟩	🟨 4
Salix nigra	🟥	🟥	🟩	🟥	🟨	🟥	🟥	🟨	🟥
Sassafras albidum	🟩	🟩	🟨	🟥	🟥	🟥	🟥	🟩	🟨 4
Thuja occidentalis	🟩	🟩	🟩	🟨	🟨	🟥	🟩	🟨	🟩 1
Tilia americana	🟥	🟥	🟥	🟨	🟥	🟥	🟩	🟨	🟥
Tsuga canadensis	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟨	🟥 5
Ulmus americana	🟩	🟥	🟥	🟩	🟩	🟥	🟩	🟥	🟨 4
Ulmus rubra	🟥	🟩	🟥	🟩	🟥	🟥	🟩	🟨	🟥

4.2 Accumulated Results

In the section below, I examine the results of all the scenarios together to understand how each tree species survived multiple scenarios. As described in the methods chapter, the different number of tree species in scenarios 9, 10, 11 requires three separate evaluations. These different evaluations will go by the names evaluation 1, 2 and 3. Each evaluation was done twice because Scenario 8 has two sections (a and b). The first time includes scenario 8a and the second time includes scenario 8b; the combination of the two will be described as the result of each evaluation. Tree species not surviving the McKenney *et al.* (2007a & b) study were deleted from these evaluations.

4.2.1 Evaluation 1

The first evaluation examines the results of Scenarios 2 to 8 (a and b) in addition to Scenario 9. The results are as follow:

Tree species are categorized into four groups (Table 4.13 and 4.14). Group one are tree species succeeding in all scenarios. *F. grandifolia* is the only tree species in this group. Group two are tree species failing only one scenario. Group three are tree species failing two scenarios. And the last group is tree species that fail more than two scenarios. No tree species fails more than four scenarios. The categories are presented in the colours as they were presented in the scenarios. The first two groups are coloured green. The third group of trees was coloured yellow and the fourth group was coloured red.

The results of Scenario 1 are also included in the tables. This helps to understand how well the tree species that are currently planted in Halifax are doing compared to the scenario analysis.

Table 4.13. Accumulated scenario results for NS native trees species - With Scenario 8a.

Scientific Name	scenario 2	scenario 9	scenario 3	scenario 4	scenario 5	scenario 6	scenario 7	scenario 8a	Number of failing scenarios	scenario 1
Acer rubrum	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟩	1	🟩
Acer saccharum	🟩	🟨	🟨	🟨	🟩	🟥	🟨	🟩	1	🟩
Betula alleghaniensis	🟩	🟩	🟨	🟨	🟩	🟥	🟨	🟩	1	🟩
Betula papyrifera	🟩	🟩	🟨	🟥	🟩	🟥	🟨	🟩	2	🟥
Carpinus caroliniana	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Carya cordiformis	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Castanea dentata	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Fagus grandifolia	🟩	🟨	🟨	🟨	🟩	🟨	🟩	🟩	0	🟥
Fraxinus americana	🟩	🟨	🟩	🟨	🟩	🟥	🟨	🟩	1	🟩
Fraxinus pennsylvanica	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟩	1	🟥
Gleditsia triacanthos	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Juglans cinerea	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Juglans nigra	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Liriodendron tulipifera	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Magnolia acuminata	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Nyssa sylvatica	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Picea glauca	🟩	🟨	🟥	🟨	🟥	🟨	🟨	🟥	⬛	🟩
Picea rubens	🟩	🟥	🟨	🟥	🟥	🟨	🟨	🟥	⬛	🟥
Pinus strobus	🟩	🟨	🟩	🟨	🟥	🟩	🟨	🟥	⬛	🟩
Platanus occidentalis	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Populus balsamifera	🟩	🟥	🟥	🟥	🟨	🟩	🟥	🟩	4	🟥
Populus tremuloides	🟩	🟥	🟥	🟨	🟨	🟥	🟨	🟩	3	🟩
Prunus serotina	🟩	🟨	🟨	🟥	🟩	🟥	🟨	🟩	2	🟩
Quercus alba	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Quercus macrocarpa	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Quercus rubra	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	1	🟩
Quercus velutina	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Robinia pseudoacacia	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Sassafras albidum	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Thuja occidentalis	🟩	🟩	🟥	🟨	🟥	🟨	🟨	🟥	⬛	🟩
Tsuga canadensis	🟩	🟥	🟨	🟨	🟥	🟩	🟨	🟥	⬛	🟩
Ulmus americana	🟩	🟨	🟩	🟨	🟩	🟥	🟨	🟨	1	🟩

⬛ tree species not native to Nova Scotia or not in Scenario 8a

Table 4.14. Accumulated scenario results for NS native trees species - With Scenario 8b.

Scientific Name	**scenario 2**	**scenario 9**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**	**scenario 8b**	**Number of failing scenario**	**scenario 1**
Acer rubrum	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟥	⬛	🟩
Acer saccharum	🟩	🟨	🟨	🟨	🟩	🟥	🟨	🟥	⬛	🟩
Betula alleghaniensis	🟩	🟩	🟨	🟨	🟩	🟥	🟨	🟥	⬛	🟩
Betula papyrifera	🟩	🟩	🟨	🟥	🟩	🟥	🟨	🟥	⬛	🟥
Carpinus caroliniana	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Carya cordiformis	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Castanea dentata	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Fagus grandifolia	🟩	🟨	🟨	🟨	🟩	🟨	🟩	🟥	⬛	🟥
Fraxinus americana	🟩	🟨	🟩	🟨	🟩	🟥	🟨	🟥	⬛	🟩
Fraxinus pennsylvanica	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟥	⬛	🟥
Gleditsia triacanthos	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Juglans cinerea	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Juglans nigra	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Liriodendron tulipifera	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Magnolia acuminata	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Nyssa sylvatica	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Picea glauca	🟩	🟨	🟥	🟨	🟥	🟨	🟨	🟩	🟨 2	🟩
Picea rubens	🟩	🟥	🟨	🟥	🟥	🟨	🟨	🟩	🟥 3	🟥
Pinus strobus	🟩	🟨	🟩	🟨	🟥	🟩	🟨	🟩	🟩 1	🟩
Platanus occidentalis	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Populus balsamifera	🟩	🟥	🟥	🟥	🟨	🟩	🟥	🟥	⬛	🟥
Populus tremuloides	🟩	🟥	🟥	🟨	🟨	🟥	🟨	🟥	⬛	🟩
Prunus serotina	🟩	🟨	🟨	🟥	🟩	🟥	🟨	🟥	⬛	🟩
Quercus alba	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Quercus macrocarpa	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Quercus rubra	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	⬛	🟩
Quercus velutina	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Robinia pseudoacacia	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Sassafras albidum	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Thuja occidentalis	🟩	🟩	🟥	🟨	🟥	🟨	🟨	🟨	🟨 2	🟩
Tsuga canadensis	🟩	🟥	🟨	🟨	🟥	🟩	🟨	🟩	🟨 2	🟩
Ulmus americana	🟩	🟨	🟩	🟨	🟩	🟥	🟨	🟥	⬛	🟩

⬛ tree species not native to Nova Scotia or not in Scenario 8b

4.2.2 Evaluation 2

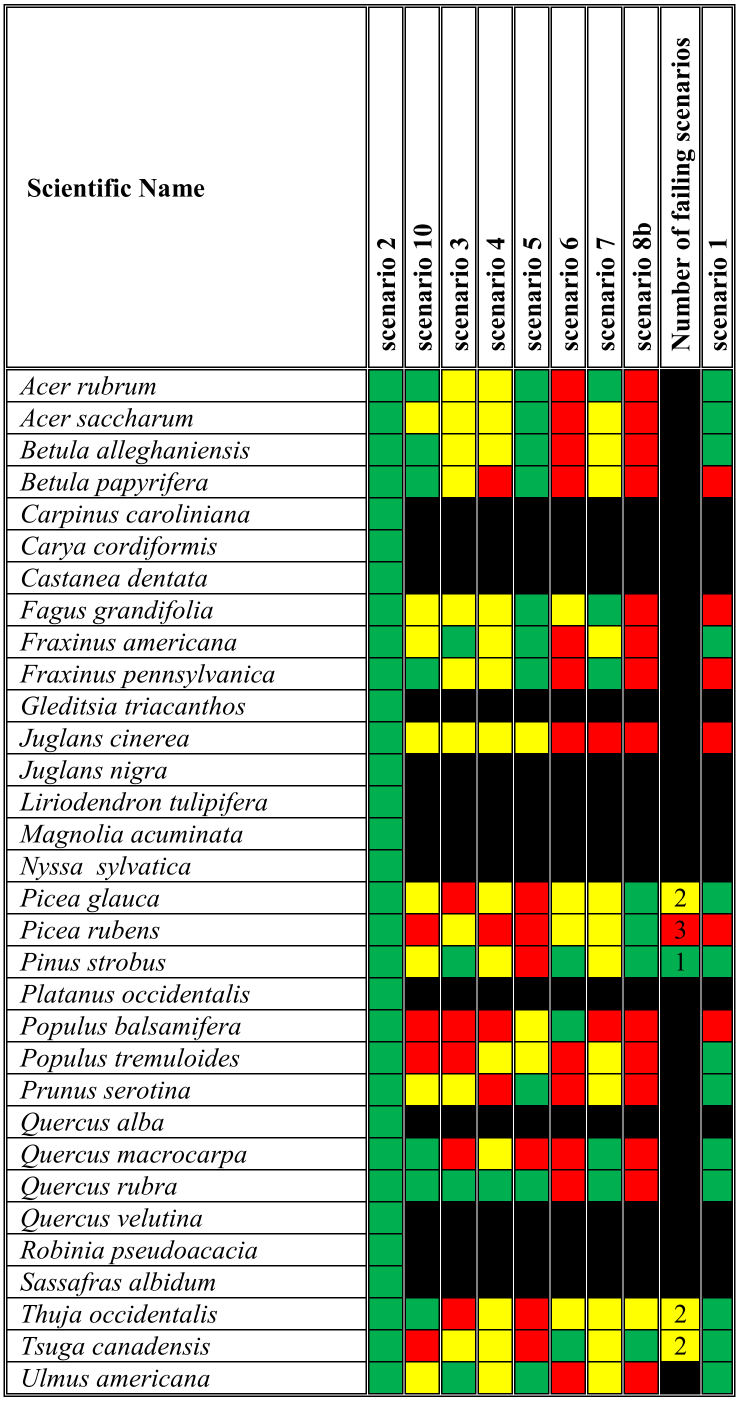
The second evaluation examines the results of Scenarios 2 to 8 (a and b) in addition to Scenario 10. The results are represented as they were represented in Evaluation 1. *F. grandifolia* is still the one tree species succeeding in all scenarios in this evaluation (Tables 4.15 and 4.16). The results of this scenario are also compared to the results of Scenario 1.

Table 4.15. Accumulated scenario results for Acadia native tree species - With Scenario 8a.

Scientific Name	**scenario 2**	**scenario 10**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**	**scenario 8a**	**Number of failing scenario**	**scenario 1**
Acer rubrum	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟩	🟩 1	🟩
Acer saccharum	🟩	🟨	🟨	🟨	🟩	🟥	🟨	🟩	🟩 1	🟩
Betula alleghaniensis	🟩	🟩	🟨	🟨	🟩	🟥	🟨	🟩	🟩 1	🟩
Betula papyrifera	🟩	🟩	🟨	🟥	🟩	🟥	🟨	🟩	🟨 2	🟥
Carpinus caroliniana	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Carya cordiformis	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Castanea dentata	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Fagus grandifolia	🟩	🟨	🟨	🟨	🟩	🟨	🟩	🟩	🟩 0	🟥
Fraxinus americana	🟩	🟨	🟩	🟨	🟩	🟥	🟨	🟩	🟩 1	🟩
Fraxinus pennsylvanica	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟩	🟩 1	🟥
Gleditsia triacanthos	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Juglans cinerea	🟩	🟨	🟨	🟨	🟨	🟥	🟥	🟩	🟨 2	🟥
Juglans nigra	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Liriodendron tulipifera	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Magnolia acuminata	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Nyssa sylvatica	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Picea glauca	🟩	🟨	🟥	🟨	🟥	🟨	🟨	🟥	⬛	🟩
Picea rubens	🟩	🟥	🟨	🟥	🟥	🟨	🟨	🟥	⬛	🟥
Pinus strobus	🟩	🟨	🟩	🟨	🟥	🟩	🟨	🟥	⬛	🟩
Platanus occidentalis	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Populus balsamifera	🟩	🟥	🟥	🟥	🟨	🟩	🟥	🟩	🟥 4	🟥
Populus tremuloides	🟩	🟥	🟥	🟨	🟨	🟥	🟨	🟩	🟥 3	🟩
Prunus serotina	🟩	🟨	🟨	🟥	🟩	🟥	🟨	🟩	🟨 2	🟩
Quercus alba	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Quercus macrocarpa	🟩	🟩	🟥	🟨	🟥	🟥	🟩	🟩	🟥 3	🟩
Quercus rubra	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩 1	🟩
Quercus velutina	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Robinia pseudoacacia	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Sassafras albidum	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Thuja occidentalis	🟩	🟩	🟥	🟨	🟥	🟨	🟨	🟥	⬛	🟩
Tsuga canadensis	🟩	🟥	🟨	🟨	🟥	🟩	🟨	🟥	⬛	🟩
Ulmus americana	🟩	🟨	🟩	🟨	🟩	🟥	🟨	🟨	🟩 1	🟩

⬛ tree species not native to Acadia or not in Scenario 8a

Table 4.16. Accumulated scenario results for Acadia native tree species - With Scenario 8b.



Scientific Name	**scenario 2**	**scenario 10**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**	**scenario 8b**	**Number of failing scenarios**	**scenario 1**
Acer rubrum	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟥	⬛	🟩
Acer saccharum	🟩	🟨	🟨	🟨	🟩	🟥	🟨	🟥	⬛	🟩
Betula alleghaniensis	🟩	🟩	🟨	🟨	🟩	🟥	🟨	🟥	⬛	🟩
Betula papyrifera	🟩	🟩	🟨	🟥	🟩	🟥	🟨	🟥	⬛	🟥
Carpinus caroliniana	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Carya cordiformis	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Castanea dentata	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Fagus grandifolia	🟩	🟨	🟨	🟨	🟩	🟨	🟩	🟥	⬛	🟥
Fraxinus americana	🟩	🟨	🟩	🟨	🟩	🟥	🟨	🟥	⬛	🟩
Fraxinus pennsylvanica	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟥	⬛	🟥
Gleditsia triacanthos	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Juglans cinerea	🟩	🟨	🟨	🟨	🟨	🟥	🟥	🟥	⬛	🟥
Juglans nigra	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Liriodendron tulipifera	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Magnolia acuminata	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Nyssa sylvatica	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Picea glauca	🟩	🟨	🟥	🟨	🟥	🟨	🟨	🟩	🟨 2	🟩
Picea rubens	🟩	🟥	🟨	🟥	🟥	🟨	🟨	🟩	🟥 3	🟥
Pinus strobus	🟩	🟨	🟩	🟨	🟥	🟩	🟨	🟩	🟩 1	🟩
Platanus occidentalis	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Populus balsamifera	🟩	🟥	🟥	🟥	🟨	🟩	🟥	🟥	⬛	🟥
Populus tremuloides	🟩	🟥	🟥	🟨	🟨	🟥	🟨	🟥	⬛	🟩
Prunus serotina	🟩	🟨	🟨	🟥	🟩	🟥	🟨	🟥	⬛	🟩
Quercus alba	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Quercus macrocarpa	🟩	🟩	🟥	🟨	🟥	🟥	🟩	🟥	⬛	🟩
Quercus rubra	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	⬛	🟩
Quercus velutina	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Robinia pseudoacacia	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Sassafras albidum	🟩	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Thuja occidentalis	🟩	🟩	🟥	🟨	🟥	🟨	🟨	🟨	🟨 2	🟩
Tsuga canadensis	🟩	🟥	🟨	🟨	🟥	🟩	🟨	🟩	🟨 2	🟩
Ulmus americana	🟩	🟨	🟩	🟨	🟩	🟥	🟨	🟥	⬛	🟩

⬛ tree species not native to Acadia or not in Scenario 8b

4.2.3 Evaluation 3

The third evaluation examines the results of Scenarios 2 to 8 (a and b) in addition to Scenario 11. The results are presented as they were in the previous evaluations (Tables 4.17 and 4.18). *F. grandifolia* and *G. triacanthos* are the only successors in all the scenarios. The results of this evaluation are also compared to the results of Scenario 1.

Table 4.17. Accumulated scenario results for US native tree species - With Scenario 8a.

Scientific Name	scenario 2	scenario 11	scenario 3	scenario 4	scenario 5	scenario 6	scenario 7	scenario 8a	Number of failing scenarios	scenario 1
Acer rubrum	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟩	1	🟩
Acer saccharum	🟩	🟨	🟨	🟨	🟩	🟥	🟨	🟩	1	🟩
Betula alleghaniensis	🟩	🟩	🟨	🟨	🟩	🟥	🟨	🟩	1	🟩
Betula papyrifera	🟩	🟩	🟨	🟥	🟩	🟥	🟨	🟩	2	🟥
Carpinus caroliniana	🟩	🟨	🟥	🟥	🟥	🟥	🟨	🟩	4	🟥
Carya cordiformis	🟩	🟩	🟥	🟩	🟩	🟨	🟩	🟩	1	🟥
Castanea dentata	🟩	🟥	🟩	🟥	🟩	🟨	🟥	🟩	3	🟥
Fagus grandifolia	🟩	🟨	🟨	🟨	🟩	🟨	🟩	🟩	0	🟥
Fraxinus americana	🟩	🟨	🟩	🟨	🟩	🟥	🟨	🟩	1	🟩
Fraxinus pennsylvanica	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟩	1	🟥
Gleditsia triacanthos	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟩	0	🟥
Juglans cinerea	🟩	🟨	🟨	🟨	🟨	🟥	🟥	🟩	2	🟥
Juglans nigra	🟩	🟩	🟩	🟨	🟩	🟥	🟩	🟩	1	🟩
Liriodendron tulipifera	🟩	🟥	🟩	🟨	🟩	🟨	🟥	🟩	2	🟩
Magnolia acuminata	🟩	🟨	🟩	🟥	🟩	🟩	🟨	🟩	1	🟥
Nyssa sylvatica	🟩	🟩	🟥	🟥	🟩	🟨	🟨	🟩	2	🟩
Picea glauca	🟩	🟥	🟥	🟨	🟥	🟨	🟨	🟥	⬛	🟩
Picea rubens	🟩	🟥	🟨	🟥	🟥	🟨	🟨	🟥	⬛	🟥
Pinus strobus	🟩	🟨	🟩	🟨	🟥	🟩	🟨	🟥	⬛	🟩
Platanus occidentalis	🟩	🟨	🟩	🟥	🟩	🟥	🟨	🟩	2	🟥
Populus balsamifera	🟩	🟥	🟥	🟥	🟨	🟩	🟥	🟩	4	🟥
Populus tremuloides	🟩	🟥	🟥	🟨	🟨	🟥	🟨	🟩	3	🟩
Prunus serotina	🟩	🟨	🟨	🟥	🟩	🟥	🟨	🟩	2	🟩
Quercus alba	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟩	1	🟩
Quercus macrocarpa	🟩	🟩	🟥	🟨	🟥	🟥	🟩	🟩	3	🟩
Quercus rubra	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	1	🟩
Quercus velutina	🟩	🟩	🟩	🟥	🟩	🟥	🟨	🟩	2	🟥
Robinia pseudoacacia	🟩	🟨	🟨	🟩	🟩	🟥	🟨	🟩	1	🟩
Sassafras albidum	🟩	🟨	🟥	🟨	🟨	🟨	🟥	🟩	2	🟥
Thuja occidentalis	🟩	🟩	🟥	🟨	🟥	🟨	🟨	🟥	⬛	🟩
Tsuga canadensis	🟩	🟥	🟨	🟨	🟥	🟩	🟨	🟥	⬛	🟩
Ulmus americana	🟩	🟨	🟩	🟨	🟩	🟥	🟨	🟨	1	🟩

⬛ tree species not in scenario 8a

Table 4.18. Accumulated scenario results for US native tree species - With Scenario 8b.

Scientific Name	**scenario 2**	**scenario 11**	**scenario 3**	**scenario 4**	**scenario 5**	**scenario 6**	**scenario 7**	**scenario 8b**	**Number of failing scenarios**	**scenario 1**
Acer rubrum	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟥	⬛	🟩
Acer saccharum	🟩	🟨	🟨	🟨	🟩	🟥	🟨	🟥	⬛	🟩
Betula alleghaniensis	🟩	🟩	🟨	🟨	🟩	🟥	🟨	🟥	⬛	🟩
Betula papyrifera	🟩	🟩	🟨	🟥	🟩	🟥	🟨	🟥	⬛	🟥
Carpinus caroliniana	🟩	🟨	🟥	🟥	🟥	🟥	🟨	🟥	⬛	🟥
Carya cordiformis	🟩	🟩	🟥	🟩	🟩	🟨	🟩	🟥	⬛	🟥
Castanea dentata	🟩	🟥	🟩	🟥	🟩	🟨	🟥	🟥	⬛	🟥
Fagus grandifolia	🟩	🟨	🟨	🟨	🟩	🟨	🟩	🟥	⬛	🟥
Fraxinus americana	🟩	🟨	🟩	🟨	🟩	🟥	🟨	🟥	⬛	🟩
Fraxinus pennsylvanica	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟥	⬛	🟥
Gleditsia triacanthos	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟥	⬛	🟥
Juglans cinerea	🟩	🟨	🟨	🟨	🟨	🟥	🟥	🟥	⬛	🟥
Juglans nigra	🟩	🟩	🟩	🟨	🟩	🟥	🟩	🟥	⬛	🟩
Liriodendron tulipifera	🟩	🟥	🟩	🟨	🟩	🟨	🟥	🟥	⬛	🟩
Magnolia acuminata	🟩	🟥	🟩	🟥	🟩	🟩	🟨	🟥	⬛	🟥
Nyssa sylvatica	🟩	🟩	🟥	🟥	🟩	🟨	🟨	🟥	⬛	🟩
Picea glauca	🟩	🟨	🟥	🟨	🟥	🟨	🟨	🟩	🟨 2	🟩
Picea rubens	🟩	🟥	🟨	🟥	🟥	🟨	🟨	🟩	🟥 3	🟥
Pinus strobus	🟩	🟨	🟩	🟨	🟥	🟩	🟨	🟩	🟩 1	🟩
Platanus occidentalis	🟩	🟥	🟩	🟥	🟩	🟥	🟨	🟥	⬛	🟥
Populus balsamifera	🟩	🟥	🟥	🟥	🟨	🟩	🟥	🟥	⬛	🟥
Populus tremuloides	🟩	🟥	🟥	🟨	🟨	🟥	🟨	🟥	⬛	🟩
Prunus serotina	🟩	🟨	🟨	🟥	🟩	🟥	🟨	🟥	⬛	🟩
Quercus alba	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟥	⬛	🟩
Quercus macrocarpa	🟩	🟩	🟥	🟨	🟥	🟥	🟩	🟥	⬛	🟩
Quercus rubra	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	⬛	🟩
Quercus velutina	🟩	🟩	🟩	🟥	🟩	🟥	🟨	🟥	⬛	🟥
Robinia pseudoacacia	🟩	🟥	🟨	🟩	🟩	🟥	🟨	🟥	⬛	🟩
Sassafras albidum	🟩	🟥	🟥	🟨	🟨	🟨	🟥	🟥	⬛	🟥
Thuja occidentalis	🟩	🟩	🟥	🟨	🟥	🟨	🟨	🟨	🟨 2	🟩
Tsuga canadensis	🟩	🟥	🟨	🟨	🟥	🟩	🟨	🟩	🟨 2	🟩
Ulmus americana	🟩	🟥	🟩	🟨	🟩	🟥	🟨	🟥	⬛	🟩

⬛ tree species not in scenario 8b

4.3 The Characteristic Count Analysis

This section examines the results of the second procedure taken to tree species selection. In the characteristics count method, the total number of green, yellow and red characteristics that each tree species received in each scenario using the analytical tool was counted (a combined number of 57 characteristics was studied in the analysis procedure). As described in Chapter 3, each colour was given a value. So for each tree species, the characteristics were counted and multiplied by their values. The results of this procedure are presented in the calculated value column of Table 4.19 also with the analytical Tool. It is important to mention that those tree species that failed the Mckenney *et al.* (2007a & b) study were not included in this procedure.

Table 4.19. Calculated tree value from all characteristics studied in all scenarios for tree species that succeeded in Scenario 2.

Scientific Name	number of red characteristics (value=0)	number of yellow characteristics (value=1)	number of green characteristics (value=2)	calculated tree values
Acer rubrum□	13	9	17	43
Acer saccharum□	14	10	15	40
Betula alleghaniensis□	13	12	14	40
Betula papyrifera□	14	7	18	43
Fagus grandifolia□	11	9	19	47
Fraxinus americana□	11	11	17	45
Fraxinus pennsylvanica□	12	9	18	45
Picea glauca□	13	13	13	39
Picea rubens□	16	9	14	37
Pinus strobus□	13	6	20	46
Populus balsamifera□	19	7	13	33
Populus tremuloides□	17	8	14	36
Prunus serotina□	14	10	15	40
Quercus rubra□	8	9	22	*53
Thuja occidentalis□	13	9	17	43
Tsuga canadensis□	11	11	17	45
Ulmus americana□	12	5	22	49
Juglans cinerea■	18	8	13	34
Quercus macrocarpa■	9	9	21	*51
Carpinus caroliniana	16	6	17	40
Carya cordiformis	9	9	21	*51
Castanea dentata	17	8	14	36
Gleditsia triacanthos	8	9	22	*53
Juglans nigra	8	7	24	*55
Liriodendron tulipifera	16	6	17	40
Magnolia acuminata	15	5	19	43
Nyssa sylvatica	11	7	21	49
Platanus occidentalis	17	7	15	37
Quercus alba	11	7	21	49
Quercus velutina	10	12	17	46
Robinia pseudoacacia	15	8	16	40
Sassafras albidum	16	7	16	39

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

*: tree species with the most suitable characteristics

CHAPTER 5: DISCUSSION

This research has aimed at developing a comprehensive method for considering multiple factors and scenarios in tree-species selection for cities, specifically the city of Halifax. I have tried to incorporate important elements that were lacking in previous tree-species selection methods.

5.1 Comparison of Previous Tree-Species Selection Methods to this Research

The USDA (2004) large-tree argument is a general preposition that tree size is the key criterian in tree selection. This research compares the benefits of larger stature trees as opposed to smaller stature trees, mostly from the economic standpoint, and does not further examine details of site constraints and other limiting factors that could prevent certain tree species from thriving. Furthermore the effects of a changing climate on trees are not considered. For instance, large trees may be more vulnerable to the stronger winds and windstorms that are predicted to happen more frequently because of the changing climate. In my research I do not insist on the planting of larger trees. Adaptation to both the urban environment and the future climate of the study area are criteria that are important in my tree-species selection method. In my research, trees are not just studied in relation to their size, but are also examined in many other characteristics. However the results of Scenario 5 (the robustness of the large-tree argument to climate change) show that all except for two of the trees studied in my research that will succeed in the future climate of Halifax are in agreement with the large tree argument and are considered to be fairly tall trees.

The Saebo *et al.* (2003) tree-species selection research for the Nordic countries studied the many stresses imposed on trees from urban environments. Similar to what I have done in this research, they studied a variety of tree characteristics before developing their tree selection method. The Saebo *et al.* (2003) research also examined other tree-species selection methods used throughout Europe, for example the Dafo system that is used in Denmark or in Sweden where they select the neighbouring tree-species of the nature surrounding the urban environment for planting in cities. Saebo and colleagues combined their characteristic study with the advantages of other tree selection methods used in

Europe, and in the end suggested the differentiation of the selection criteria for street, park and woodland tree species. Compared to my research, the extent of the characteristics studied in Saebo *et al.* (2003) research is far less than the tree characteristics used in my tree species database. Saebo and colleagues mainly examined tree tolerances to urban stress, whereas in my research, in addition to those, I also consider growth habits, cultural importance, different applications, hazards, and many other characteristics of the trees. Also, despite the fact that Saebo *et al*. (2003) insist on considering climate adaptation before selecting tree species, their study lacks any notice of climate change effects on tree species and their future climatic ranges. On the other hand, my research used the results of the McKenney *et al.* (2007a & b) future climate envelope research to examine if the tree species I studied will be well fitted to the future climate of Halifax.

In Cushing's (2009) study, tree selection is based on both what the literature represents and also the knowledge and experience gathered from experts working with trees in different cities. It does mention the importance of studying tree physiology and its relation to site conditions where a tree is to be planted. Cushing's guide uses Saebo *et al.,* (2003) differentiation between the criteria for selecting tree species. Similar to my research, we have both used a combination of details, literature and databases to develop a tree species selection tool, However, Cushing's selection guide uses fewer criteria than the criteria used in my tree-species database and lacks explicit attention to climate change in tree-species selection. It does not examine the range shifts of tree species and whether the trees currently being planted in the Greater Toronto Area will be suited to the future climate and if they will survive the change.

On the other hand, Yang's (2009) research on species selection in relation to climate change for the city of Philadelphia does examine range shifts of tree species. He used the results from the McKenney *et al.* (2007a & b) climate envelope study on 60 tree species to examine future climatic ranges of the trees currently existing in Philadelphia. He examines the main pests and diseases of these tree species in Philadelphia and climate change effects on them as well. This leads him to the development of a tree-species list for planting in Philadelphia's urban forest. Although I used the results of McKenney's climate envelope study to examine future climatic ranges for the tree species as Yang did, I did not study future climate envelopes of the main pests and diseases of the tree species. Due to the extent of this research, the climate envelopes of the main pests and diseases of the tree species were not studied, but the main pests and diseases currently affecting the tree species were considered as criteria in my tree selection and trees that could be at risk of serious threats from pests and pathogens were either omitted or were given less value for plantation in comparison to other tree species. What seems to be missing from Yang's (2009) study is including stresses imposed on trees from the urban environment and taking into account growth factors of tree species that will limit the successful establishment of some species in certain places. In my work, I studied tree species extensively in relation to urban environments with the development of the tree species database.

The developed tree species database in this research enabled the examination of trees species across a wide variety of criteria. These criteria cover different aspects of trees from general growth information to biotic needs, tree tolerances to different stresses, wood value, aesthetic factors, main pests and diseases, negative issues of trees, cultural importance, and the interaction between trees species, humans and wildlife. In the database, 95 characteristics were used to describe individual tree species. This helped me gain broad knowledge of each tree species before developing the tree selection methods.

The climate envelope research used in this study is that of McKenney *et al.* (2007a & b), which examine current and future distribution of 130 North American tree species. There are a few projects that have studied climate envelopes for trees and plants in North America: the, McKenney *et al.* (2007a & b) research is the most recent and enables the study of broader ranges of tree species across borders of Canada and United States of America as opposed to other research such as the Iverson *et al.* (2004) climate envelope research where they only study 134 eastern United States trees species. The results of the McKenney *et al.* (2007a & b) study were used to determine which species will be suitable for Halifax, Nova Scotia, based on the future climate of the region.

Another step taken in this research but not in other studies is that of examining tree species in multiple scenarios as opposed to just one. These scenarios can be useful in different situations. For instance, if there is a need to sequester carbon dioxide faster, we could use the results of Scenario 3 -The robustness of tree species that are better at sequestering carbon dioxide to climate change-, Alternatively, in places where we need to have the least amount of hazard from trees (for example around children's playgrounds), we could use the results of Scenario 6 -The robustness of tree species with the least negative effects in urban environments to climate change-. Yet the combined results of all scenarios will give the option of selecting tree species that have all or most of the desired outcomes of all the scenarios developed in this research. What my research has done in addition to all the steps mentioned above and to ensure that the scenario analysis is a suitable method in selecting tree species, a second method was used to find if there were similarities in the results achieved from both methods. The second method (the characteristic count analysis) was solely based on selecting tree species based on their good, medium and bad characteristics for plantation in urban environments.

5.2 Discussion on the Results of this Research

The results achieved from the two methods; the scenario analysis and the characteristic count analysis, are very much alike. Several tree species received the same rating from both methods (Table 5.1). However, for those tree species that did not receive the same rating, there is not a dramatic difference between their ratings. Of the 32 tree species that have future climatic ranges in Halifax, 13 had the same rating in both methods, and 19 had a level difference between the ratings (*e.g.* if they received green from one method, they received yellow from another). This difference could have happened due to the repetition of some characteristics in different scenarios. Meaning that if a tree had a good characteristic that had been repeated in different scenarios, it would have resulted in a better outcome in the scenario analysis for the tree than in the characteristic count analysis, and vise versa.

There was only one tree species that had a big gap between the ratings it received, *Q. macrocarpa*, which received a green star from the characteristic count and a red from the scenario analysis. As predicted in Chapter 3, this was a result of failing characteristics that were repetitive in various scenarios.

Table 5.1. Comparison of results of the two analytical methods.

Scientific Name	**Results from the scenario analysis method**	**Results from the characteristic count method**
Acer rubrum□	🟩	🟨
Acer saccharum□	🟩	🟨
Betula alleghaniensis□	🟩	🟨
Betula papyrifera□	🟨	🟨
Fagus grandifolia□	🟩 *	🟩
Fraxinus americana□	🟩	🟨
Fraxinus pennsylvanica□	🟩	🟩
Picea glauca□	🟨	🟥
Picea rubens□	🟥	🟥
Pinus strobus□	🟩	🟩
Populus balsamifera□	🟥	🟥
Populus tremuloides□	🟥	🟥
Prunus serotina□	🟨	🟨
Quercus rubra□	🟩	🟩 *
Thuja occidentalis□	🟨	🟨
Tsuga canadensis□	🟨	🟩
Ulmus americana□	🟩	🟩
Juglans cinerea■	🟨	🟥
Quercus macrocarpa■	🟥	🟩 *
Carpinus caroliniana	🟥	🟨
Carya cordiformis	🟩	🟩 *
Castanea dentate	🟥	🟥
Gleditsia triacanthos	🟩 *	🟩 *
Juglans nigra	🟩	🟩 *
Liriodendron tulipifera	🟨	🟨
Magnolia acuminata	🟩	🟩
Nyssa sylvatica	🟨	🟩
Platanus occidentalis	🟨	🟥
Quercus alba	🟩	🟩
Quercus velutina	🟨	🟩
Robinia pseudoacacia	🟩	🟨
Sassafras albidum	🟨	🟥

□: tree species native to NS ■: tree species native to NB in addition to those native to NS

*: tree species that have received the highest rating based on the analysis methods used.

The results of both methods were shown to urban forest experts in Halifax consisting of a landscape architect, an arborist, and a city planner. In a meeting, the ratings that each tree species received were discussed and opinions and concerns were expressed for each tree species. The initial species list (Table 5.2) was developed following the discussion at the meeting. The most important decisions made at the meeting are as follows:

1) Most of the tree species that received the same rating from both methods were represented in the suggested tree list for Halifax with the same colour.

2) After the main pests and diseases of tree species were discussed, in cases where there were serious threats imposed by certain types of pests, the lower rating that the tree species received from either of the methods was chosen to represent the species in the recommended tree list for Halifax. This was done to take a precautionary approach given the lack of information about the future range of pest and disease.

3) On the other hand, those tree species that are considered valuable or are listed as Acadian old-growth tree species such as *A. saccharum* and *T. canadensis* were represented with the upper rating that they received from either of the methods in the recommended tree list for Halifax. This was done to take action in preserving these species.

4) For those species that had failed according to both methods and had received a red-colour rating, however if they had cultural importance for the city or if they were listed as endangered species, their ratings were changed and they were given a yellow colour. This decision was based on keeping these tree species because of their values but at the same time the yellow colour also indicated that they could not be planted everywhere and that urban foresters needed to take caution before planting them. *P. rubens* received the red-colour rating from both methods of analysis; however, because it is the provincial tree of Nova Scotia its rating was changed in the recommended tree species list for Halifax to yellow so that urban foresters would be encouraged to preserve the species.

5) Another species that was extensively discussed in the meeting was *G. triacanthos* which received a green star from both methods. Urban foresters have previously tried to plant this species in Halifax but have not yet been successful with its survival. There is a possibility that this species may not be well suited to the current climate but would be able to survive in the future climate. Therefore in the recommended species list for Halifax, this species lost its star and was only represented with green.

6) Since there was a big gap between the two ratings that *Q. macrocarpa* received from the two methods, and to take account of the red-colour rating that it received in the scenario analysis, this species lost its star and was represented in the recommended species list for Halifax with a green colour only.

7) *U. americana* has lost most of it population across North America because of the dutch elm disease (Tree Canada 2011). However tree experts in Halifax are not overly concerned because it seems that the disease has not been affecting the *U. americana* population here and that the disease has not yet become a threat. In addition, the urban forest planners have recently been planting purportedly disease-resistant cultivars of the species. Therefore, the experts decided to keep the green-colour rating that this tree received from both methods because of the many benefits of the species and if in the future, the urban foresters experience decline in the species population, precautionary steps would be taken as needed in its plantation.

Table 5.2. Recommended tree species for plantation in Halifax under a changing climate.

Scientific Name	**The combined results of both methods**
Acer rubrum□	* 🟩
Acer saccharum□	🟩
Betula alleghaniensis□	🟩
Betula papyrifera□	🟨
Fagus grandifolia□	🟩
Fraxinus americana□	🟩
Fraxinus pennsylvanica□	🟩
Picea rubens□	🟨
Pinus strobus□	🟩
Prunus serotina□	🟨
Quercus rubra□	🟩
Thuja occidentalis□	🟨
Tsuga canadensis□	🟩
Ulmus americana□	🟩
Juglans cinerea■	🟨
Quercus macrocarpa■	🟩
Carya cordiformis	* 🟩
Gleditsia triacanthos	🟩
Juglans nigra	* 🟩
Liriodendron tulipifera	🟨
Magnolia acuminate	🟨
Nyssa sylvatica	🟩
Platanus occidentalis	🟨
Quercus alba	🟩
Quercus velutina	🟨
Robinia pseudoacacia	🟩
Sassafras albidum	🟨

□: tree species native to NS   ■: tree species native to NB in addition to those native to NS

*: tree species that have received the highest rating from both methods of analysis

5.3 Discussion on the Recommended Tree List

The recommended tree species all have future climatic ranges in Halifax as determined using the McKenney *et al.* (2007a & b) analysis. They can tolerate most of the various stresses imposed by the urban environment and require modest amounts of care and maintenance. Most can tolerate strong winds, salt and freezing rain which are important in the context of Halifax. They have low known risks of pest and pathogen invasions, and they are not considered to be invasive. Also, according to the results of Scenario 8 (a &b), none of them are considered to be unattractive.

Tree species were selected for study from the eastern shore of North America for two reasons. First, they are the tree species that will migrate most readily into Nova Scotia based on their north-easterly ranges. Second, it is better to select tree species from similar climatic zones. The climate in maritime regions does not resemble that of continental regions. Therefore, trees that usually grow in continental areas may not be as successful when they grow in maritime areas (Saebo *et al.* 2003). Climate similarities can be used as a basis for tree-species selection. Non-indigenous species should be tested and approved by urban foresters before being widely planted in cities (Saebo *et al.* 2003). One should have in mind that not all alien plants are considered to be invasive. The recommended species list offers a variety of tree species which will help to maintain urban forest biodiversity which will help ensure the future health of the urban forest.

The tree species selected for the Halifax urban forest are and will be well suited to the Halifax urban environment and therefore the chances of the trees becoming maladapted will be relatively low, which in turn potentially minimizes the loss due to climate-change disturbances. The well-adapted tree species can respond best to pest and insect infestations and disease outbreaks.

5.4 Research Limitations

This research has limitations both in the data collection phase and the analysis phase. Here I review limitations of the research and cover areas where improvement is needed.

The limitations of the data collection phase include:

1) **The number of characteristics.** Although this research examines 95 tree characteristics, to make the database more complete, some characteristics could be added to the list, specifically those that had to be deleted from the list at some point because of the lack of data. Examples of some of these characteristics could include: the degree of sprouting branches when pruned, long day plants, short day plants, timing of bud-break, and timing of leaf-drop. These characteristics could help to better understand where to plant tree species.

2) **The number of tree species.** The research avoided the study of the cultivars and varieties of the chosen tree species. There is a possibility that many of the cultivars and varieties would have been successful in both methods of analysis. There is even a possibility that the future climatic ranges of the cultivars and varieties of those tree species that themselves did not have a future climatic range in Halifax would have extended further than the original species, and possibly would have made it to the recommended species list.

   As tree plantations in urban settings is mostly human-assisted, tree species from other parts of North America could also have been examined to find their suitability for plantation in Halifax, even if they are not in close enough proximity to have the ability to migrate to this region. In the predicted future climate, a tree species that currently exists along the Pacific coast of Canada, for example, may also be able to grow and thrive in the Atlantic coast Canada. This examination was outside the scope of this research.

3) **The lack of data.** Some tree species have been studied extensively because of their beauty, their wood quality, their fruits etc., and some have not been studied to that extent. Thus, there was a lack of data for some tree species and further research on them would complete the database. There is also a significant amount of anecdotal data on tree species that were gathered from experienced gardeners, nursery owners, and homeowners. More scientific research is needed to validate these data.

4) **Lack of consensus between experts**. In some cases, experts have strong difference in opinions on certain tree characteristics. This variety of ideas may stem from the different growth behaviours of trees in different areas or even differences in the expertise and the objectives of the person examining trees. For instance, landscape architects may study trees and examine them differently from the perspective of horticulturists. The option to consult local experts was added to the study to help resolve disagreements. The local experts helped to choose or correct the data based on their experience with tree species in Halifax and the behaviour they had previously seen in the various species. If experts could gather and agree on certain characteristics, there would be less uncertainty in the database.

The limitations in data analysis are caused mainly by the subjective decisions made throughout the analysis phase. These include decisions on:

1) **Assignment of ratings**. Decisions such as how the result column of each scenario was colour-rated, and what caused a tree to receive a green, yellow, or red colour, were to some extent subjective. One might decide to take a different approach and instead of choosing that a failure in one of the characteristic would cause a tree to receive a yellow rating in the result column, one would choose to give the yellow colour rating to trees that fail two characteristics. These types of subjective decisions were mostly seen in the result column of those scenarios where none of the tree species survived in any of the characteristics. For instance, in Scenario 6 which examines different tree hazards in urban conditions, when none of the species survived the scenario, it meant that none of the species in this research were completely without hazard. It was decided to count the number of failing characteristics to understand which tree has the minimal hazard, and the way the result column of these scenarios were rated was mainly based on my decisions.

2) Also the characteristics examined in the scenarios were assigned equal weights in the species selection process. This was done because we had no grounds upon which to assign variable criterion weightings. Users of the analytical tool are fully

at liberty to make such variable assignments. The characteristic count analysis method was chosen to solve this issue to some extent.

3) **Break points in scatter charts.** For several of the characteristics for which there was a need to find a range, scatter charts where made and the spread of the data was examined. Natural breakpoints were examined by me and my supervisor and were used to define ranges for the characteristics. For example by examining chart 2 in Appendix 1 one might decide to define trees shorter than 10 as short stature trees instead of the decision made in this research, where trees under 20 were defined as short stature trees. Future researchers may use other breakpoint methods such as Jenks Natural Break Optimization (McMaster and McMaster, 2002). However my examination of the breakpoints is a very simple approach and observing the charts one could identify the natural breakpoint in data.

4) **Recommending tree species based on the results of McKenney *et al.* (2007a & b) climate envelope research.** This research has recommended species based on them having future climatic ranges in Halifax. However, I am not indicating that those species that do not have future climatic ranges in Halifax by the year 2100 will not be able to survive if planted here; they may just not be as healthy as they would be within their natural climatic envelope.

5.5 Benefits of the Methods used in the Study

The developed method has several benefits:

- Firstly, the database is a cumulative outcome from other studies and databases gathered together to form a comprehensive database which includes characteristics that each of the original sources were missing.

- The colour referencing system used in the database will easily help to track the sources of which data for trees were obtained and change them if they do not seem reasonable. The database can be useful to anyone working on tree-species selection for urban planting.

- Using the results of a climate envelope research in this study before selecting tree species will increase the stability of the urban forest in the changing climate, reducing maintenance costs which could then be contributed to other venues such as an increase in tree plantations.
- The use of multiple scenarios to examine tree-species growth in cities will give the ability to urban foresters and planners to select tree species as needed and based on the situation they are facing.
- An advantage of the analytical tool is the ease it gives to translating words and numbers into colours without losing the value of the data. The tool will give to any urban forester or any tree expert an ability to select tree species. Even if urban foresters disagree with some of the data, data can be changed to their standard and they can easily use the tool and find whether their species of interest will be well suited for their desired location.

5.6 Final Words

Researchers should have in mind that even if there are uncertainties in the climatic predictions, it would not be harmful to prepare the urban forest for the worst-case scenario. The tree species that are poorly adapted to their climate will carry their undesirable effects into future decades and that is not what urban foresters should let happen. As Owen *et al*. (2009) describe, "Sustainable forest management aims to sustain the health of forest ecosystems while providing ecological, economic, social, and cultural opportunities for the long term".

Admittedly, the methods developed and used in this research to select tree species for the future of Halifax are of low sophistication. If urban forest managers would prefer a more sophisticated method, I would encourage them to develop such methods and compare their results to that of this research. If the results are similar, then we might be able to assume that the tool developed in my research is sufficient to select suitable tree species. However, if the results are substantially different, then further investigation should be made to find the weaknesses in each method.

CHAPTER 6: CONCLUSION

Trees in the urban forest are under pressure from the harsh urban environment. If they are to survive the stresses and live to become mature, they should be well adapted to their surrounding environment. They should be able to tolerate conditions that they do not usually face in their natural environments. Not every tree is suitable for growing in urban conditions and if planted in undesirable locations, they could become a nuisance or fail to be beneficial. To prevent the troubles caused by non-adapted trees, it is best to select tree species that can tolerate the urban environment and live to become mature so that they could provide the city with all their benefits.

Trees in the urban environment are important not only because of the many benefits they provide but also because they represent life and joy, they become symbols in people's lives, they become part of people's memories, and they also help people to connect to the nature surrounding them. They become parts of history and carry stories from the ancient time to the future.

Fortunately, nowadays people are recognizing the values of these organisms and are taking efforts to improve the health and wellbeing of the urban forest while managing the trees in parks, street, and in their backyards. One of these efforts from the research community is to conduct and publish research on how to maintain and care for the urban forest. My research is one such contribution.

The path that I have taken in helping to improve urban forest management is to incorporate various urban conditions combined with the adaptation of trees to the future climate of Halifax, Nova Scotia, as criteria in an enriched tree-species selection method. I have suggested a list of tree species which can be planted in Halifax that will survive and would be in their optimum conditions during periods of climate change. These trees should be adapted to the predicted future climate by the year 2100.

Those managing the urban forests should keep in mind the use of various sources and try various methods when they are taking care of urban trees. Whether they are planting trees grown from seeds or they plant those that are cultivated for specific reasons, they should help diversify the urban forest, as diversity is one of the keys to a healthy urban forest.

They should use trial and error, examine, change and adapt as the situation and the environment surrounding them changes. They should make sure that they have knowledge of tree physiology and how they responsd to urban settings.

The message I have provided in this research is mostly aiming those managing trees on city properties. However, I have not forgotten the private landowners, It is hoped that the latter group will also change their perspective towards urban forests and the trees they plant in their properties. Because of the large numbers of private landowners one way to target them is to try to change the attitudes and thoughts of nursery owners towards tree species and ask them to change their planting stock to the tree species that will be well adapted to the future urban environment. After all, private landowners buy their trees mainly from nurseries.

There were several objective developed at the start of this research all of which were met in the end. However, there are many opportunities for further research to improve the health of the urban forest and also tree-species selections for urban settings. Some examples of these include:

- Comprehensive research on tree species to enrich the database both with less-uncertain data and additional tree traits for consideration. This is particularly the case for Canada, as it seems that the USA has taken a lead in studying its native tree species. Details of Canadian native tree species are harder to find than those tree species that grow in the USA and there are more published resources on USA native tree species than there are in Canada.
- Examining the cultivars and varieties of the tree species considered in this research to understand how they may respond to the future climate and various urban stresses. This also ties into the previous point because cultivars, varieties and hybrids of trees are not as well studied compared to the original native tree species.
- Including the results of future climatic distributions of pests and pathogens in research such as this to examine their potential effects on the tree species.

I hope that my research will be useful to many urban foresters, urban planners, landscape architects, horticulturists, and tree experts. It could be used as a step in improving urban forestry in Halifax and in Canada, thus contributing in some useful measure to achieving sustainable urban forest management.

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APPENDIX 1: SCATTER CHARTS USED TO DEFINE RANGES FOR DATASETS USED IN THE SCENARIOS

Figure A.1. The longevity of the tree speices studied in this research (ranked from lowest to highest).

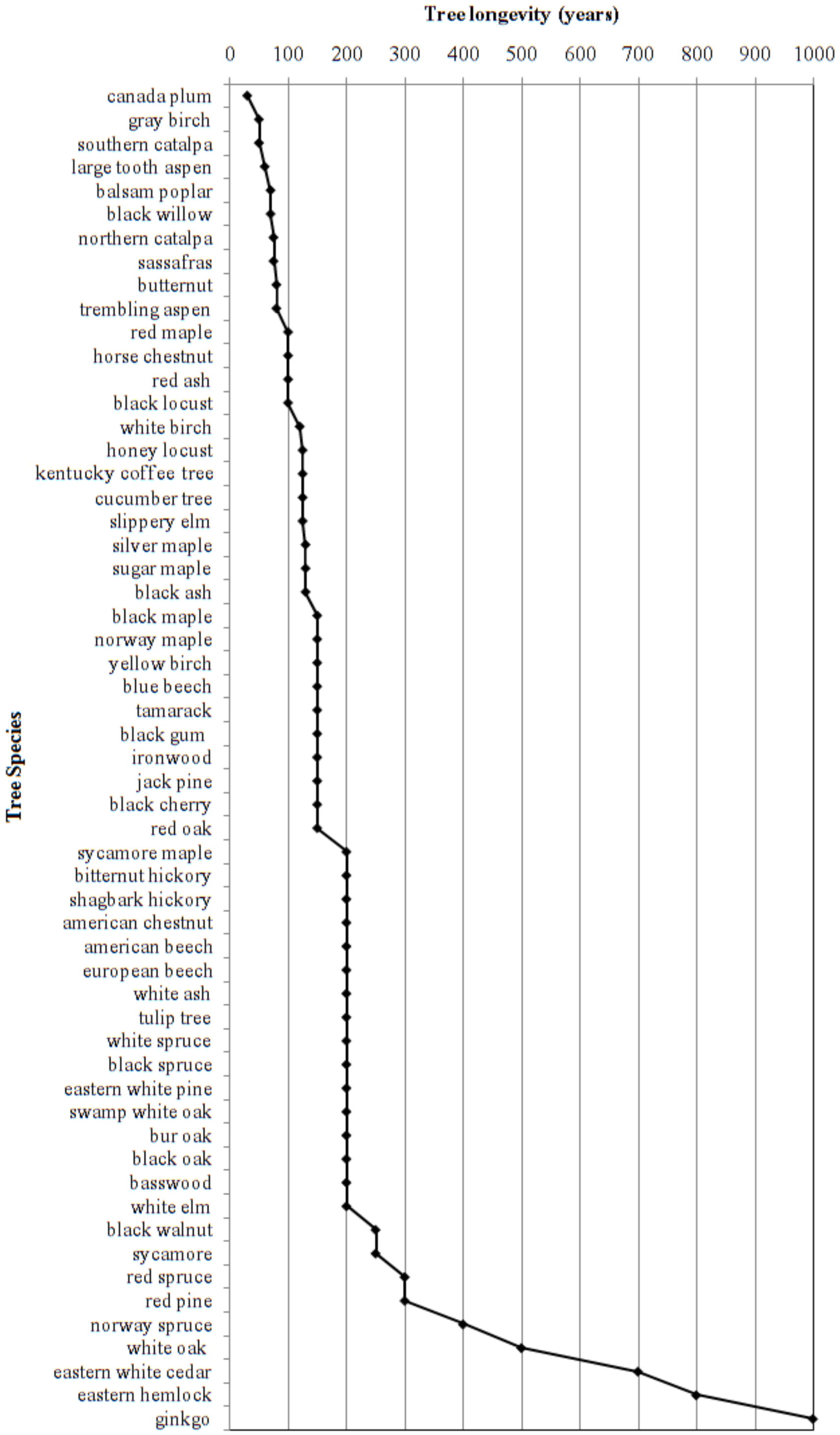


Figure A.2. The height at maturity of the tree species studied in this research (ranked from smallest to tallest).

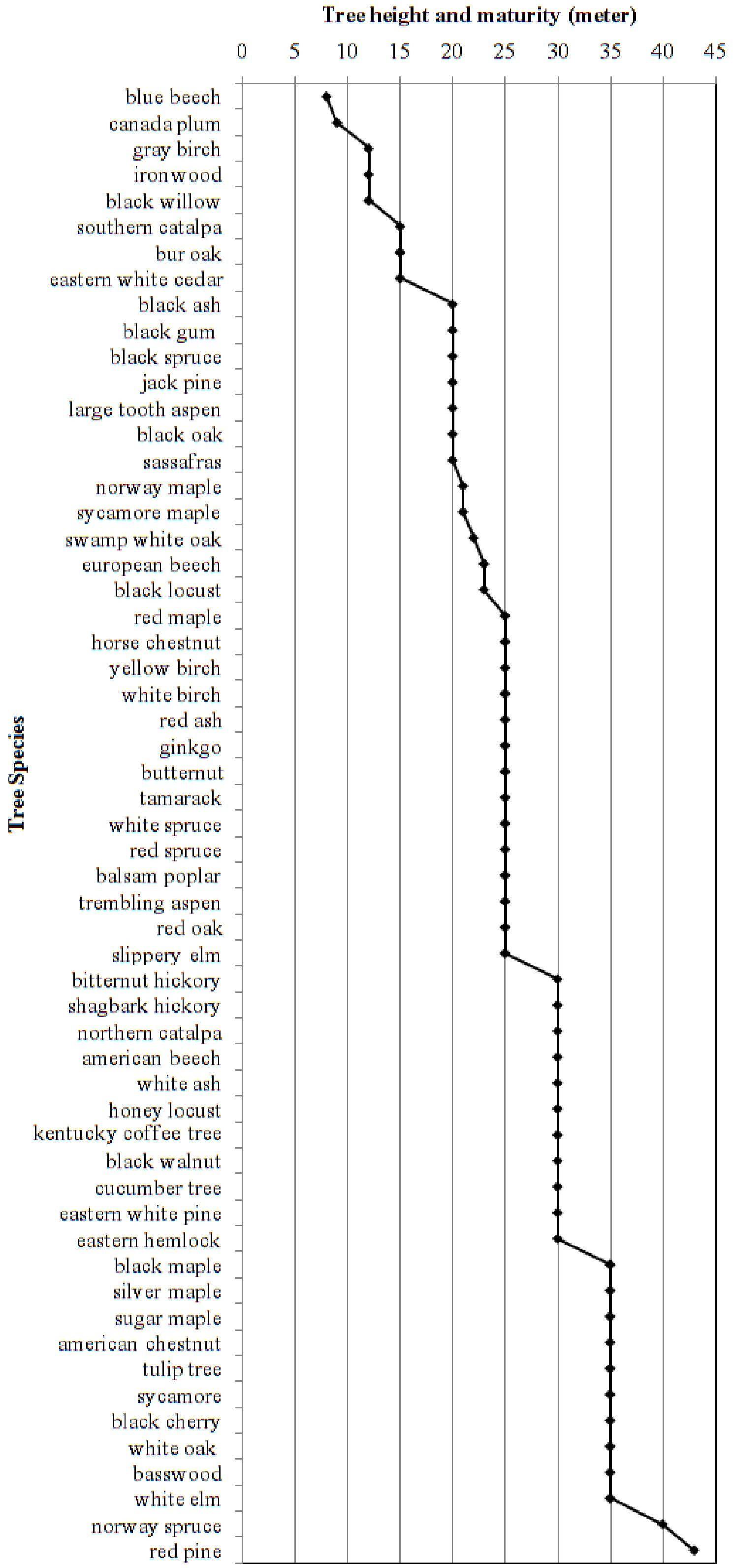


Figure A.3. The Daimeter at maturity of the tree species studied in this research (ranked from smallest to largest).

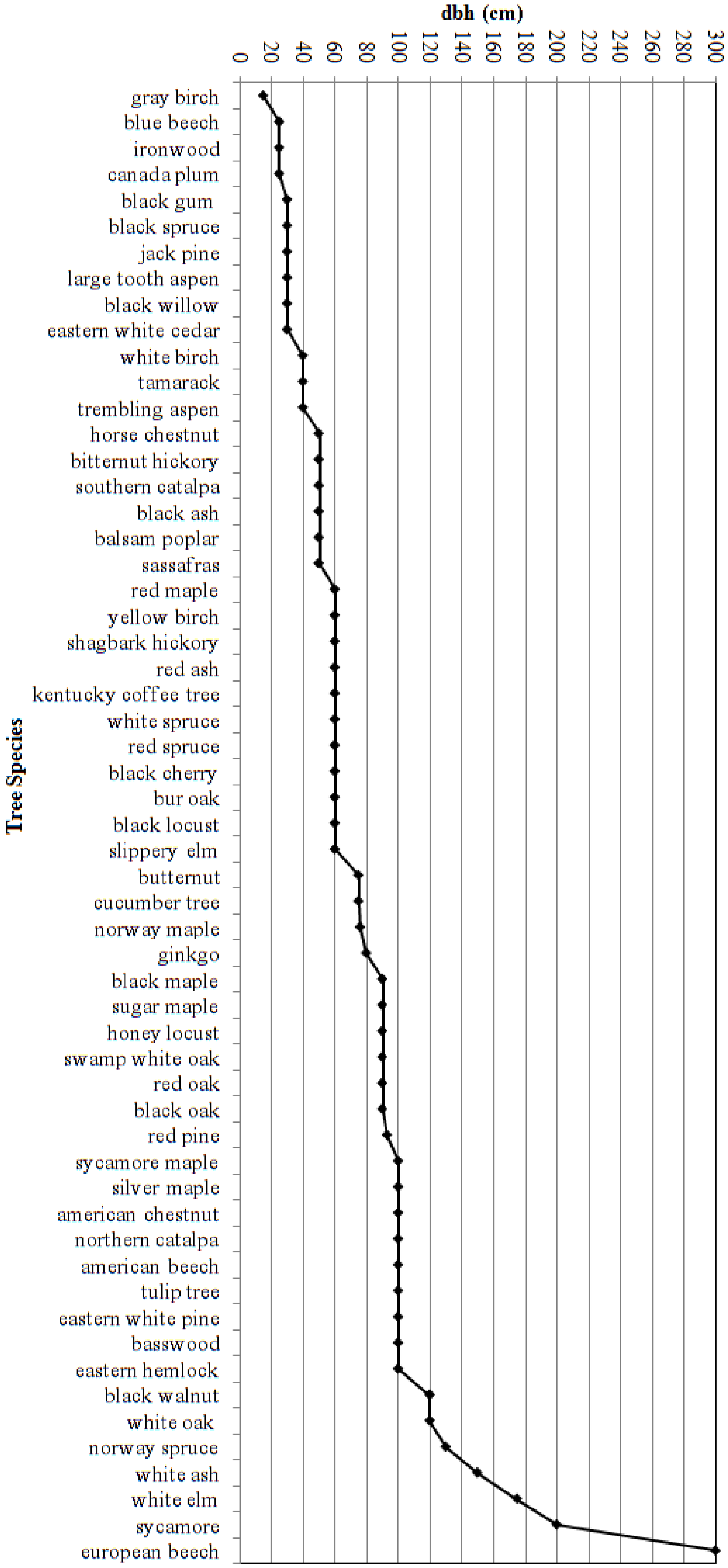


Figure A.4. The number of failing characteristic of the tree species studied in Scenario 6 (the robustness of the tree species with the least negative effects in urban environments to climate change) (ranked from lowest to highest).

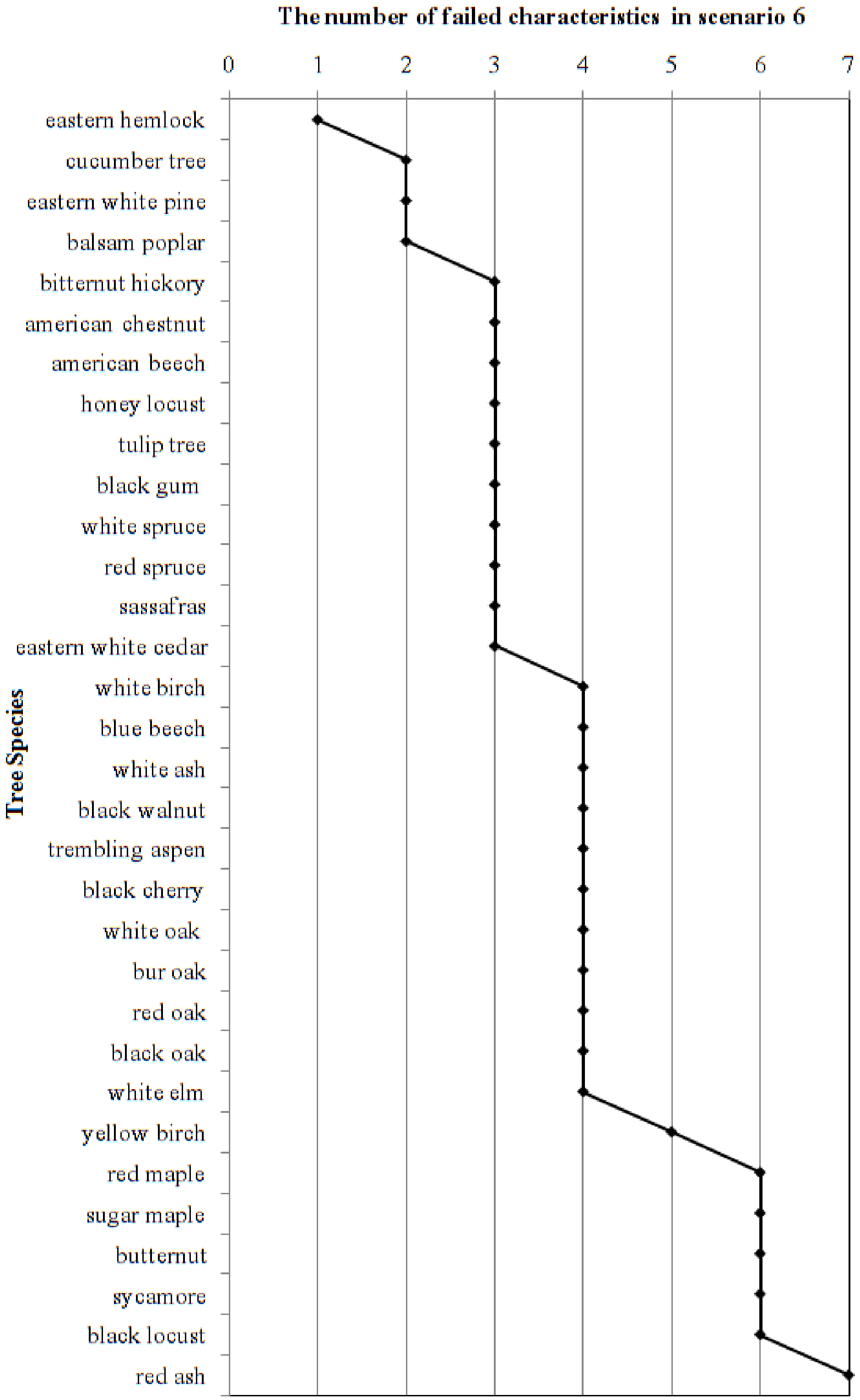
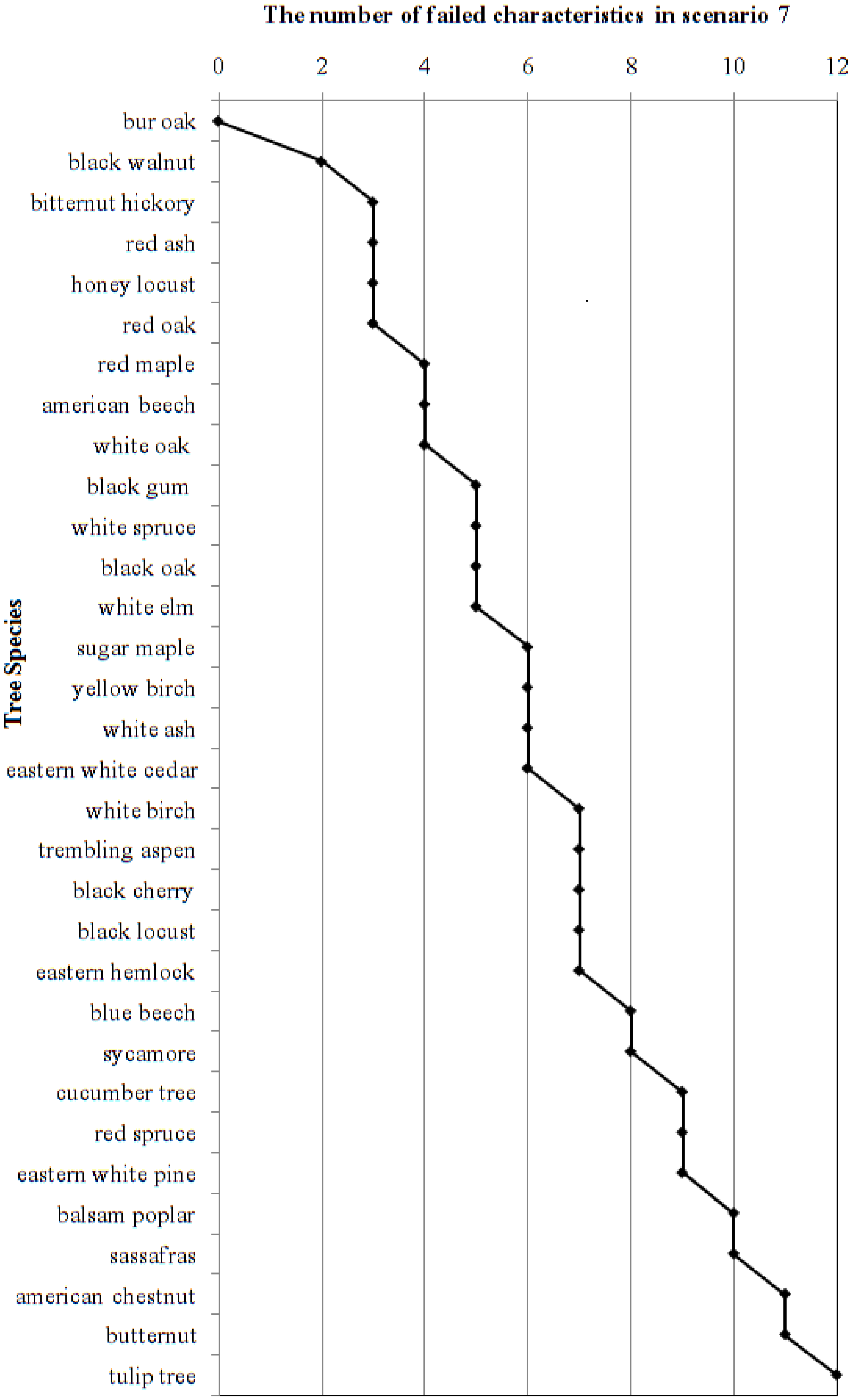


Figure A.5. The number of failing characteristic of the tree species studied in Scenario 7 (the robustness of the tree species with the desired tolerances in urban environments to climate change) (ranked from lowest to highest).



APPENDIX 2: ELECTRONIC DATABASE DESCRIPTION

The electronic database was created as a part of this research is available in School for Resource and Environmental Studies website and can be downloaded using the following links:

http://sres.management.dal.ca/People/Professors/Peter_Duinker.php

or at: http://sres.management.dal.ca/Files/Rostami & Duinker - Tree Species Database.xlsx

A written description of the electronic database is as follow:

1- Database was created by Maliheh Rostami and Peter Duinker using the Microsoft Excel spreadsheet software.

2- The scientific name of 57 tree species native to Nova Scotia, New Brunswick, and the eastern seaboard of the United States of America were entered spreadsheet.

3- 95 tree characteristics were studied for all the 57 tree species.

4- The total number of cells used for entering the data in the spread sheet is 5616.

5- Data are presented in different colours representing the source of the data. Information on the connection of the colours to the data source can be seen at the bottom of the database.

6- The references used for collecting the data in the electronic database are shown in Appendix 3.

APPENDIX 3: ELECTRONIC DATABASE REFERENCE LIST

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