GIS-BASED MULTI-CRITERIA DECISION ANALYSIS (MCDA) FOR PRIORITIZING TREE-PLANTING SITES IN HALIFAX URBAN PARKS

by

Xin Liu

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

at

Dalhousie University
Halifax, Nova Scotia
August, 2018

Table of Contents

Lists of Tables

Lists of Figures

Abstract

In Halifax, the lack of canopy cover and urges for better management of urban forests stimulated the Urban Forest Master Plan (UFMP), which was adopted by council in 2012. One goal of the UFMP is to increase the canopy cover in Halifax peninsula to 40% in parks. To achieve this goal, two questions need to be solved: where to plant trees and where to plant first. Thus, this research provided a two-phase solution by incorporating GIS-based Multi-criteria Decision Analysis (MCDA). The first phase selected candidate parks by setting limitations on park location, management authority, area, and a ground survey. This phase resulted in identification of 28 candidate urban parks in the Halifax peninsula. The second phase included eight criteria to feature benefits brought by urban trees. These criteria were weighted by experts through consultations and then used to calculate the ranking of the 28 parks.

Acknowledgements

Many thanks to my supervisor Peter Duinker, who helped me through my Master's studies.

Many thanks to my parents, who financially and mentally supported my living overseas.

Many thanks to the people I met, I got to know, and I made friends with.

CHAPTER 1 INTRODUCTION

With the growing human population in cities, the urban area has become both denser and larger. Meanwhile, increasing wealth and the growing pursuit of wellness are propelling residents to search for more green spaces inside the dense concrete world (Benedict & McMahon, 2006). Especially after proposing the concept of sustainable development, green infrastructure in urban areas has become an important element in building up a sustainable urban environment (McDonald, 2015). In Halifax, the municipal government has been working on managing its urban forest for decades. However, due to land competition between the increasing demands from both green and grey infrastructures, the available space for urban trees is limited. In addition to that, the available space has not been fully utilized. These cause a significant lack of canopy cover, which is only 19% in the Halifax Peninsula. This number ranks last among all 10 communities within the Urban Forest Master Plan (UFMP) study area (HRM Urban Forest Planning Team, 2013, p58).

The ecosystem services provided by urban trees have been demonstrated in various literatures (e.g. Canedoli, 2016; Coutts & Hahn, 2015; Dobbs, Escobedo & Zipperer, 2011; Rogers, Hansford, Sunderland, Brunt, & Coish, 2011). For Halifax, local research also have been done and affirmed the importance of these trees. Foster and Duinker (2017) applied the i-Tree Eco tool to recalculate the value of urban trees in the UFMP study area. This study demonstrates that the structural value of trees alone is over 1.5 billion CAD. Moreover, these trees are able to sequester 20,392 tonnes of gross carbon, which can be valued at 735 thousand CAD based on carbon's market price and 2.84 million CAD on Social Cost of Carbon (SCC). Peckham, Duinker, and Ordóñez (2013) completed an opinion study to obtain comments from residents on the urban forest in Halifax. This research demonstrates that although urban forests in Halifax have mostly recovered from the devastation of Hurricane Juan in 2003, residents still feel a lack of shade around them. The feeling of lacking trees appears not only along the streets but also in parks. Thus, the UFMP set goals to increase canopy cover in the Halifax peninsula from 19% to 50% over the long term and emphasized the canopy growth expectation in parks (HRM Urban Forest Planning Team, 2013).

To reach the designated targets in the UFMP, the municipal government needs support from NGOs and other community groups to organize tree-planting activities. These groups are responsible for recruiting volunteers and organizing tree-planting events after which the municipal government will take over maintenance work. Based on the empirical experience from Professor Peter Duinker, organizers must contact urban forest managers for the spatial information on potential planting sites before each tree-planting activity. However, there is a lack of information in this step. The urban forest managers do not have at hand a list of all planting sites and the priorities of these sites are not readily set. Decisions are made based directly on managers' personal experience and intuition. This approach may neglect certain criterion that managers would find it important as a basis for decision-making. Thus, a systematic way of making decisions for tree planting activities is necessary and urgent.

The main purpose of this research is to provide guidance for urban forest managers in decision-making of potential planting sites. To build up a systematic model, GIS-based

Multi-criteria Decision Analysis (MCDA) was chosen as the fundamental concept. It helps to combine preferences from decision-makers about the key elements and the geographical characteristics of potential planting sites so that the result comes from a systematic and defensible process. The secondary purpose is to test two weighting methods, the rating method and the pairwise comparison method, in the site ranking phase and to compare their applicability for decision-making. As a pilot study, this research provides a pathway to model urban forest decision-making processes and opens discussions on the potential for future systematic decision-making.

CHAPTER 2 LITERATURE REVIEW

This research is an application of decision-making methods to an urban-forest management issue. Thus, the literature review includes two parts. In the urban forest management part, it sets the scope of the evolution of urban forests, their characteristics, and how these characteristics affect urban forest management. The information provided in this part is the fundamental knowledge for criteria selection in decision-making procedures. The subsequent review of decision-support systems provides basic decision-making procedures and possible methods that could be and already being applied in the urban forest management context.

2.1 Urban forest management

2.1.1 Introduction to Urban Forestry

Urban forestry was first established as a branch of forestry in the 1970s. The first definition was provided by E. Jorgenson from University of Toronto as: "Urban forestry is a specialised branch of forestry and has as its objective the cultivation and management of trees for their present and potential contributions to the physiological, sociological, and economic well-being of urban society. These contributions include the over-all ameliorating effect of trees on their environment, as well as their recreational and general amenity values" (Miller, Hauer & Werner, 2015, p.7). There are many other definitions proposed, but a broad agreement has proved elusive (Konijnendijk, Ricard, Kenney & Randrup, 2006). Most definitions emphasize the special physical environment in urban settings and reconciliation of the natural environment with social effects as the main features in urban forestry studies (Dwyer et al., 2003). Brown (2007) conducted an analysis on 58 different urban forestry definitions and categorized the key words into six topics: people, geography, benefit, resource, activity, and science.

Urban forestry as a discipline was first set up in North America and then spread to European countries in the 1980s (Randrup, Konijnendijk, Dobbertin & Prüller, 2005). Although it is a relatively new academic branch, tree management was actually carried out by humans through the whole history of civilization. The first tree planting record can be dated back to 4,000 years ago in Egyptian tombs. The Assyrian parks in 700 B.C., the Hanging Gardens of Babylon in 600 B.C., and Greek cities in 500 B.C. provided evidence of using vegetation, including trees, in urban settings (Phillips, 1993). Trees for garden decoration were prevalent in the middle ages. However, this was restricted to elites. Until the Renaissance, with the proposal to "bring nature back to the cities", tree was gradually absorbed as an important element in city design (Gerhold, 2007). Since then, diverse application of trees appeared in city landscape design. Gardens, city parks, small squares, and linear promenades are all now represented in the landscape design of European cities (Bradley, 1995). Garden designs in some eastern countries, such as China and Japan, also have a long history of combining trees into architecture design in human settings (Bradley, 1995).

In North America, the application of trees in urban landscapes was copied from Europe by the newcomers in colonial times. In 1646, Boston was the first city in the New World that organized tree planting for public shade after suffering from a lack of trees in the city area due to clearcutting for construction ten years earlier (Phillips, 1993). Since then, more and more cities started to plant and protect trees. Meanwhile, with the thriving of horticulture as a science and the establishment of forestry colleges in North America, more techniques were applied in urban forestry such as tree species selection, tree maintenance, and pest control in an urban environment (Phillips, 1993).

Even with improving arboriculture technologies, canopy in many cities did not increase incrementally. Diseases introduced by invasive species made significant impacts on urban trees. Dutch elm disease (DED) was one of the most severe cases. In the early 20th century, the outbreak of DED in North America cities killed millions of elm trees, which was a predominant species in urban forests at that time (Raupp, Cumming & Raupp, 2006). This event aroused an awareness of the importance of species diversity in urban forests and led to a more sophisticated consideration in biotic stress for tree selection in urban forest management (Bassuk, 1990).

Nowadays, rapid urbanization processes attract more concentration on urban forestry studies. Demographic statistics demonstrated that we have become an urban species. As of the year 2006, over 50% of the global population lived in cities (Carreiro, 2008). European and North American countries have a higher percentage of urban residents, which is about 75-80%, than other countries around the world (Carreiro, 2008). Compact cities with high population density have induced negative impacts on the physical and psychological well-being of residents (Carreiro, 2008). One of the solutions to this issue is to increase the "green", especially trees, inside the "grey" infrastructures (e.g. buildings, roads) (Kimmel et al., 2013). With the help of various researchers, the values of trees are re-recognized and no longer limited to social amenities (Register, 2006). Studies have proved that trees not only have environmental values but also provide positive influences on economics. These outcomes helped urban forestry receive more support from residents, businesses, and governments.

2.1.2 The Benefits and Disservices of Urban Forest

From designing plans, buying trees, and planting trees, to pruning and removing/replacing dead trees, the whole process of urban forest management costs municipal governments a large amount of money every year. However, maintenance of the urban forest is still considered as a worthwhile enterprise. Investment in urban forests is not only based on the intuitive understanding of the aesthetic value of urban trees, but also supported by more and more quantitative research. Take Halifax for example - based on the UFORE model (Nowak & Crane, 2000), the total benefits brought by the urban forest worth $44.2 million per year (HRM Urban Forest Planning Team, 2013). This model only calculated part of the benefits brought by the urban forest, which include energy conservation, CO_2 reduction, air quality improvement, and storm water control (Nowak & Crane, 2002). However, the total benefits are more than these.

Physical/environmental Benefits

Air quality. Urban trees are able to reduce airborne pollutants by exchanging gases with the atmosphere and capturing chemical pollutants and particulates that can be harmful to people (Nowak & Dwyer, 2007; Ordóñez & Duinker, 2013). It is estimated that an urban street with trees has a 60% reduction in street-level particulates (a type of air pollution from the burning of fuel) compared to an urban street with few or no street trees (Kadir & Othman, 2012).

Hydrology. The intense surface runoff during rainfall events can be reduced by trees through the water storage and evaporation functions of leaves (Xiao, McPherson, Ustin, Grismer & Simpson, 2000). Trees' root systems also help rainwater penetrate soils. Furthermore, the pervious surfaces surrounding trees facilitates rainwater to infiltrate into soils compared to built-up areas such as concrete and asphalt roads.

Carbon sequestration. The benefit of carbon sequestration is brought by trees through the process of photosynthesis. The carbon be stored in roots, stems, and branches (HRM Urban Forest Planning Team, 2013). In Halifax, the street trees are estimated to hold more than two million tonnes of carbon and this number can increase by more than 100,000 tonnes annually (HRM Urban Forest Planning Team, 2013). Another way for urban trees to reduce atmospheric carbon is through reducing energy consumption. This is because the presence of the trees helps to reduce the demands for household heating and air conditioning (McPherson & Simpson, 2002).

Biodiversity. Urban ecosystems are home not only for humans. Small mammals, birds, and insects are also significant elements in this highly modified ecosystem. Urban trees play an important role in promoting biodiversity conservation (Adams, 1994). Well-designed and managed urban parks provide important living space for endangered species even inside of huge metropolitan areas, e.g. Central Park in New York. Moreover, tree species at risk can be planted and conserved in urban settings as part of the urban forest. It is possible for some adaptable species to be chosen as street trees (HRM Urban Forest Planning Team, 2013).

Climate. Studies have shown that urban areas are warmer than the surrounding countryside by 0.5 – 1.5 ℃ on average in temperate latitudes, and up to 3℃ in tropical areas (Chen & Jim, 2008). This phenomenon is intensified by the lack of vegetation and the common occurrence of dark surfaces in urban areas (Grimmond & Oke, 1995; Whitford, Ennos & Handley, 2001). Urban forests can be helpful to reduce overheating in urban areas by direct shading and evapotranspirational cooling (Oke, Crowther, McNaughton, Monteith & Gardiner, 1989).

Social/Economic Benefits

Aesthetics. This is the first benefit of urban trees appreciated by people (Ordóñez, Duinker, Sinclair, Beckley & Diduck, 2016) the hardest to evaluate in numbers. Aesthetic benefit is difficult to quantify because it is related to people experiencing different colours, structures, forms, and densities (Kaplan & Kaplan, 1989). Studies have shown that the appearance of trees in urban settings helps people enjoy life more (Louv, 2011). Trees are also considered as a connection between urban life and nature (Dwyer et al., 1992). Peckham et al. (2013) demonstrated that this benefit was the most frequently mentioned one in the research for evaluating urban forest values in citizens in Halifax.

Recreation. Providing recreational opportunities for residents is one of the generally acknowledged functions of urban forests, especially urban parks. People are inclined to choose parks for outdoor activities, such as cycling, walking, jogging, and dog-walking (Arnberger, 2006).

Human health. Urban trees are able to directly contribute to healthier urban living space by reducing air pollutants, e.g. ozone, nitric acid vapour, nitrogen dioxide, ammonia, sulfur dioxide and particulate matters. Shading is also helpful for preventing high exposure under ultraviolet radiation (Nowak & Dwyer, 2007). Additionally, there is an association between healing and urban forests. Patients recovered faster when they had a view of trees while recuperating after surgery in hospital (Ulrich, 1984, 1986, 1999).

Economics. Urban forests are not managed for timber production, so no direct economic value is obtained from them. However, studies have demonstrated that trees can add value to residential properties (Anderson & Cordell, 1988). Consumer behaviour is also positively related with urban green area. Wolf (2003) showed that stores in districts with trees can charge 9% higher prices and customers are 30% more satisfied with products that they purchased.

Disservices of Urban Forest

It is generally perceived that the benefits provided by urban trees outweigh their adverse impacts, but their detriments need careful consideration during urban forest management. Trees can be threats to infrastructure. Their growing root systems are capable of cracking concrete pavement (McPherson, 2000) and even building foundations. The falling branches from trees on windy days are dangerous for residents and passersby and may cause damage to public and private infrastructure (Lopes, Oliveira, Fragoso, Andrade, & Pedro, 2009). Trees growing close to electrical wires may disrupt power delivery to homes and businesses (Powell & Lindquist, 2011). In Halifax, tree trimming is an important part of the work of NS Power Inc. to ensure reliable power delivery (Nova Scotia Power, 2017).

Urban trees may generate health concerns. The pollen produced by trees during the growing season may cause severe allergic reaction in some people (Cariñanos & Casares-Porcel, 2011). Trees may even worsen the air quality since densely planted trees along street canyons could block the dispersion of pollutants such as PM-2.5 (Jin, Guo, Wheeler, Kan & Che, 2014). The volatile organic compounds (VOCs) released from trees may cause secondary formation of ground-level ozone, which is detrimental to humans (Nowak, Crane & Stevens, 2006).

The maintenance of urban forest can be costly and even outweigh the benefits brought by trees (Dobbs et al., 2011). Trees are not always welcomed in urban settings. The debris drop from the trees, such as dead branches, sap, and leaves are unwanted (Kovacs et al., 2010) so that needs extra clean up. Shade, although preferred by some residents, may be considered detrimental by people wanting longer views and opportunities for gardening. The trees planted in unfavourable directions from a house may limit the sunlight in winter time so that heating costs are higher (Tyrväinen, 2001). The density of canopy cover also influences residents' feelings. Dense canopy may cause depressed feelings and a sense of lack of safety for some people (Schroeder & Anderson, 1984).

All that said, though, it is clear that the detrimental effects of trees are far outweighed by their benefits. Careful urban forest management can readily improve the flow of benefits and minimize the adverse effects.

2.1.3 Sustainability and Urban Forest Management

Sustainability is defined as "meeting the basic needs of all and extending to all the opportunity to fulfil their aspirations for a better life" (Brundtland, 1987, p.12). This concept is now widely applied in diverse industries and has been leading a significant change for the whole world since it was proposed.

In the forestry discipline, the discussion of sustainability can be dated back to 1987, when the Brundtland Commission Report (Brundtland, 1987) proposed potential pathways for achieving sustainable development. This provided inspiration for a new forest management paradigm. In June 1992, the concept of integrity in environment and development was raised at the "Earth Summit", which was formally called the United Nations Conference, in Rio de Janeiro (United Nations, 1992), which marked the start of long-term global-wide discussions on sustainability.

The concept of sustainable management relating to logging yields already existed in the forest industry (Brown, Hanson, Liverman, & Merideth, 1987) so the new concept was quickly and broadly adopted by governments after the UNCED. Different from traditional sustained-yield forest management, the new sustainable forest management includes wider considerations, especially the social and environmental values of forests. As some early scholars argued, sustainable forest management involves consideration of social values and can be considered as an adaptive social process to satisfy future forest needs (Romm, 1993; Ticknor, 1993). As a relatively new branch of forestry, urban forestry also quickly adopted the concept of sustainability (Clark, Matheny, Cross & Wake, 1997). There are two interfaces between urban forest and sustainability: the improvement of urban sustainability contributed by urban forests (Ordóñez & Duinker, 2013) and the sustainability of urban forests themselves (Dwyer, Nowak, & Noble, 2003).

Urban sustainability has been interpreted as "the economic, social, and physical organization of cities and their populations in ways that accommodate the needs of current and future generations while preserving the quality of the natural environment and its ecological functions over time" (Vojnovic, 2014, p.535). Cities are difficult to consider as sustainable because they are highly dependent on the hinterland for essential resources and waste disposal (Rees & Wackernagel, 2008). To measure the sustainability of an urban area, a set of indexes was created which includes broad categories such as inter- and intra-generational equity, protection of the natural environment, minimization of natural resource use, and community and individual well-being (Maclaren, 1996). The values provided by urban forest, as mentioned in the previous section, are able to contribute to the overall urban sustainability.

To maximize the contribution of urban forest to urban sustainability, urban forest needs to improve its own sustainability. Urban forest sustainability is defined in terms of maintaining healthy and functional vegetation and associated systems that provide long-term benefits desired by the community (Dwyer et al., 2003). This definition emphasizes the role of urban forest managers and urban forest users in achieving sustainability. Although the debate around this definition is continuing, researchers and scholars seem to agree that the final goal of sustainable forest management is maintaining forest benefits through space and time (Wiersum 1995).

For a measurement of urban forest sustainability, some studies have been done to provide criteria and indicators (C&I) for evaluation. One approach was derived from a part of the Montreal Process in sustainable forest management (Kenney, Van Wassenaer & Satel, 2011). Studies for C&I of sustainable urban forest management are far fewer than for sustainable forest management, but there are some attempts. In studies done by Clark et al. (1997) and Kenney et al. (2011), the researchers outlined specific criteria representing the sustainability of the urban forest and specific indicators that may be measured. These two sets of evaluation tools, although not widely adopted in urban forest management, at least reveal some thoughts regarding urban forest sustainability. In the C&I lists, canopy cover is an important criterion but not the sole one for evaluation. Some other considerations on the structure of urban forests are also emphasized such as diversity of tree species and age, and the native species proportion among all trees. In terms of social perspective, the C&I tools also list several criteria for evaluating collaborations with public agencies and local residents, which indicate expectations on a more participatory management approach for urban forests.

In urban ecosystems, the social and ecological factors are constantly changing so sustainability as a goal is subject to considerable variation. Ultimately, the attributes of a sustainable urban forest—what it looks like, how it functions, and how it is managed—depend on which ecological functions and social benefits are desired, who chooses them, and at what scale these elements are being sustained (Gregerson, Lundgren & Byron, 1998; Maser, Bormann, Brookes, Keister & Weisland, 1994; Wiersum, 1995). An appropriate approach to urban forest planning and management needs to lead to sustainable urban forest structure and health over time and space and this approach must be firmly grounded in the key characteristics of the urban forest (Dwyer et al., 2003).

2.1.4 Characteristics of urban forest and the challenges in management

Although urban forestry shares much with conventional forestry, it has many distinctive characteristics compared to the forest woodlands as discussed in forestry studies. Due to these differences, urban forest management faces challenges that the previous experience in forestry can rarely help.

Different from traditional forest management, timber production is not a goal in urban forest management. Thus, the economic value of urban forest is more complex and indirect. The value appreciated by stakeholders of urban forests, which means the local residents, are greater on the social perspectives such as aesthetics and resources for recreation activities (Peckham, Duinker, & Ordóñez, 2013; Tyrväinen, Silvennoinen, & Kolehmainen, 2003). Evaluating these values requires subjective procedures and may change with social values and norms. These complexities bring difficulties to the overall understanding of urban forest values.

As the social perspective on contributions of urban forests is heavily valued by stakeholders, urban forest managers have to put this part into consideration in management processes. The social values regarding urban forests have been well-studied, including topics such as the influences of race, class, and gender (Heynen & Perkins, 2005; Heynen, Perkins & Roy, 2006; Landry & Chakraborty, 2009; Perkins, 2015). Studies have shown that canopy cover is positively related with income, which brought into discussion the uneven spatial distribution of urban trees and environmental inequity (Schwarz et al., 2015). In addition, residents also contribute to urban forests as upper- and middle-class homeowners are more likely to plant trees where they live than lower-class renters (Perkins, Heynen, & Wilson, 2004). In the Urban Forest Master Plan (UFMP) of Halifax, social equity is listed as one of the principles (HRM Urban Forest Planning Team, 2013).

Another distinguishing characteristic of urban forests is the strong influence of human forces towards trees. Humans determine the location for tree planting and also which trees will be removed. During urban development, land use changes may cause massive tree removal and replanting in a short period of time. Also, tree species are selected by urban forest managers based on users' perspectives. Thus, in urban forest, it is human forces rather than nature that have more powers in shaping the forest structure (Dwyer et al. 2003). Moreover, some natural forces in shaping the urban forests, such as insects and disasters, can even be minimized by human forces (Dwyer et al. 2003). The powerful and versatile application of human forces pose significant challenges for management (Dwyer et al. 2003).

Like all forests, urban forests undergo changes with the growth, development, and succession of their biological components over time (Dwyer et al., 2003). These changes will exist even without human disturbance. However, the powerful human forces toward trees, as mentioned above, are occurring at a much more rapid pace. The swift human forces for change, coupled with relatively slow biological processes, makes urban forest management particularly complex and challenging (Dwyer et al., 2003). Land use changes in urban development induce significant impacts on urban forest distribution. They determine ground cover types and opportunities for tree establishment and growth (Dwyer et al., 2003). The changing of neighbourhood residents around urban forests may prompt different attitudes and approaches regarding tree management in the area.

In addition to previously mentioned challenges, the physical environment of urban areas is not favourable for urban trees as well. Even with efforts to treat pests, trees growing in the urban area still face challenges which seldom happen in natural environments. Urban trees have relatively limited growing space for both crowns and roots, less permeable land surface and a higher probability to encounter vandalism. In snowy areas, salt is a dangerous element for trees, especially seedlings. Salt is important in Northern areas during winter time for melting ice. Large quantities of salt are spread on sidewalks and roads every year. When the ice melts, the salt will be dissolved in water and will significantly increase the solution concentration around trees' roots. These negative impacts may cause a higher death rate of urban trees without appropriate management.

To deal with these challenges which involve consideration of both natural science and social science, decision-making processes in urban forest management need to be sophisticated enough to ensure that the values of urban trees and the demands of urban forest users are well balanced.

2.2 Multi-criteria Decision Analysis (MCDA) as a Decision Support System (DSS)

A Spatial Decision Support System (SDSS) is defined as "an interactive, computer-based system designed to support a user or group of users in achieving higher effectiveness in decision-making while solving a semi-structured spatial decision problem" (Malczewski, 1999, p.281). Decision-making problems are in a spectrum from completely structured to thoroughly unstructured decisions while most real-life situations fall within these two extremes so that are called semi-structured problems (Malczewski & Rinner, 2016). Site searching and site problems, site allocation problems, land use suitability evaluation etc. - these problems all fall into the semi-structured category. The structured part of these kinds of problems can be solved by computer while the unstructured parts need the wisdom from stakeholders and decision-makers (Malczewski & Rinner, 2016).

"The primary aim of the system is to improve the effectiveness of decision making by incorporating decision makers' knowledge and experience into computer-based procedures" (Malczewski & Rinner, 2016, p.9). Thus, through SDSS, previously separate tools could be integrated together to improve efficiency. To build up a computer-based DSS for tackling spatial allocation problems, using MCDA techniques incorporated with GIS is a solution (Malczewski & Rinner, 2016).

GIS is a system for collecting, storing, manipulating, analyzing, and presenting geographic data to obtain information for decision-making (Chang, 2011). It is good at handling geographic data and computing, but not well-suited for handling subjective issues such as value judgements, preferences, and attitudes. Combining MCDA methods and techniques into GIS operations is a way to alleviate this shortcoming of GIS (Malczewski & Rinner, 2016). GIS can provide a tool for handling the disagreements over facts by providing more and better information, while the MCDA can help in diminishing the disagreements over values among the conflicting interest parties (Feick & Hall, 1999; Jakowski & Nyerges, 2001). Integration of MCDA with GIS is able to enhance the capability of GIS in storing and analyzing data on the decision-makers' preferences. As argued by Malczewski & Rinner (2015), the MCDA approach provides a methodology for guiding the decision-maker(s) through the critical process of clarifying relevant issues to the decision situation. The combination of GIS with MCDA allows the introduction of value judgements (i.e., preferences with respect to evaluation criteria and/or decision alternatives) from anyone who participates in the decision-making process (Malczewski & Rinner, 2016). Through this decision-making process, the MCDA approach will help decision-making participants to develop a constructive and systematic approach to the problem, and will help decision-makers to understand the result of the procedure, which includes trade-offs among criteria (Bell, Hobbs & Ellis, 2003; Nyerges and Jankowski, 2009; Malczewski & Rinner, 2016). In all, GIS-MCDA focuses more in constructing methods towards problems rather than identifying the perfect solutions (Malczewski & Rinner, 2016).

2.2.1 Introduction to MCDA

The previous section discussed the function of MCDA when applied with GIS in a decision-making process. This section aims to provide some basic information on the key elements of MCDA.

As defined by Belton and Stewart (2001), MCDA is an "umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter". It is rooted in operational research and support for single decision-makers (Mendoza & Martins, 2006). In recent years, studies have shifted the emphasis from multi-stakeholder processes towards structuring decision alternatives and their consequences, which would improve the quality of the decision-making process (Fish et al., 2011).

Normally in the MCDA process, decision-makers have to choose one from a set of decision alternatives based on their judgements and preferences. These alternatives are evaluated through a set of interdependent criteria according to decision-maker's thoughts and preferences (Malczewski & Rinner, 2016). This process can be complex when decisions need to be made on goals with abundant criteria. MCDA, as a decision-support method, is helpful in providing a structured way of analyzing the situation, so that the decision will result in a reasonable and satisfactory outcome (Kangas & Kangas, 2005) . In this procedure, two important elements are involved: decision-maker(s), and criteria

(Malczewski & Rinner, 2016).

Decision-maker and Criterion

A decision-maker is an entity with the responsibility to make decisions (Malczewski & Rinner, 2016). The number of decision-makers can vary from one to many, depending on the problem and situation. With the demand of more participants in decision-making and the availability of technology support, it is now possible for hundreds of people to be involved in one decision-making process. When decision-making involves more than one decision-maker, the degree of consensus will be an important determinant of the nature of the decision-making process (Massam, 1988). Thus, the consistency of the group's goals, preferences, and beliefs, instead of the numbers, is the most distinctive trait of a multiple stakeholder and decision-maker, compared with individual ones (Hwang & Lin, 1987). Techniques not only expand the number of decision-makers, but also bring in computer-based models into the decision-making process (Parker et al., 2003; Sengupta & Bennett, 2003; Malczewski & Rinner, 2016). These computer programs are considered as agents, which are characterized by properties such as autonomy, reactivity, and rationality (Woolridge & Jennings, 1995; Sengupta & Bennett, 2003; O'Sullivan & Unwin 2010). Part of the "humanistic characteristics" (i.e. preferences, beliefs, and opinions) can be transferred into computer models so that it is possible to simulate some real-world situation (Malczewski & Rinner, 2016, p.24).

As stated before, a MCDA process will result in decisions from a set of alternatives. These alternatives are evaluated on the basis of a set of criteria. Both an individual criterion and the set of criteria as a whole should possess some key properties to adequately represent the multi-criteria nature of the decision situation (Keeney 1992). Each criterion must be measurable. A set of criteria should be complete (it should cover all aspects of a decision problem), operational (the criteria can be meaningfully used in the analysis), decomposable (the set of criteria can be broken into parts to simplify the process), non-redundant (to avoid the problem of double counting), and minimal (the number of criteria should be kept as small as possible) (Malczewski & Rinner, 2016). Criterion is make up of two components, the concept of objective and the attribute (Malczewski 1999).

An objective is a statement about the desired state of a system under consideration (e.g., a spatial pattern of accessibility to primary schools) (Malczewski & Rinner, 2016). An attribute is considered as a property of an element of a real-world geographic system (e.g., transportation system, location-allocation system, or land-use pattern) (Malczewski & Rinner, 2016). To be specific, an attribute is a measurable quantity or quality of an entity (Malczewski & Rinner, 2016). Objective acts as the direction of one or more attributes. The direction can be interpreted as either "the more of the attribute, the better" or "the less of the attribute, the better" (Malczewski & Rinner, 2016). This direction will determine whether a maximization or a minimization function will be used in standardizing attribute(s) of an objective, so that the value of different criteria can be comparable.

2.2.2 Standardization, Weighting, and Decision Rules

Standardization

The attribute value may vary across different measurement scales. This brings difficulties when making evaluations on decision alternatives (Nyerges & Jankowski, 2009). This problem can be solved by a standardization process which converts values into a comparable scale (Nyerges & Jankowski, 2009). There are two common approaches to standardization: linear and nonlinear.

The linear approach is called the ratio standardization. The formula is:

$$x'_{ij} = \frac{x_{ij}}{x_j^{max}}$$

The x_{ij}' is the standardized score for the *i*th alternative and the *j*th criterion. x_{ij} is the raw data value and x_j^{max} is the maximum value of all alternatives of the *j*th criterion. The standardized values range from 0 to 1 and are linearly related to the raw data values. This formula only applies on benefit criteria, meaning “the higher score the better” (Nyerges & Jankowski, 2009). For cost criteria, “the lower score the better” situation, the below formula will be applied as follows:

$$x'_{ij} = 1 - \frac{x_{ij}}{x_j^{max}}$$

Or

$$x'_{ij} = \frac{x_j^{min}}{x_{ij}}$$

where x_j^{min} is the minimum score for the *j*th criterion.

This linear transformation of raw data retains the order of magnitude in standardized scores. But it has disadvantages. The lowest standardized score is not always equal to zero, which may cause some difficulties with the interpretation. Besides, when the raw data cover the range of negative and positive values, this will bring difficulties in interpreting the scores.

The nonlinear standardization method solves these disadvantages. The formula of nonlinear standardization for a benefit criterion is:

$$x'_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}}$$

The formula for a cost criterion is:

$$x'_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}}$$

This procedure preserves the 0 to 1 range for standardized scores. Although it does not retain a linear relationship of standardized scores with the raw data, it guarantees the worst score to be 0 and the best score to be 1 and is also better at handling negative values.

Weighting

One of MCDA's important features is the capability to provide a constructive approach so that the preferences of decision-maker(s) can be evaluated. To obtain those preferences, one of the common methods is weighting. As defined by Nyerges & Jankowski (2009), weight is a numeric amount which is assigned to an evaluation criterion, indicating its relative importance with respect to other criteria in the decision situation. Normally, weights are normalized and the sum of all weights will equal to 1. A larger weight will indicate more importance of a certain criterion. In GIS-MCDA, a three basic weighting methods for application: ranking, rating, and pairwise comparison (Malczewski, 1999).

Ranking

The ranking method only requires decision-makers to rank all the criteria based on their preference (Stillwell et al., 1981). A straight ranking method can be applied by assigning the most important criterion as 1 and second important as 2, etc. (Malczewski & Rinner, 2016). Then the ranks will be converted into weights through this formula:

$$w_k = \frac{n - p_k + 1}{\sum_{k=1}^{n} (n - p_k + 1)}$$

where w_k is the k^{th} criterion weight, n is the number of criteria under consideration ($k = 1, 2, \ldots, n$), and p_k is the rank position of the criterion.

The ranking method is straightforward and simple. In some situations, this method is able to provide satisfactory results in criterion weights assessments (Stillwell et al. 1981). This method is simple but lacks a theoretical foundation (Malczewski & Rinner, 2016).

Rating

The rating method requires decision-makers to estimate criterion weights on the basis of a predetermined scale, such as a scale of 0 to 100. The most important criterion will be assigned to 100 and the lease important ones assigned to 0. After rating, weights are normalized by dividing each of the weights by the sum total. Similar to the ranking method, the rating method is also considered as lacking theoretical foundation (Malczewski & Rinner, 2016). Moreover, application of the rating method is limited to small numbers of criteria (Nyerges & Jankowski, 2009). Even with these downsides, this method is still attractive and has been demonstrated in its applications in different studies (McDaniels & Roessler, 1998; Stewart & Joubert, 1998). This method has been integrated into an ArcGIS based decision-making system developed by Ozturk and Batuk (2011).

Pairwise Comparison

The pairwise comparison technique is based on the analytic hierarchy process (AHP) method which was developed by Saaty (1980). This method is widely applied in diverse research aspects (e.g. Ananda & Herath, 2005; Qureshi & Harrison, 2003). Based on Mendoza & Prabhu (2000), AHP is summarized as a four-step procedure described as follows: Firstly, set up the decision hierarchy by decomposing the problem into a hierarchy of interrelated elements. Secondly, generate input data consisting of comparative judgements (i.e., pairwise comparisons) of decision elements. Thirdly, synthesize the judgements and estimate the relative weights. Finally, determine the aggregate relative weights of the decision elements to arrive at a set of ratings for the decision alternatives.

Decision Rules

The Weighed Sum and Weighed Product Models

Consider n alternatives $\{A_1,\ldots,A_n\}$ with m deterministic criteria $\{C_1,\ldots,C_m\}$. The alternatives are fully characterized by the decision matrix $\{S_{ij}\}$, where S_{ij} is the score that measures how well alternative A_i does on criterion C_j. The weights $\{w_1, w_2,\ldots, w_m\}$ account for the relative importance of the criteria. Given the focus on synthesis models, it is assumed that the scores and weights have been obtained using systematic rather than ad-hoc techniques. It can be concluded that (1) these activities are very important and non-trivial, and (2) the weights represent trade-offs between the various criteria and therefore their values depend on the underlying scales (Bouyssou et al. 2001). In the WSM the score of alternative Ai is given by $S(A_i) = \Sigma\, w_j S_{ij}$, where the sum is over j = 1,2,…,m. For consistency, all criteria must be expressed in the same units.

In the WPM the score of alternative A_i is given by $S(A_i) = \Pi\, S_{ij}\, w_j$, where the product is over j = 1,2,…,m. The WPM eliminates alternatives with poor attributes. From the comparison of WSM and WPM, it can be seen that these two similar methods incorporate similar equations but may lead to different solutions. In general, to solve the same problem, it is possible to adopt different functions with different solutions. Among all models, none can be considered as the “super model” that can be appropriate to all decision-making situations.

Other Approaches

The above approaches are the main practical implementations of multi-attribute decision-making (MADM) (Malczewski, 1999). To adapt to the complexity of real-world situations, numerous approaches have been developed. Under this MADM category, the value/utility function approaches are another popular method in environmental management. They include several functions in depicting decision-makers' preferences and are able to incorporate uncertainty into decisions (Malczewski, 1999). Other than the MADM, there is another category of decision approaches named as Multi-objective decision-making (MODM). This category of rules defines the set of alternatives in terms of a decision model consisting of a set of objective functions and a set of constraints imposed on the decision variables (Malczewski, 1999). These approaches can be combined or integrated to obtain more-optimal decisions (Kaya & Kahraman, 2011).

2.2.3 MCDA for Urban Forest Management

Managing trees in the urban context is totally eligible to be considered as "wicked problems" which means there may be no correct or best solution to problems (Shindler & Cramer, 1999). Due to this feature of urban forest management, especially when involving spatial planning, it requires general publics, stakeholders, and experts from different fields to join the decision-making process for reaching a relatively optimal decision. Thus, a systematic and objective decision-making process is necessary.

The MCDA method stands out as a good solution for decision-making problems especially for which requires holistic evaluation between different decision alternatives (Kangas & Kangas, 2005). As concluded by Belton and Stewart (2001), it has four features. First, MCDA method requires listing out multiple criteria relevance with the topic and the criteria may involves conflicts. Second, the process of designating criteria help to structure the problem. Third, the MCDA method could provide models for discussion. Forth, "it offers a process that leads to rational, justifiable, and explainable decisions" (Mendoza & Martins, 2006). The ability to incorporate participants' preference information into geospatial data features the strong advantage of MCDA so that has been widely applied in natural resource management research (Mendoza & Martins, 2006).

In the forest management field, Segura, Ray and Maroto (2014) conducted a thorough review on decision support systems applied in this field and they pointed to MCDA as one of the most important methods in forestry decision-making. Among all the research which applied MCDA, the Analytic Hierarchy Process (AHP), Simple Multi-Attribute Rating Technique (SMART), and ELimination and Choice Expressing REality (ELECTRE) are relatively popular (Segura, Ray, & Maroto, 2014). Another review of forest management, which was completed by Diaz-Balteiro and Romero (2008), focused more on the MCDA method. The writers analyzed more than 250 references and categorized them into nine different MCDA approaches in nine topic categories. Urban forest is not listed as a separate topic in the review and reviews of MCDA related to urban forest management are rare.

Although MCDA applied to the urban forest management was uncommon in my literature review on MCDA application in forestry, the concept of MCDA has been needed in some cases of urban forest management. In Belgrade, MCDA was used for selecting the most appropriate management policy for a forest situated within a city zone (Lakicevic, Srdjevic, Srdjevic, & Zlatic, 2014). And in New York, a group of researchers used a GIS-based approach to prioritize tree planting locations (Locke et al., 2010). In this case, MCDA was not clearly indicated as the applied method, but based on the description, the process of selecting criteria, setting weights, and ranking scores matches with the features of MCDA. Sometimes, the topic of urban forest management is intertwined with other topics (e.g.: urban park design (Zucca, Sharifi, & Fabbri, 2008), tree planting (Kirnbauer, Kenney, Churchill, & Baetz, 2009), or land suitability issues (Konijnendijk et al., 2007) which applied MCDA but they are rare under the category of urban forest management.

For applying MCDA to reach sophisticated decisions in urban forest management, some information tools are of great importance. Mapping and GIS have been widely adopted in urban forest management as tools for representing tree inventory (Kenney, Wassenaer, & Satel, 2011) and there are some further developments of software based on them. i-Tree is one of many information tools that must be mentioned here. It is a peer-reviewed, free package of tools developed by USDA in 2006 which helps to analyze and predict urban forest conditions (Nowak et al., 2010; USDA Forest Service, 2016). As stated in the i-Tree official website (i-Tree Canopy, n.d.), i-Tree tools have the ability to articulate the significance of community trees in terms of pollution mitigation, storm water run-off reduction, carbon sequestration and storage, and more. This has allowed i-Tree users to improve tree management, plan strategically, increase community awareness, engage decision-makers, and build new partnerships (USDA Forest Service, 2016).The interactive interface of i-Tree tools has the potential to attract governments, citizens, and urban planners towards further understanding of the important role of the urban forest in attaining urban sustainability (Pothier & Milward, 2013).

Six tools are included in the i-Tree package. Among them, i-Tree Eco and i-Tree Street are more commonly applied in urban forest management than others. i-Tree Eco was named as Urban Forest Effects and Values (UFORE) when developed in the late 1990s (King & Locke, 2013). It helps quantify the ecosystem goods and services of urban forests based on *in situ* inventory data and some meteorology data (e.g. pollution, precipitation) (Nowak & Crane, 2000; Nowak, Crane, Stevens & Hoehn, 2005). The i-Tree STREET, named STRATUM (Street Tree Resource Analysis Tool for Urban Forest Managers) before, was released in 2006 (McPherson, 2010). It is a model to monetize the value of public street trees specifically (Hilde & Paterson, 2014). It is capable of estimating the structure, function, and value of a community's public street tree population based on randomly sampled street segments (USDA Forest Service, 2016). i-Tree, along with some other decision support tools (e.g. CITYgreen, TreeLink), provides up-to-date on-ground information for decision-making (Nowak, Hoehn, Crane, Stevens, & Walton, 2007). Beyond them, some urban forest management groups developed extensions based on existing software to adapt to their local situation (Findlay, 2013) or even developed their own software to meet their local management needs (Kirnbauer, Kenney, Churchill & Baetz, 2009). Sound and reliable information provided by these decision support tools can be used as a base for successful MCDA on the urban forest.

CHAPTER 3 METHODS

3.1 Study Area

The study area of the UFMP covers 10 communities which comprise most of the highly populated areas in HRM. Among them, the Halifax peninsula was chosen as the study area for this pilot study. There are two reasons for choosing the peninsula. First, the Halifax peninsula is the most urbanized area with the least tree canopy cover among all communities (HRM Urban Forest Planning Team, 2013). Second, it has the highest population density in HRM and future changes will have impacts on more residents compared with other communities. Borrowing the concept of “marginal utility” from microeconomics, which means more efficiency because if small changes could benefit more, the outcome of this study in a more populated area would have larger marginal utility. Third, the peninsula has the most abundant free dataset available for research.

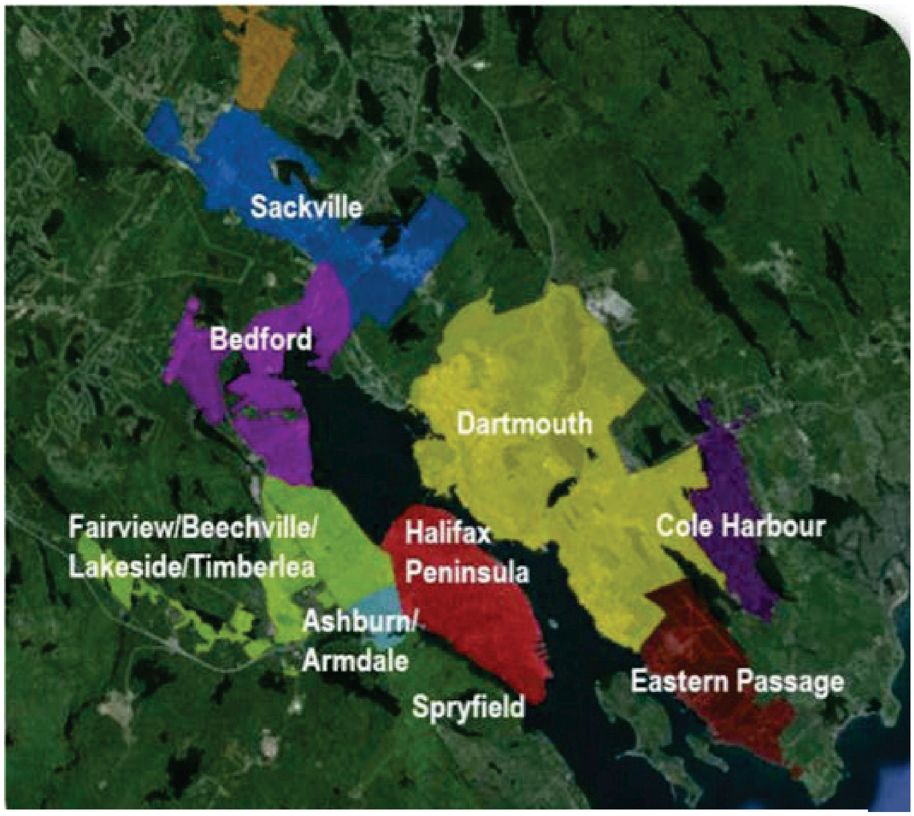


Figure 1: Study area of UFMP (HRM Urban Forest Planning Team, 2013)

3.2 Detailed Methods

To build a model for decision-making related with spatial features, the core idea is to use GIS-based MCDA. MCDA is defined as an " umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter" (Belton & Stewart, 2001). This method has been widely applied in environmental management but not in urban forest management as far as I can tell. So this is a pilot study that is trying to conceptualize key features of urban forests and combine them with their geographic characteristics in a decision-making process.

In this study, the MCDA method for urban tree planting is used in two phases: the site searching phase and site ranking phase (Malczewski, 2004). The concept of these two phases was derived from land-use suitability analysis where MCDA is frequently used. In the site searching phase, a set of candidate sites identified within a certain study area based on designated features. In the site ranking phase, which is normally called site selection in land suitability studies, features of the sites should be described and the sites are ranked through a process involving criteria setting and weighting. This phase is able to provide a rank of all candidate sites that enables decision-makers to select from them. For both the site searching phase and the site ranking phase, it is assumed that there is a given study area and the area is subdivided into a set of basic units such as polygons or rasters (Malczewski, 2004).

3.2.1 Phase 1: Site Searching Analysis

Within the study area of the UFMP in the Halifax peninsula, there are 99 recorded parks in the database. These parks have different geographic features and are designed for different purposes. To identify parks for suitable community tree-planting activities, four criteria were selected. They are: location, management authority, area, and a ground survey result (Table 1).

Location is the most fundamental criterion. The candidate parks must be located in the study area of this research, the Halifax peninsula. To change the landscape within parks, the urban forest managers must be able to guarantee that they have total stewardship of those parks. Thus, parks managed by the federal government, school boards, or private organizations were eliminated from the candidate list. The qualified parks have to be managed solely by the HRM. The park area is also taken into consideration as a criterion here. As new trees definitely will occupy spaces within parks, park area must be larger than the land usage of a one-time tree planting activity. Based on previous experience, we assume that each tree planting activity in Halifax would gather 20 volunteers and plant 500 seedlings. To spare enough growing space for seedlings, each tree would take 2 square meters space, which is 1.42 m apart from each other. Thus, 1000 square metres is chosen to be the basic unit for each tree planting activity. Any park area under 1000 square metres is eliminated from the list.

However, the above information is still not enough to designate the potential sites for future tree planting activities. Information from the spatial dataset includes errors and incorrect, outdated, and omitted information. So, a ground survey on pre-selected parks is indispensable. An *in situ* investigation could provide more-detailed ground information on the potential available spaces and it is a chance to observe the daily utility of these spaces by park visitors. Data on how residents are using parks and which area of the park is more frequently used can only be obtained by ground surveys.

Ground survey was conducted during August to November 2015. All parks which meet the location, management authority, and area criteria were visited at least one time when there were residents using them. Through eye sight observations, playgrounds, sports fields and places with bedrocks were marked as not suitable for tree planting. Moreover, places which well-known for entertainment activities such as snow sliding were also eliminated from potential tree planting.

The site selection phase is based on a Boolean logic that parks failed to meet the criteria should be eliminated from consideration in the next step. This whole process is outlined in Figure 2.

Table 1: Criteria in Site Searching Phase

#	Criteria	Description	Data Source
1	**Location**	The candidate parks must be located within the Halifax peninsula.	HRM UFMP Geodatabase 2013
2	**Management Authority**	The candidate parks must be managed by HRM only.	HRM Geodatabase 2012
3	**Area**	Park area needs to be larger than 1000 m^2.	HRM Geodatabase 2012
4	**Ground Survey Result**	All potential parks need to have at least one potential tree-planting site within the park.	Ground survey done in 2015

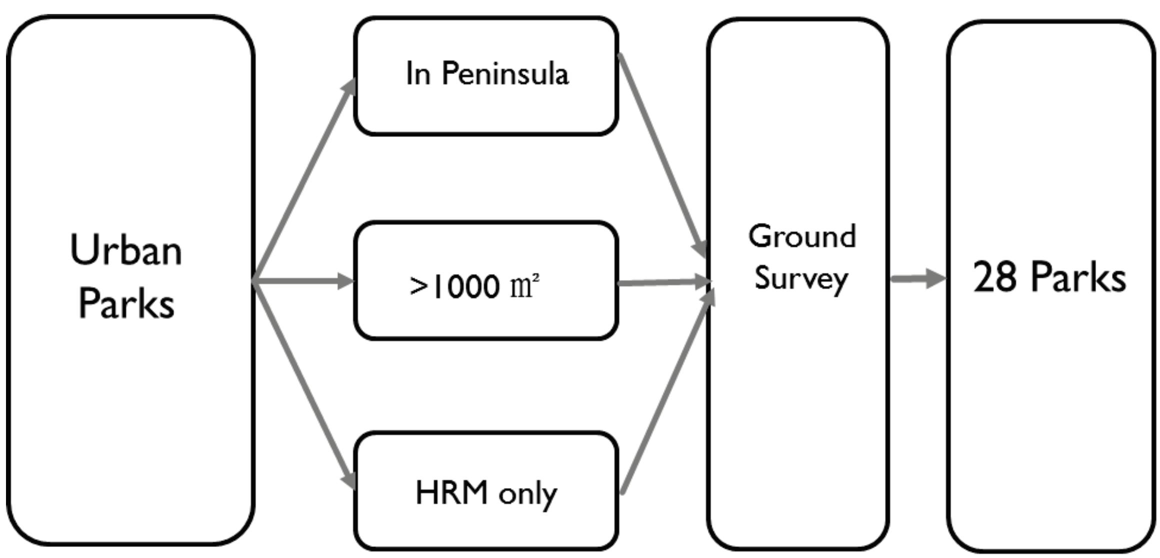


Figure 2: Steps in the Site Selection Phase

3.3.2 Phase 2: Site Ranking

After the site searching step, qualified parks are picked from the candidates and need to be ranked based on key features that have strong links to urban forest management. The features not only include the natural and physical information, but also the preferences of people who are managing or using these parks. The ideal situation is to obtain comments and thoughts from surrounding residents on the potential changes of urban forests around them. However, due to the limitation of time and financial costs, information of preferences was collected from a rather smaller group of people such as urban forest experts, managers, and those who are actively involved in community tree planting events. As urban residents, they are park visitors; comparing to others, they have more professional knowledge on urban forests to help in decision-making.

To set priorities on selected parks, criteria were developed to evaluate parks from both environmental and social aspects. Because the final goal of priority setting aims at finding the park that has the highest urgency and largest benefits brought by tree planting, the criteria must be representative of key elements of what residents and communities are concerned about.

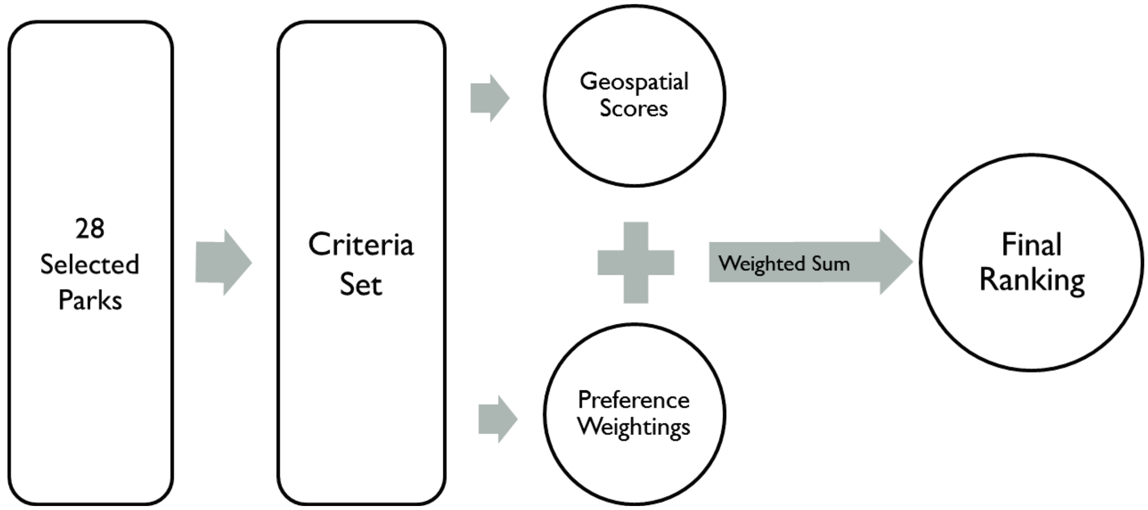


Figure 3: Steps in the Site Ranking Phase

Criteria Information

There are two categories of criteria: environmental and social. The environmental category focuses on the natural physical features related with selected parks, while the criteria under the social category aim at depicting the potential social factors that affect people who may benefit from increasing tree canopy.

The environmental category includes three criteria and two of them are related to canopy cover which is the fundamental goal listed in the UFMP. Planning for a tree planting activity normally first targets places with the least canopy coverage unless confined by other limitations. So “Park Canopy” was selected as a criterion. Considering that city parks are closely linked to the surrounding neighbourhood and changes in parks would have impacts on the residents, the “Neighbourhood Canopy” was also selected. The extent of the relevant neighbourhood was set as 300 m walkable distance surrounding the selected park. The walkable distance, although it varies with purposes and services, is normally set to 400 m (El-Geneidy, Grimsrud, Wasfi, Tétreault & Surprenant-Legault, 2014). However, in our case, considering visitors will need to walk inside the park for certain distances to notice landscape changes, the walkable distances outside of parks was set to be shorter than typically used in such analyses. Canopy cover is considered as an important indicator to evaluate the condition of the urban forest (Kenney, Van Wassenaer, & Satel, 2011). It is used as a criterion in other tree planting allocation research (Locke et al., 2010). For these criteria, the lower the canopy cover, the higher the priority for planting trees.

The other criterion under the environmental category is the road length enclosed within a certain buffered area around selected parks. This criterion is designed to evaluate benefits on air filtration brought by urban trees. In recent years, the association between high-traffic-volume roadways and negative health effects have been demonstrated using epidemiological studies (Baldauf, Thoma, Hays, Shores, Kinsey, Gullett, ... & Khlystov, 2008). Trees are considered to alleviate the effects by capturing particulate matter such as PM-2.5 (Nowak, 2014). Although Halifax has relatively low air pollution according to air quality monitoring results (Government of Nova Scotia, 2014), pollution during rush hours in city core areas is still noticeable. In addition, trees would have higher pollutant absorbability in locations with higher pollutant concentrations (McDonald, 2015). To reduce the potential harm caused by air pollutants efficiently, places with higher traffic volume, especially during rush hours, would need more trees (Nowak, 2014).

The high-traffic-volume roads were identified based on expert opinion. Pollutant dispersion varies depending on the type of pollutants. Based on Zhou and Levy (2007), a distance of 100 to 400 m for elemental carbon or PM mass concentration, 200 to 500 m for NO2, and 100 to 300 m for ultra-fine particles (UFP) count would elevate the risks of adverse health effects. Balancing the distance for the different pollutants, the buffered distance for depicting the air filtration function of trees was chosen as 200 m. The longer the road length included, the higher the priority for tree planting.

The social category contains five criteria. These five criteria were chosen to evaluate the potential social factors associated with tree planting. They are: Bus Stops, Population, Building Coverage, Elementary Schools, and Household Income. These criteria evaluate the number of people that may be affected by tree planting and focus on two special social groups (students and residents of low socioeconomic status).

The “Bus Stops” criterion is based on the number of bus stops in a 200-m buffer around the perimeter of the candidate parks. Considering car drivers will not be that much affected by the distance from home to parks, this criterion focuses on accessibility using the transit system. The larger the number of bus stops around the park, the higher the planting priority.

The “Population” criterion directly indicates the number of people that may be influenced or benefit from tree planting. The higher the population density, the higher the priority for tree planting. However, the available population data indicate only people who live in that area, and exclude people who work there. Thus, the “Building Coverage” criterion is designed to fix this issue. Based on the presumption that as long as there is a building, there will be people either living or working there, the “Building Coverage” criterion is able to include the need for green space in working places. Besides, this criterion also partly represents the potential heat island effect during the summer. For both of these two criteria, with the higher the number, the higher the priority for planting trees.

The criterion “Elementary School” counts the number of elementary schools near the park. The trees planted near schools can be good learning chances for young students nearby. It is also possible for the HRM to cooperate with schools to establish long-term formal environmental education programmes on the park trees. Thus, school number around selected parks was chosen as a criterion. The more schools located around the park (a 500-m buffer), the higher the priority for tree planting.

“Household Income” is chosen to evaluate the equity condition. Putting equity into consideration for tree planting comes from the UFMP. The urban forest on public land is a public good so it should serve society as a whole and provide clear benefits for people in low socioeconomic status neighbourhoods. Based on previous research, neighbourhoods with higher canopy cover normally are safer (Kuo & Sullivan, 2001) and have higher property values (Heynen & Lindsey, 2003; Sander, Polasky, & Haight, 2010). To redistribute society’s wealth and improve the security condition for these neighbourhoods, tree planting activities need to consider the equity issue. Thus, for neighbourhoods with lower annual household income, the priority for planting trees is higher.

Criteria Scoring and Standardization

Scores of each criterion were calculated through tools in ArcGIS 10.2.2 (Esri, 2014). Reference the detailed processing procedure in Appendix I.

The pre-processed scores of parks include counts, percentages, and length in metres. These scores are incomparable at this step so they need to be standardized. There are two standardization formulae depending on the prioritizing logic. One is “the higher the score the better”, which is called a benefit criterion, and the other one is “the lower the score the better", which called a cost criterion. Canopy Cover in Park, Canopy Cover in Neighbourhood, and Equity are cost criteria, whereas the rest of them are benefit criteria. For a benefit criterion, the standardization formula is:

$$x'_{ij} = \frac{x_{ij} - \min(\mathrm{x}_j)}{\max(\mathrm{x}_j) - \min(\mathrm{x}_j)}$$

where x_{ij}' means score after standardization, x_{ij} means the score of the indicator.

The formula for a cost criterion is:

$$x'_{ij} = \frac{\max(\mathrm{x}_j) - x_{ij}}{\max(\mathrm{x}_j) - \min(\mathrm{x}_j)}$$

where x_{ij}' means score after standardization, x_{ij} means the score of the indicator.

After standardizing, scores range between 0 and 1, and variations are preserved. Although this method does not retain a linear relationship with the raw data, it guarantees the worst score to be 0 and the best to be 1 so that they become comparable.

Criteria Weighting and Decision Rule

Scores only are not enough for priority setting for selected parks. From decision-makers' perspectives, these criteria may not be equally important. Thus, the criteria weighting process is critical in combining subjective preferences into decision-making. The thoughts are represented by weights put into each criterion. Methods for obtaining weights can vary. In this study, both rating and the pairwise comparison method were used so that a comparison between these two methods can be made. Considering that my study sought to preserve the differences among participants, weightings were obtained individually as opposed to in a group so that influences from others are avoided.

The rating method requires participants to provide rates based on a pre-determined scale which is set to be from 1 to 10 in this study. According to the ratio estimation procedure (Easton, 1973), a score of 10 is assigned to the most important criterion and 1 to the least important criterion. Less important ones are given smaller scores proportionately. After all criteria receive rating scores, they are normalized by dividing each score to the sum total. The formula is:

$$w_j = \frac{r_j}{\sum r}$$

Compared to the rating method, the pairwise comparison is more complicated. It requires participants to make one-to-one comparisons each time. This method employs an underlying scale with values from 1/9 to 9 to rate the relative preferences for the two criteria. Considering the complexity of an 8 x 8 comparison matrix, in this study, the importance index is simplified to include odd numbers only (Table 2).

Table 2: Pairwise Comparison Indexing Chart

Definition	**Index**	**Definition**	**Index**
Equally important	1	Equally important	1/1
Slightly more important	3	Slightly less important	1/3
Much more important	5	Way less important	1/5
Far more important	7	Far less important	1/7
Extremely more important	9	Extremely less important	1/9

To obtain final weights, the matrix undergoes a normalization process, followed by a consistency analysis process to test whether the original preference ratings of each participant were consistent. The normalization process takes three steps, for a 3 x 3 matrix of pairwise elements:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix}$$

1) Sum the values in each column of the pairwise matrix

$$C_{ij} = \sum_{i=1}^{n} C_{ij}$$

2) Divide each element in the matrix by its column total to normalize the pairwise matrix

$$X_{iJ} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}} \begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix}$$

3) Divide the sum of the normalized column of the matrix by the number of criteria used (n) to generate the weighted matrix

$$W_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n} \qquad \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix}$$

In the consistency analysis process, the consistency vector is calculated by multiplying the pairwise matrix by the weights vector.

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} = \begin{bmatrix} Cv_{11} \\ Cv_{12} \\ Cv_{13} \end{bmatrix}$$

$$Cv_{11} = \frac{1}{W_{11}} [C_{11}W_{11} + C_{12}W_{21} + C_{13}W_{31}]$$

$$Cv_{21} = \frac{1}{W_{21}} [C_{21}W_{11} + C_{22}W_{21} + C_{23}W_{31}]$$

$$Cv_{31} = \frac{1}{W_{31}} [C_{31}W_{11} + C_{32}W_{21} + C_{33}W_{31}]$$

With the consistency vector, it is able to calculate lambda (λ) and the consistency index (CI).

$$\lambda = \sum_{i=1}^{n} Cv_{ij}$$

$$\mathrm{CI} = \frac{\lambda - \mathrm{n}}{n - 1}$$

The consistency ratio is defined as follows:

$$C_r = \frac{CI}{RI}$$

where RI is the random index, the consistency index of a randomly generated pairwise comparison matrix. If Cr < 0.1, it indicates a reasonable level of consistency in the pairwise comparisons; if Cr ≥ 0.1, the values of the ratio are indicative of inconsistent judgements. When Cr shows inconsistency, it is suggested to re-do the pairwise comparison until Cr < 0.1 is reached. But for this pilot study, the inconsistency results were kept and accepted (Saaty, 1980).

After obtaining weights of all criteria, the Weight Sum Model (WSM) is applied. The final score of a selected park would be calculated through this formula:

$$A_i = \sum_j w_j \, x_{ij}$$

where x_{ij} is the score of the *i*th alternative with respect to the *i*th attribute, and the weight w_j is a normalized weight, with that sum of $w_j = 1$. The weights represent the relative importance of the attributes.

Consultation

Considering this research is a pilot study, the weights obtaining process is based on consultations through experts. The experts with professionalism could not only provide weights, but also comments and suggestions from their experience and thoughts. The experts chosen in this research were all professionals in urban forest management or city planning so that they have sound knowledge basis for commenting. Decision-making is also included in experts' daily works, thus, they have more experience in commenting the selection of decision-making criteria than the general publics.

Six to twelve experts were targeted so that information would not be overwhelming. The consultation was conducted in a face-to-face individual meeting so that thoughts from each expert would not be influenced by others and differences could be preserved. Before the consultation started, experts were informed with a brief introduction of this research on the purposes and targets; then followed descriptions of all weighting criteria.

During the consultation, both of the two weighting methods, the rating method and the pairwise comparison method, were conducted through filling charts on printed papers. Then, experts were asked to fill an evaluation chart for each criterion on their validity and provide comments on them. The whole process was designed to be finished in one hour.

CHAPTER 4 RESULTS

The Results section includes two parts, which are counterparts of the two phases in the Methods section. The Site Selection part presents site searching results in which parks with potential planting opportunities are identified through four pre-determined criteria. The Site Rank part presents weights obtained from two weighting methods derived from an expert consultation process and final rankings for all selected parks.

4.1. Site Selection

Four criteria were developed to select qualified parks for potential naturalization for community tree planting. These four criteria are: location, area, management authority (corrected by experts' opinion), and a ground survey. After applying location and area criteria, the information for which is in the geodatabase provided by HRM, the number of candidate parks was reduced to 76 from over a thousand in the municipality.

The management authority information also exists in the HRM geodatabase; however, this information needed corrections and further filtrations. For those parks which are managed solely by HRM, there are historical sites and mis-categorized neighbourhood parks, which are not suitable for community tree-planting activities. Thus, these kinds of parks were crossed off from the list.

With 50 candidate parks at hand before the fourth step, the ground survey criterion was crucial because it involves consideration of social and recreational utilization of the parks in addition to environmental perspectives. Spaces solely covered by grass are capable of receiving planted trees but if park visitors need these open spaces for activities such as sports, they were eliminated from the scope of this research. After the ground survey, parks with potential sites for community tree-planting are selected. The whole process finally resulted in 28 parks for site ranking in the next step (Figure 3).

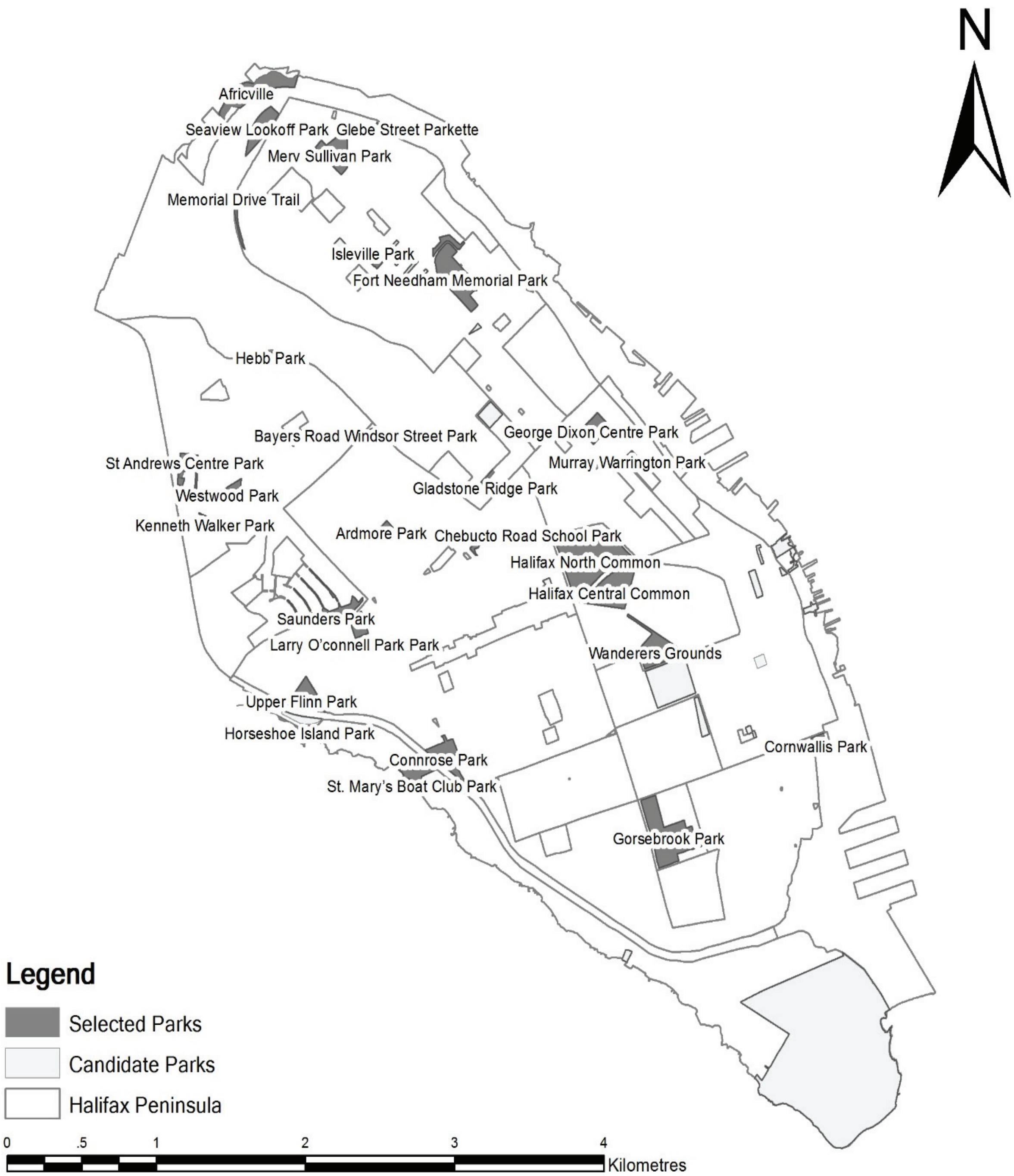


Figure 4: Selected Parks in the Halifax Peninsula

4.2. Site Ranking

To rank the selected parks, the geospatial information relating to the eight selected criteria were calculated first. Results of this step are named geospatial scores. Then, expert preferences regarding each criterion were developed into weights obtained from consultation processes. These weights were calculated using a Weighted Sum Model (WSM) and resulted in priority scores for each park. The priority scores were used for ranking the parks.

4.2.1 Geospatial Scores

For each park, the geospatial scores for each criterion were calculated based on pre-existing geospatial-related information by using the ArcGIS 10.2.2 (Esri, 2014) with the processes showed in Appendix I. Results for each criterion were in different units (Table 3) (Raw data attached in Appendix II). To convert them into comparable numbers, a standardization process was applied so that all scores are in the same range from 0 to 1 (Table 4).

Table 3: Data Sources, Units, and Ranges

Criteria	Data Source	Unit	Min	Max
Park Canopy	Halifax Peninsula Airphoto 2010	Percentage	0.60%	37%
Neighbourhood Canopy	Halifax Peninsula Airphoto 2010	Percentage	0.50%	48%
Road Length	HRM Geodataset 2012	Meter	0.00	6439.12
Bus Stops	HRM Geodataset 2012	Count	0	24
Population	Statistics Canada 2011	Number	382.20	4240.34
Building Coverage	HRM Geodataset 2012	Percentage	1%	28%
Elementary Schools	HRM Geodataset 2012	Count	0	3
Household Income	Statistics Canada 2011	Canadian Dollar	19034.18	87498.50

Table 4: Geospatial Scores of Selected Parks

Park Name	Park Canopy	Neighbourhood Canopy	Road Length	Bus Stops	Population	Building Coverage	Elementary Schools	Household Income
Africville	0.69	1.00	0.24	0.08	0.00	0.00	0.00	0.26
Ardmore Park	0.64	0.00	0.07	0.17	0.41	0.66	0.00	0.22
Bayers Road Windsor Street Park	0.14	0.84	0.11	0.42	0.19	0.67	0.33	0.20
Chebucto Road School Park	0.38	0.17	0.33	0.50	0.57	0.87	0.33	0.20
Connrose Park	0.64	0.04	0.12	0.04	0.28	0.47	0.67	0.85
Cornwallis Park	0.15	0.95	0.23	0.46	0.62	0.92	0.33	0.09
Fort Needham Memorial Park	0.15	0.56	0.34	0.71	0.48	0.58	0.67	0.16
George Dixon Centre Park	0.24	0.90	0.34	0.58	0.67	0.69	0.33	0.03
Gladstone Ridge Park	1.00	0.50	0.29	0.54	0.34	1.00	0.67	0.16
Glebe Street Parkette	0.92	0.94	0.13	0.13	0.10	0.34	0.00	0.23
Gorsebrook Park	0.71	0.40	0.32	0.71	0.85	0.77	1.00	0.41
Halifax Central Common	0.72	0.95	1.00	0.71	0.42	0.62	0.00	0.49
Halifax North Common	0.88	0.83	0.99	1.00	1.00	0.69	0.00	0.33
Hebb Park	1.00	0.97	0.07	0.17	0.05	0.43	0.67	0.20
Horseshoe Island Park	0.64	0.23	0.29	0.42	0.25	0.37	0.00	0.30
Isleville Park	0.70	0.35	0.29	0.46	0.26	0.52	0.33	0.23
Kenneth Walker Park	0.45	0.56	0.00	0.13	0.19	0.55	0.00	0.11
Larry Oconnell Park	0.60	0.08	0.42	0.25	0.37	0.50	0.00	0.36
Memorial Drive Trail	0.96	0.93	0.14	0.08	0.12	0.28	0.00	0.24
Merv Sullivan Park	0.78	0.76	0.13	0.54	0.34	0.42	0.33	0.22
Murray Warrington Park	0.71	0.87	0.27	0.25	0.47	0.75	0.33	0.00
Saunders Park	0.30	0.21	0.44	0.38	0.61	0.60	0.33	0.26
Seaview Lookoff Park	0.30	0.91	0.36	0.29	0.07	0.13	0.00	0.25
St Andrews Centre Park	0.81	0.68	0.00	0.08	0.31	0.41	0.33	0.05
St Marys Boat Club Park	0.00	0.11	0.09	0.00	0.09	0.32	0.67	1.00
Upper Flinn Park	0.21	0.02	0.25	0.25	0.30	0.44	0.00	0.38
Wanderers Grounds	0.74	0.77	0.29	0.17	0.13	0.51	0.33	0.61
Westwood Park	0.90	0.62	0.04	0.25	0.33	0.53	1.00	0.09

4.2.2 Weights

Weights are the representation of experts' preferences on each criterion. They were obtained through consultations by using two methods: rating and pairwise comparison. The two methods resulted in different weights and consequently different rankings.

Rating Method

In the consultations, experts were asked to rate each criterion in a 1 to 10 range, where 1 indicates the least importance and 10 indicates the most important criterion from the expert's consideration (Table 5). The rates were then normalized into weights in a 0 to 1 range (Table 6).

Table 5: Criterion Ratings Derived from Expert Consultation (Each expert is denoted by a letter from A to H)

Criteria	A	B	C	D	E	F	G	H
Park Canopy	10	1	10	10	8	9	10	7
Neighbourhood Canopy	9	5	10	10	7	10	9	8
Road Length	10	6	5	10	7	8	8	7
Bus Stops	4	8	5	5	7	5	8	7
Population	5	8	5	8	8	5	8	8
Building Coverage	8	10	7	10	8	9	8	7
Elementary Schools	7	7	9	7	6	9	8	8
Household Income	6	8	9	9	9	10	8	8

Table 6: Weights Derived from Table 5

Criteria	A	B	C	D	E	F	G	H	AVG	STD
Park Canopy	0.17	0.02	0.17	0.14	0.13	0.14	0.15	0.12	0. 13	0. 04
Neighbourhood Canopy	0.15	0.09	0.17	0.14	0.12	0.15	0.13	0.13	0. 14	0. 02
Road Length	0.17	0.11	0.08	0.14	0.12	0.12	0.12	0.12	0. 12	0. 02
Bus Stops	0.07	0.15	0.08	0.07	0.12	0.08	0.12	0.12	0. 10	0. 03
Population	0.08	0.15	0.08	0.12	0.13	0.08	0.12	0.13	0. 11	0. 03
Building Coverage	0.14	0.19	0.12	0.14	0.13	0.14	0.12	0.12	0. 14	0. 02
Elementary Schools	0.12	0.13	0.15	0.10	0.10	0.14	0.12	0.13	0. 12	0. 02
Household Income	0.10	0.15	0.15	0.13	0.15	0.15	0.12	0.13	0. 14	0. 02
SUM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
STD	0.04	0.05	0.04	0.03	0.01	0.03	0.01	0.01	0.01	

In Table 6, the average weightings for each criterion indicate small differences between the criteria. The largest weight is 0.14 whilst the smallest weight is 0.10. Meanwhile, the standard deviation varies quite little across the criteria set. The highest standard deviation appears for the park canopy criterion which indicates that experts have relatively different thoughts on the importance regarding this criterion. The standard deviation for each expert ranges from 0.01 to 0.05. Among the eight experts, three of them had a standard deviation rounded to 0.01, which means that the variation of their weights for the criteria are small. They did not express preference differences among the criteria. The final average weightings for each criterion are also in a low-variation condition.

Pairwise Comparison

A pairwise comparison method was also conducted during the expert consultations. Experts were asked to fill the comparison table by making one-to-one comparisons.

During implementation of the method, experts experienced some difficulties as eight criteria need 28 independent comparisons. The given weight ranged from 1/9 to 1 or 1 to 9, depending on the importance (see Appendix III) between any two criteria; this was also a barrier to expeditious accomplishment using this method.

Using a spreadsheet tool for calculating the weights, the pairwise comparison method provided direct weightings and a consistency ratio (Cr) for evaluating the robustness of results. All weightings range between 0 and 1 as shown in Table 7. A noticeable thing here is that, among the eight participating experts, there are 3 out of 8 having a Cr value larger than 0.1. This indicates that their comparison results lack consistency between each pair so that the values are not strongly reliable from a theoretical perspective (Saaty, 1980).

Table 7: Pairwise Comparison Weights

Criteria	A	B	C	D	E	F	G	H	AVG	STD
Park Canopy	0.29	0.02	0.17	0.16	0.14	0.14	0.22	0.15	0. 16	0. 07
Neighbourhood Canopy	0.17	0.04	0.14	0.25	0.14	0.21	0.22	0.15	0. 17	0. 06
Road Length	0.05	0.08	0.06	0.12	0.10	0.10	0.15	0.15	0. 10	0. 04
Bus Stops	0.03	0.11	0.04	0.02	0.17	0.04	0.05	0.13	0. 07	0. 05
Population	0.07	0.24	0.05	0.13	0.06	0.05	0.16	0.10	0. 11	0. 06
Building Coverage	0.23	0.14	0.08	0.13	0.06	0.09	0.08	0.09	0. 11	0. 05
Elementary Schools	0.10	0.14	0.19	0.03	0.06	0.23	0.06	0.13	0. 12	0. 06
Household Income	0.06	0.22	0.27	0.17	0.28	0.15	0.06	0.10	0. 16	0. 08
Cr	**0.10**	0.08	0.07	**0.17**	**0.13**	0.05	0.09	0.08		
STD	0. 09	0. 07	0. 08	0. 07	0. 07	0. 07	0. 07	0. 02	0. 03	

Park rankings

To generate final rankings, weights given by eight experts were averaged. The two weighting methods result in different weights for each criterion, thus different priority scores for the parks (Table 8). However, with differences, the ranking sequences of these methods do have some similarities. Most parks have similar scores for both methods and the overall ranking sequences are close (Figure 5). To test this in a statistical way, correlation between the results of the two methods resulted in $r = 0.98$, indicating that the two methods are strongly similar.

Table 8: Priority Score

Park Name	Rating	Pairwise Comparison
Africville	29.97	35.04
Ardmore Park	27.41	27.64
Bayers Road Windsor Street Park	36.97	36.97
Chebucto Road School Park	41.51	38.97
Conmrose Park	40.18	42.40
Cornwallis Park	47.46	46.27
Fort Needham Memorial Park	44.68	42.23
George Dixon Centre Park	46.98	45.72
Gladstone Ridge Park	56.87	56.68
Glebe Street Parkette	36.72	41.53
Gorsebrook Park	63.79	62.53
Halifax Central Common	61.72	62.18
Halifax North Common	70.21	69.09
Hebb Park	46.24	50.60
Horseshoe Island Park	31.11	31.84
Isleville Park	39.30	39.61
Kenneth Walker Park	25.99	27.60
Larry Oconnell Park	32.38	32.47
Memorial Drive Trail	36.09	41.26
Merv Sullivan Park	44.25	46.27
Murray Warrington Park	46.63	47.81
Saunders Park	38.72	36.93
Seaview Lookoff Park	29.70	32.02
St Andrews Centre Park	34.58	37.64
St Marys Boat Club Park	29.84	31.25
Upper Flinn Park	23.08	22.34
Wanderers Grounds	46.15	49.68
Westwood Park	47.74	49.64

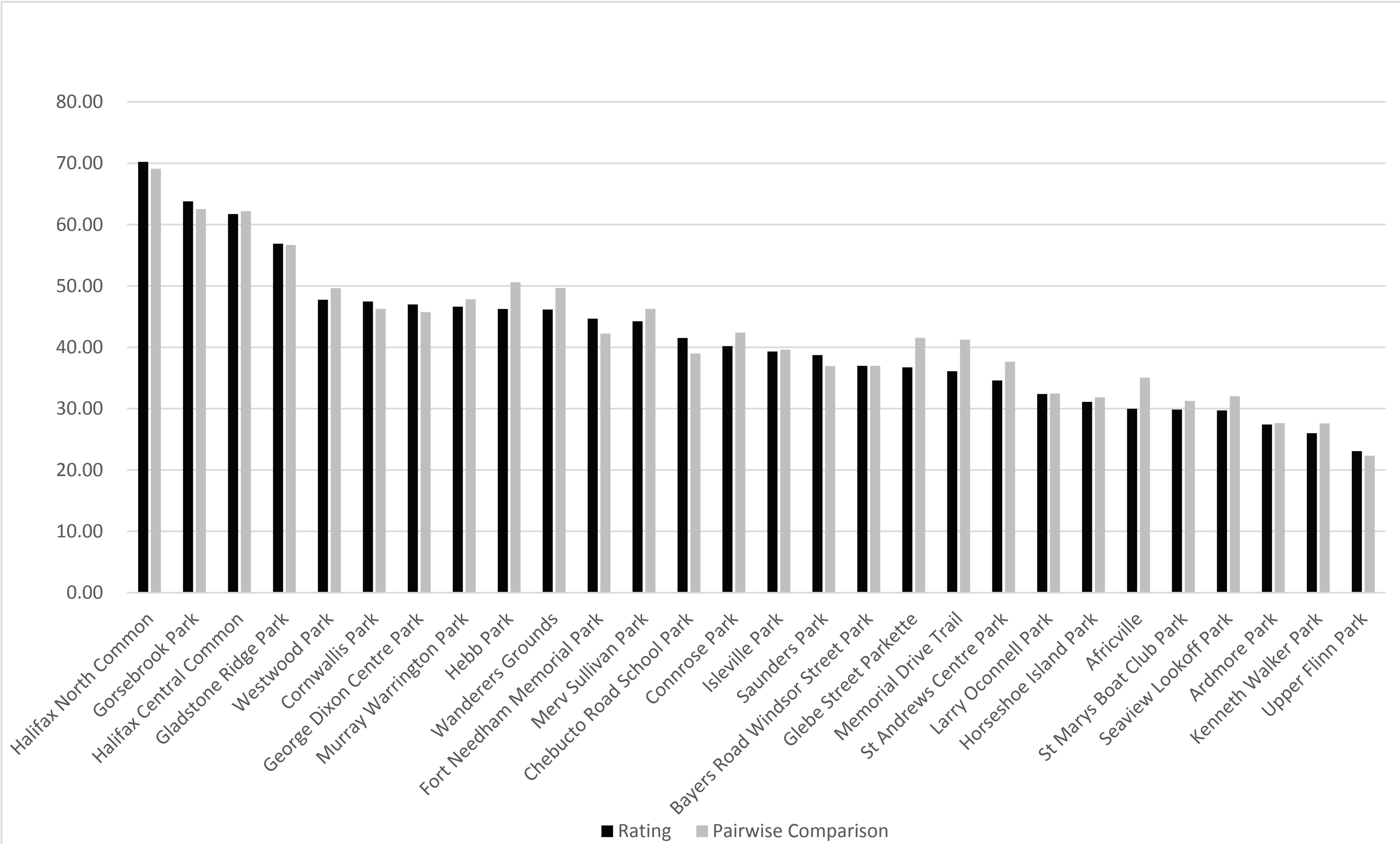


Figure 5: Priority Scores Comparison between Methods

Based on the priority scores, the parks can be categorized into four groups. Four parks with the highest scores represent a group with the highest priority for tree-planting. As indicated in Table 8, these four parks rank as the top four using both methods and the score differences between the fourth and fifth are larger than all other differences. From the fifth one, scores decline gradually. The 12th park using the Rating method and the 11th using the Pairwise Comparison may signal a second natural gap but these are much less significant than the first group. The last three parks which have the lowest scores in both methods may be reasonably said to constitute their own group with the lowest priority for community tree planting initiatives.

Table 9: Priority Score Differences

Park Name	Rating	Differences	Rank	Differences	Pairwise Comparison	Park Name
Halifax North Common	70.21	6.42	1	6.56	69.09	Halifax North Common
Gorsebrook Park	63.79	2.08	2	0.35	62.53	Gorsebrook Park
Halifax Central Common	61.72	4.84	3	5.50	62.18	Halifax Central Common
Gladstone Ridge Park	56.87	9.13	4	6.08	56.68	Gladstone Ridge Park
Westwood Park	47.74	0.28	5	0.92	50.60	Hebb Park
Cornwallis Park	47.46	0.47	6	0.04	49.68	Wanderers Grounds
George Dixon Centre Park	46.98	0.35	7	1.83	49.64	Westwood Park
Murray Warrington Park	46.63	0.40	8	1.54	47.81	Murray Warrington Park
Hebb Park	46.24	0.09	9	0.00	46.27	Cornwallis Park
Wanderers Grounds	46.15	1.47	10	0.55	46.27	Merv Sullivan Park
Fort Needham Memorial Park	44.68	0.43	11	3.32	45.72	George Dixon Centre Park
Merv Sullivan Park	44.25	2.74	12	0.17	42.40	Connrose Park
Chebucto Road School Park	41.51	1.33	13	0.70	42.23	Fort Needham Memorial Park
Connrose Park	40.18	0.88	14	0.27	41.53	Glebe Street Parkette
Isleville Park	39.30	0.58	15	1.64	41.26	Memorial Drive Trail
Saunders Park	38.72	1.75	16	0.64	39.61	Isleville Park
Bayers Road Windsor Street Park	36.97	0.25	17	1.33	38.97	Chebucto Road School Park
Glebe Street Parkette	36.72	0.63	18	0.67	37.64	St Andrews Centre Park
Memorial Drive Trail	36.09	1.51	19	0.04	36.97	Bayers Road Windsor Street Park
St Andrews Centre Park	34.58	2.20	20	1.89	36.93	Saunders Park
Larry Oconnell Park	32.38	1.27	21	2.57	35.04	Africville
Horseshoe Island Park	31.11	1.14	22	0.45	32.47	Larry Oconnell Park
Africville	29.97	0.13	23	0.18	32.02	Seaview Lookoff Park
St Marys Boat Club Park	29.84	0.15	24	0.59	31.84	Horseshoe Island Park
Seaview Lookoff Park	29.70	2.29	25	3.61	31.25	St Marys Boat Club Park
Ardmore Park	27.41	1.42	26	0.05	27.64	Ardmore Park
Kenneth Walker Park	25.99	2.91	27	5.25	27.60	Kenneth Walker Park
Upper Flinn Park	23.08		28		22.34	Upper Flinn Park

Differences between the two methods

The original purpose of this project was to look for parks with the high priority for community tree-planting. The priority is represented by the priority scores calculated through combining geospatial scores and criteria weightings. This research applied two weighting methods. Although with high similarities, a comparison between the weighting scores reveals some differences.

In Figure 6, a rank comparison was made between the methods based on priority scores. Arrows indicate rank ordering differences larger than three. In this comparison, arrows are clustered in the middle range from the fifth to the twentieth. This indicates that the weighting differences between two methods mostly influence the middle range of the ranking.

Park Name	Rating	Rank
Halifax North Common	70.21	1
Gorsebrook Park	63.79	2
Halifax Central Common	61.72	3
Gladstone Ridge Park	56.87	4
Westwood Park	47.74	5
Cornwallis Park	47.46	6
George Dixon Centre Park	46.98	7
Murray Warrington Park	46.63	8
Hebb Park	46.24	9
Wanderers Grounds	46.15	10
Fort Needham Memorial Park	44.68	11
Merv Sullivan Park	44.25	12
Chebucto Road School Park	41.51	13
Connrose Park	40.18	14
Isleville Park	39.30	15
Saunders Park	38.72	16
Bayers Road Windsor Street Park	36.97	17
Glebe Street Parkette	36.72	18
Memorial Drive Trail	36.09	19
St Andrews Centre Park	34.58	20
Larry Oconnell Park	32.38	21
Horseshoe Island Park	31.11	22
Africville	29.97	23
St Marys Boat Club Park	29.84	24
Seaview Lookoff Park	29.70	25
Ardmore Park	27.41	26
Kenneth Walker Park	25.99	27
Upper Flinn Park	23.08	28

Rank	Pairwise Comparison	Park Name
1	69.09	Halifax North Common
2	62.53	Gorsebrook Park
3	62.18	Halifax Central Common
4	56.68	Gladstone Ridge Park
5	50.60	Hebb Park
6	49.68	Wanderers Grounds
7	49.64	Westwood Park
8	47.81	Murray Warrington Park
9	46.27	Cornwallis Park
10	46.27	Merv Sullivan Park
11	45.72	George Dixon Centre Park
12	42.40	Connrose Park
13	42.23	Fort Needham Memorial Park
14	41.53	Glebe Street Parkette
15	41.26	Memorial Drive Trail
16	39.61	Isleville Park
17	38.97	Chebucto Road School Park
18	37.64	St Andrews Centre Park
19	36.97	Bayers Road Windsor Street Park
20	36.93	Saunders Park
21	35.04	Africville
22	32.47	Larry Oconnell Park
23	32.02	Seaview Lookoff Park
24	31.84	Horseshoe Island Park
25	31.25	St Marys Boat Club Park
26	27.64	Ardmore Park
27	27.60	Kenneth Walker Park
28	22.34	Upper Flinn Park

Ranking Difference equals to 3

Ranking Difference equals to 4

Figure 6: A Comparison between Methods Based on Ranks

The two weighting methods also displayed differences in deviations. The pairwise comparison has slightly more variation in average weightings among criteria (Table 6 and Table 7). Regarding each criterion, the park canopy, neighbourhood canopy, and household income criteria received relatively higher scores in both weighting methods. In addition, the bus stops criterion has the lowest weighting in both methods. Meanwhile, the weights of road length and building coverage criteria are higher in the rating method than in pairwise comparison. Thus, for weightings of criteria, the pairwise comparison method is able to obtain more preference differences from participants.

Looking at the standard deviations of each participant's weightings, they are always higher for the pairwise comparison than for the rating method. In the rating method, the standard deviation varies from 0.01 to 0.05, and three out of eight participants had a standard deviation of 0.01. On the other hand, in the pairwise comparison method, the standard deviation varies from 0.02 to 0.09, which is in a larger range and larger numbers compared to the rating method.

Experts' comments on the criteria

In the rating method, rates were required to be given a number larger than zero, which denies an expert from rejecting the criterion. To test the validity during the consultations, experts were asked to examine the validity of each criterion and provide their comments. In Table 10, eight experts' comments are summarized and categorized into three columns.

Of the eight criteria, seven were thought to be valid by all eight experts. Only the Bus

Stops criterion received two invalidity votes. The Bus Stops criterion was considered not valid due to two factors. First, this criterion only counts transit users so it is not applicable to car drivers and people who walk to parks. Second, within the peninsular boundary, transportation method was not considered a constraint factor for people visiting parks. Comments on this criterion matches with experts' weightings result that the Bus Stops criterion received the lowest weights in both weighting methods.

Three criteria were nominated for more-detailed indicators. For the Road Length criterion, experts suggested to use stratify road types to indicate the importance of the road so that ingredients of air pollutants can be identified in more specific information. Moreover, this criterion was suggested to not only count potential air pollutant absorption capability by trees, but also to be used for evaluating storm-water run-off which is also an important factor affected by trees.

The building coverage criterion itself includes two aspects: the social aspects that represent people who are using the buildings, and the environmental aspect in which the heat island effect is strongly correlated with concrete coverage. However, it is also an element related to storm-water run-off, as suggested. For further evaluating the heat island effect, solar exposure data are more straightforward.

For the population criterion, the geospatial score calculation was based on the 2011 census done by Statistics Canada. Although I doubt that the population distribution in the Halifax peninsula has changed significantly from then until now, a future population transition trend was suggested to be a better evaluation approach and would be more accurate than statistics on past populations.

Table 10: Expert Comments on the Criteria (Blank cells indicate no comments)

Criteria	Pros	Cons	Suggestions
Park Canopy	Most important, first evaluated	Low canopy cover doesn't mean lots of room for planting	
Neighbourhood Canopy			
Road Length	Important for evaluate carbon and air pollutant absorption.		Consider impervious of surrounding surfaces as it is able to indicate storm water run-off. Road types can be stratified for better capturing types of air pollutants.
Bus Stops		Not necessary especially on the peninsular Not a transit user.	
Population	Certainly be considered and will influence the future methods on planting design.		Population changing trend is better considered.
Building Coverage	Heat Island Effect is important to consider as climate change will lead to higher temperature in summer.		Also an environmental consideration on storm water management and soil volume for tree growth. Solar exposure may be used as an indicator.
Elementary Schools	Can be applied to community education and environmental		

	stewardship. Important, nature should be installed at an early age.		
Household Income	Valid to be included.	But potentially covered under canopy cover and education criteria.	

Experts also suggested four additional criteria that would be valuable for decision-making on park planting priorities: playgrounds, aesthetics, established working partnerships, and site history. Playgrounds attract children who, as a vulnerable demographic group in relation to sun exposure, would benefit from additional tree shade. The aesthetics criterion was proposed from a landscape perspective. If a park has needs for visual improvements, tree plantings may be considered. For future tree planting, if a park already has some work done by, or has partnerships with, community groups or NGOs, it may be considered to have a high priority. Finally, site history, or the land use history of the site, is considered to determine whether the park landscape is suitable to have more trees or not, so it is proposed as a criterion as well.

In addition to commenting on the validity of the criteria, two experts mentioned that these criteria may have interdependence so that weights given to one criterion would be partly represented in the weights of others. To test this proposition, calculation of correlations on each criterion pair were carried out (Figure 5). Three pairs of criteria demonstrated relatively strong correlation. They are: Bus Stops-Road Length, Population-Bus Stops, and Building Coverage-Population. Their correlations are 0.72, 0.76, and 0.69

respectively. All three pairs have a significant relationship ($p<0.001$). The negative correlation between the Neighbourhood Canopy and Household Income merits further analysis.

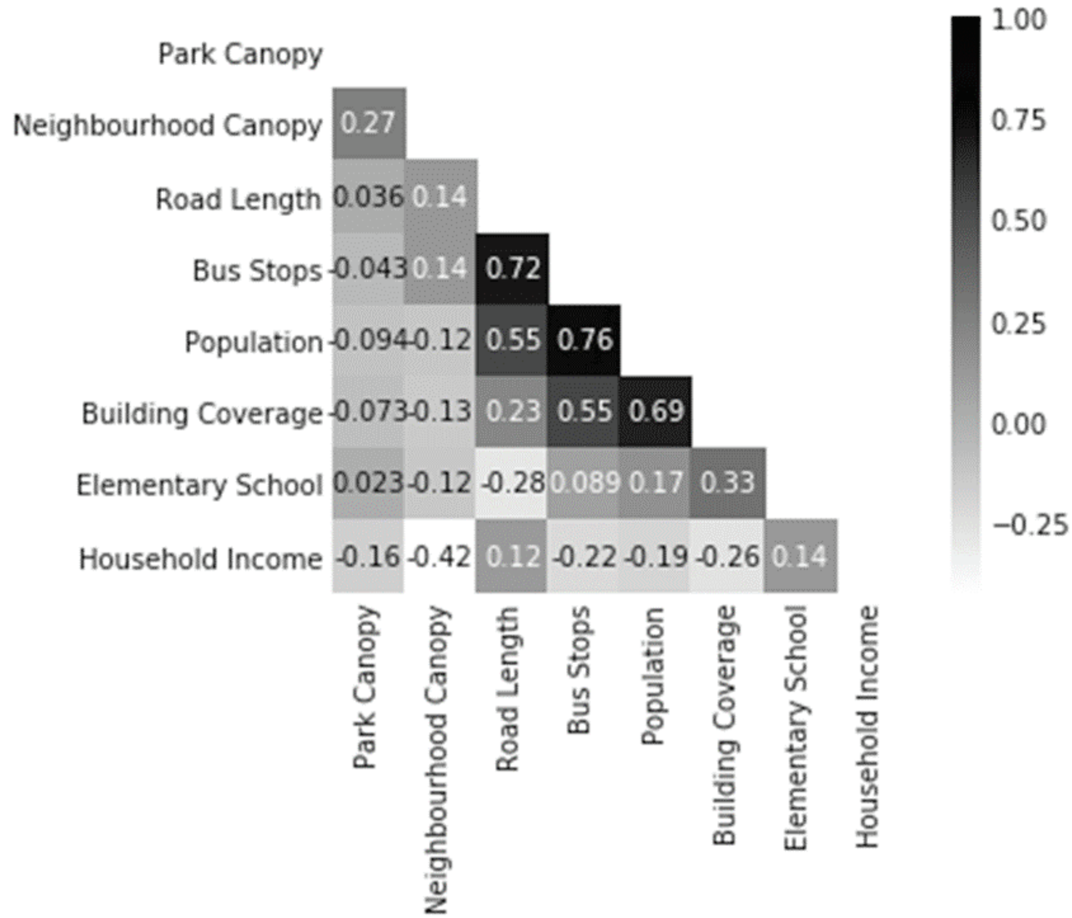


Figure 7: Correlation between Criteria

CHAPTER 5 DISCUSSION

5.1 A Comparison between Two Weighting Methods

In this research, two weighting methods were applied, the simple rating method and the pairwise comparison method. The simple rating method is easily understandable and applicable, but it lacks a theoretical foundation as it only requires participants to provide rates based on their subjective judgements (Malczewski, 1999). On the contrary, the pairwise comparison method has an algorithm for calculating weights from comparison charts and is appended with a consistency ratio (Cr) for evaluating the reliability of results (Saaty, 1980). Due to differences in complexity, the time consumption of these two methods differs a lot. In this research, the rating method required only eight evaluation steps so that took much less time than the pairwise comparison method, which required 27 comparisons to cover all pairs of criteria. This heavy workload is a barrier for implementing the pairwise comparison method more broadly.

In addition to the time consumption issue, pairwise comparison does not perform well in terms of result quality. Among the eight experts, three of them have a Cr value larger than 0.1 (Table 6), which indicates that the participants failed to keep good consistency between each pair of weighting criteria (Saaty, 1980). In this situation, it is suggested to redo the whole process until a Cr value less than 0.1 is reached (Saaty, 1980), which would consume more than double of the workload for participants. The reason for this quality defects may due to the complexity of weighting procedure in this research. There are eight criteria so that participants have to repeat 27 times weightings. In literature reviewed, the number of criteria is mostly ranges between three and five for each hierarchy (Malczewski & Rinner, 2016; Schmoldt et al., 2013; Malczewski, 1999). Through the Cr value, this result indicates that using pairwise comparison for eight criteria is barely achievable and clearly affects the result.

Even with the differences between methods themselves, the result of the two methods are of great similarity; the correlation result by r value is 0.98. This indicates a strong correlation between the results of the two weighting methods. But based on Table 5 and Table 6, the weightings in pairwise comparison method has higher variation than the simple rating method. It is possible that one-on-one comparisons are able to elicit more preference differences between each criterion. This hypothesis worth further testify in future with larger group of participants.

The pairwise comparison method was developed by Saaty (1980) and used for obtaining weights in the AHP method. In regard to the result of this study, this method is able to extract more preference variation than the rating method. Thus, it can be a preferred option for decisions which emphasize opinions and a theoretical foundation. Its complexity issues might be addressed by reducing the number of criteria and only keeping those considered as valid and important. Another option would be to conduct the whole AHP method, categorize criteria into independent groups, and then use the pairwise comparison method within each group. Although pairwise comparison is much more time-consuming than the simple rating method, its theoretical foundation and its method for testing result quality endorse its value in decision-making. However, if one aims to include more diverse demographic groups in the weighting procedure, the simple rating method would obviously lower the barrier for participating.

5.2 Criteria selection and limitations

There are two phases in this research. In the site selection phase, criteria were designed from an experience-based perspective. However, the criteria in the site rank phase has more support from the literature.

In the first phase, the result of criteria application is Boolean, which means the parks are either selected or excluded. Among the four criteria, two of the detailed indicators are experience-based: the area and a ground survey. For the area criterion, 1000 square metres was set to be the minimum area for a community tree planting. This indicator comes from experience of previous community tree-planting events and was calculated from potential seedlings that are normally planted (500 seedlings) and ideal distances between trees (1.42 metres). This absolute number may lead to some smaller parks being overlooked by park planners. In the follow-up screening process, the ground survey is a subjective judgement process. This criterion lacks a quantitative indicator as it is trying to evaluate locations residents used for social purposes in what appeared to be a random one-time visit. Whether a certain space in a park is heavily used or not is laborious to quantify and the used spaces do not always have clear boundaries, so the result of this criterion may lead to inaccuracy. Thus, during this process, broader spaces were taken into consideration to include more potential planting sites into the study.

In the second phase, criteria were selected from a broader scope. Canopy cover comes from residents' thoughts in previous Halifax-based research (Peckham et al., 2013), and Road Length and Building Coverage are based on the ecosystem goods and services provided by trees, as determined through literature review. The equity and canopy cover criteria are listed in the UFMP (HRM Urban Forest Planning Team, 2013) as future goals so they are of great importance for characterizing future shade in parks. Criteria used in similar research were also included, such as the canopy cover and proximate human population (Locke et al., 2010).

In the validity test, as summarized in the result section, seven of the eight criteria were considered valid by all experts; but the exception is the bus-stop criterion. This feedback acknowledged the overall design of the criteria set, while comments also suggested detailed amendments to indicators. Indicators applied in this research could be specified to gain a better depiction of influences from urban trees. For example, in the road length criterion, important roads were identified through expert experience and comments. The data obtained from experts' empirical thoughts was suggested to be substituted by the road type classification from the HRM database. New indicators could also help expand the content of a criterion. Storm water run-off was emphasized in both the road length and the building coverage criteria as it is an important function provided by urban trees. This indicator may also become an independent criterion. For the building coverage criterion, if the heat-island effect becomes an independent criterion, the solar radiation reflected from the ground would be a direct indicator than the percentage of building cover.

Besides refining the existing criteria, experts proposed four new criteria (playgrounds, aesthetics, established work/partnership, and site history) to be part of this decision-making framework. The playground criterion would target parks heavily visited by children. Trees planted in these sites could provide shade for children and protect the facilities (Parisi & Turnbull, 2014). This geospatial criterion could be easily incorporated into the existing framework. Different from the playgrounds one, the other three criteria lack geographical information and thus would require different approach to capture the data. Among these criteria, the site-history criterion, which is trying to characterize impacts from previous land usage, may be more suitable for the site selection phase rather than site ranking phase as it helps determine whether the site is suitable for new tree plantings.

In addition to issues relating to each criterion, the overall design of this set of criteria received comments on its anthropocentricity. Criteria were selected and shaped for depicting tree planting influences on residents alone and put no attention on wildlife which are also urban dwellers and have important roles in providing diversity to urban ecosystems. Parks are important habitats for wildlife surviving in cities (Brown, 2008; Chiesura, 2004). These precious greenspaces in the urban environment may even be refuges for endangered species (Alvey, 2006). Although Halifax is not a large city by world standard and it is surrounded by woodland, urban parks still have a role in habitat service under the ecosystem service concept (HRM Urban Forest Planning Team, 2013). Thus, the connectivity of new planting sites with existing natural woodlands was suggested to be a new criterion to characterize the important ecological function of urban parks.

The interdependency between criteria was mentioned by experts during the consultations. If one criterion is strongly positively correlated with another, the actual weights they received would be enlarged. In the Figure 5, calculated correlations indicate three sets of strongly positively correlated criteria: bus stops and population, bus stops with road length, population and building coverage. This correlation analysis is a statistical justification for eliminating the bus-stop criterion from the list.

Among the correlations, there is one noticeable finding in the correlation between the neighbourhood canopy criterion and the household income criterion (Figure 5). In previous research, household income is normally positive proportional to canopy cover in cities (Pincetl, 2010; Schwarz et al. 2015). These results represent evidence of the social inequality of the urban tree distribution and are the basis for including equity as a criterion into the UFMP. However, the correlation analysis result here seemed to demonstrate that Halifax does not have this concern. The correlation between canopy cover and annual income even has a slightly negative correlation which indicates that residents of lower socioeconomic status in Halifax actually have more canopy cover. But this result may not be representative of the whole situation in Halifax. The calculated community areas included only the 300-m buffer of surrounding areas around selected parks. This total area is only a small part of the entire peninsula. Furthermore, the distribution of selected parks is hardly representative of the whole as well. The parks are more clustered in the northern part of the peninsula so that left the South End and Downtown areas almost empty. Thus, although this finding differs from other literature looks interesting, it merely represents the situation of parks' surrounding areas. If the overall correlation between income and canopy cover is negative, the correlation result here would actually indicate that there are places that need more canopy cover urgently in relation to the equity issue.

5.3 The Gap between Result and Reality

The GIS-based decision-making framework suggested four parks as a best starting group for community tree-planting. These four parks are the Halifax North Common, Gorsebrook Park, Halifax Central Common, and Gladstone Ridge Park. They are mostly gathered in the centre of the Halifax peninsula where population density is relatively high. Seven parks constantly ranked at the bottom of the priority list including Africville, St. Mary's Boat Club Park, Seaview Lookoff Park, and Ardmore Park.

Noticeably, this suggestion has little consistency with the real-world tree-planting activities in peninsular Halifax. In the year 2013, the St. Mary's Boat Club Park was first selected as the target park for community tree-planting with a naturalization purpose. In the next year, another tree-planting took place in the Seaview Lookoff Park to afforest its abandoned baseball field. These two parks are both in the least priority group. Meanwhile, not all planted trees were welcomed. Some seedlings planted in St. Mary's Boat Club Park were mowed illegally by a neighbouring homeowner who treasures the view of the Northwest Arm.

The result of this study cannot solve conflict issues between residents and new trees. It is only a reference guide for decision-makers on where to plant first. It would be arrogant to totally deny experience-based decisions. Moreover, GIS-based results are definitely not golden guidance to obey strictly, but the huge gap between the results of these two do reveal some issues. Before this research, the lack of a candidate park list limited the scope for selecting the target parks. Parks that outside the consideration of decision-makers would have no opportunities be included into consideration. Another problem of experienced-based decision-making is that it may neglect some key features regarding the sociological influences of tree-planting because it is difficult to evaluate using only the mind. For example, some decision-makers have an idea on canopy and population distribution, and the combination effects of both are so difficult to calculate without the help of geospatial tools. With GIS, this issue could be solved and data sources improved through quantification. Even with maps at hand, it is still difficult for experience-based decision-making to perform as well as GIS tools for these tasks. Thus, a GIS-based framework has a huge advantage in handling spatial information.

Despite the advantages in result quality, the priority ranking for parks is definitely not developed for unreflective obedience. It should work more like referencing yellow pages. The ranks alone (See Table 5 and 6) are too absolute and they blur the information in priority scores, especially for parks ranked in the middle range with close priority scores. Also, because the real-world situation may vary, top ranking does not necessarily indicate that the first tree-planting should happen there. The site selection is just a starting point for tree planting; subsequent procedures, which include onsite investigation, tree-species selection, community engagement etc., may indicate changes to the initial indications of where to start. In sum, the protocol and tools developed here are offered as flexible and customizable procedures for tree-planting for naturalizing parks.

5.4 Potential Improvements

In the data processing procedure, all data must go through the normalization process to convert different units and values into a range between 0 and 1. In this process, the minimum values in the benefit criteria were set to 0 while the maximum were set to 1. On the other hand, for cost criteria, the minimum values were set to 1 while the maximums were set to 0. This process would function well when the values for the criterion have a large range. However, when the values of the criterion are close to each other, this normalization process would enlarge the actual differences between parks so that the final ranking may be skewed, especially when the criterion is heavily weighted. Thus, it is suggested that the normalized 0 should be set to the real 0 value and all values larger than 0 (although it is the minimum in benefit criterion or maximum in cost criterion) should be calculated based on a linear relationship.

During consultations, experts proposed one important limitation of this research approach: this framework failed to account for changing future situations. The criteria were chosen to frame relevant issues at present and data selection was also based on whether they successfully represent the situations. But as a city with ambitious development plans, Halifax has new policies that may change the indicator performances and even significantly change the overall landscape of the city. Decisions made based on past datasets and present concerns may not fit future situations.

In Halifax, a new Centre Plan is about to be implemented in 2018. This plan permits landowners in certain areas to double their building coverage to densify the city core of Downtown Halifax and Dartmouth (HRM, 2017). Within the plan's affected areas, the population density and building coverage are expected to grow faster than in other areas. This trend will directly influence at least two criteria in our decision-making framework, the population and building coverage criteria. In addition to this, the canopy cover in these areas is of high likelihood to decrease due to spaces being required for new construction. In this scenario, the geospatial score of each park may encounter obvious changes and the priorities as well. Thus, with the foreseeable results of new policies, the decision-making framework could include an extra criterion specifically for analyzing the influences of important city plans.

In addition to improving the quality of the long-term result, the decision-making framework is also expected to be applied in other UFMP communities. Right now the study area only includes the Halifax peninsula. This concentrated scope brings advantages in geographical data availability and the consistency of landscape characteristics, which is of great convenience for processing the data. But advantages could become barriers. For replicating this framework in other areas, it must expand its scope to consider more-diverse landscape features and topics. Different from the Halifax peninsula which is occupied by the highest population density in the province, other communities are larger in area and have a more scattered population distribution. Meanwhile, many of these communities are better wooded and have more existing natural woodlands than the peninsula. When discussing increasing the canopy cover in these communities, the concerns would be different from the city core.

In the peninsula, residential and commercial areas cover most of the lands. Parks are close to housing neighbourhoods so that most criteria in the decision framework include a distance to set a boundary of the service delivery of parks (e.g. 300-m buffered area). However, in places outside the Halifax peninsula, parks can be far away from residents. The users of parks may not be people who are living close by. The service delivery distances of this kind of park are more complicated to evaluate. The industrial parks are under this situation.

Industrial parks are close to industrial facilities and companies. They have fewer connections with residents but more with companies and workers. Thus, criteria currently in the decision-making framework would require thorough re-evaluation. The concept of neighbourhood would not be suitable here, and the distance for considering service delivery needs to be expanded. The air filtration criterion can be kept but population and building coverage criteria need adjustment. Both of these criteria take 300 m as the buffered distance, but for industrial parks in less dense places, the distance also needs to be extended. The bus-stop criterion would be eliminated from the framework because vehicles instead of public transit are the predominant commuting tools in these areas. Meanwhile, the education and household income are probably no longer valid considering parks' distances from residential areas. For parks close to natural woodland, the criterion of connectivity, which is discussed in above sections, becomes an important criterion for selecting new tree-planting locations.

5.5 Next Steps

This research represents only a start. There is still a long way to go in making well-founded decisions on where to plant new tree seedlings in urban greenspaces. The decision-making framework provided here simply produces suggestions from the experts' side. When tackling real-world situations, detailed information from park users and local residents would highly influence the final decision.

Making decisions on the exact planting place inside the park is crucial and complex. New trees are not always welcomed especially on where the residential houses are adjoining to parks. Although property ownerships are totally different, the relationship between trees in parks and neighbourhood residential areas is sometimes closer than expectation and even with conflicts. Based on previous experiences, residents may value sunlight and sea views more than the benefits trees can provide. An act of vandalism happened at the St. Mary's Boat Club Park where seedlings were cut off six months after planting. This type of conflict is to be considered in future tree plantings.

Species selection is another crucial decision-making step. It is a determinative step in implementing sustainable management. Native or non-native (Ordóñez & Duinker, 2012), the diversity of the species (Nitoslawski, Duinker & Bush, 2016), will the species adapt to climate change (Ordóñez & Duinker, 2015). Ecological integrity in urban forests. Urban Ecosystems, 15(4), 863-877.), etc. - these questions are crucial factors to be considered. In addition to these, a fundamental factor would be whether the species can adapt to the specific natural physical environment at that place. Coastal areas (e.g. the St. Mary's Boat Club Park) would demand salt-tolerant species while abandoned baseball fields with fine gravel (e.g. the Seaview Lookoff) are more suitable for drought-tolerant species. The local environment would highly influence the survival rates of seedlings and has impacts on future workloads for tree maintenance. Suitable species would be much easier to manage.

In Halifax, NGOs are playing the main roles in organizing citizen tree-planting activities. They communicate with tree donors, and responsible for consulting the HRM for planting sites as well as recruiting volunteers to implement the planting. For the decision-making framework, the NGOs are the direct users. Right now, most citizen tree-planting activities are held in the Dartmouth area where available spaces are easier to identify. In the Halifax peninsula by contrast, only four such plantings were organized in the past five years. Thus, this decision-making framework could help increase tree plantings in the peninsula by lowering the information barriers so that providing more trees to appropriate places is facilitated.

Meanwhile, the HRM is improving its tree database by inputting geo-information for most of the newly planted street trees each year. The collaboration between the HRM and Dalhousie University is developing an updated database to help manage the urban forest in a systematically way. This research is a part of that. From a technical perspective, this decision-making framework itself has areas to be improved and opportunities found for broader applications. Future modifications could try to modify this framework to fit suburban scenarios in other UFMP communities. Besides, a more ideal application would be creating an interactive webpage with selectable criteria for citizens to participate in the decision-making process.

All thoughts above are targeting at searching for spaces for trees. It is also possible to enlarge the spaces by persuading the public to accept a more treed landscape. Compared to planting trees in a scattered way, denser wood patches could support more diverse wildlife habitats (Parsons, 1995). More trees also means more benefits brought by them. But a dense woody landscape is not always favourable. Regarding people's preferences about vegetation density, studies have been done and showed diverse results. Some people expressed preferences for denser woods and more-natural-looking landscapes (De Groot & van den Born, 2003; Tyrväinen, Mäkinen & Schipperijn, 2007) whilst some preferred open grassy areas (Hofmann, Westermann, Kowarik & van der Meer, 2012; Parsons, 1995).

One of the most important concerns on a naturalized landscape with dense woods is the personal security and safety issue (Bjerke, Østdahl, Thrane & Strumse, 2006; Jorgensen, Hitchmough & Calvert, 2002). For some people, these places are perceived as unkempt and even frightening (Özgüner, & Kendle, 2006). The feeling of unsafety is often positively correlated to tree density (Schroeder & Anderson, 1984). Factors considered to have influences on these feelings include attitudes, knowledge, familiarity with the location, and spatial arrangement (Daumants, 2004; Jorgensen et al., 2002). Thus, for park planners, a proper landscape design could increase the acceptance of more trees in a certain place. For organizations which are responsible for communicating with residents before tree planting, providing more information about the place and the plan would also create opportunities for more spaces for trees.

In all, the decision-making framework created in this study is a preliminary foundation for organizing citizen tree plantings. To plant more trees in a sustainable way in city parks requires profound collaborations between the municipal government, which has plans and expert knowledge, and local NGOs, which coordinate with tree donors, volunteers, and local residents.

CHAPTER 6 CONCLUSION

The publication of the UFMP in 2013 released new canopy coverage goals for parks in the study area and thus posed questions for park managers on where to plant new trees and where to plant them first. Different from previously experience-based assignments of plating sites to NGOs, this research developed a geo-informatics-based decision-making framework that allows decision-makers to combine natural physical information and their preferences together by using MCDA. In this new framework, there are two phases: the site-searching phase and the site-ranking phase. The MCDA method is important in both steps but using different approaches to incorporate non-quantitative information. In the site-searching phase, an on-site investigation helped to eliminate sites that are frequently used by residents, while in the site-ranking phase, consultations with decision-makers were conducted to obtain their preferences as numerical weights for each criterion.

This GIS-based MCDA framework with a two-step approach is able to provide decision-makers with a systematic way to search for candidate parks in the study area of the UFMP and finally results in a park-name list as a planting guide for tree-planting organizers. In the site-ranking phase, the research tested two weighting methods. Throughout the weighting process, the simple weighted method and the pairwise comparison method are both shown to be applicable but different in complexity. Because the two weighting methods produced results with high similarities, the simple weighted method is recommended in this case for its simplicity in application. However, the pairwise comparison method may be preferred when a sounder theoretical base is required.

Because the result of this work is a pilot study, the final ranking list is provisional. The criterion set in the site-ranking phase is open for discussion. This criterion set is designed to represent experts' values on urban trees. During the consultation process, decision-makers proposed their thoughts on some adjustments to the initial criteria, such as adding criteria on storm water and the heat-island effect. They also provided valuable suggestions for incorporating future trends into the framework so that the results could be more reliable for long-term application.

The research is a pilot step in creating a decision-making framework for urban forests in the Halifax peninsula under the UFMP scope. Because the criterion set was specially designed for the peninsula, the framework failed to include suburban conditions so that the application of the framework is geospatially limited. For the rest of the UFMP study area, situations in these suburban areas are different from the peninsula. Thus, for future studies, a redesign of the criterion set may be indispensable. Thorough examinations of differences between experts' values associated with the urban forest in the city core and the suburban area would be of great value in understanding urban forests in Halifax.

Moreover, the capability of GIS tools exceeds that of merely running a framework. Its powerful visualization function could enable the result to be displayed in vivid and interactive ways. Combining with computer science techniques, it is possible for the whole decision-making process to be displayed on a webpage to enable participation of the public in a way that turns a "black box" into a transparent one.

The management of urban forests is always complex as it is required to balance the needs of trees and demands from people, to consider social impacts on communities and influences brought to ecosystems, and to make decisions on spaces where both non-human life and humans must live in harmony. Meanwhile, the process of urbanization accumulates tensions in spatial utilization and increases the complexities for decision-makers. This is the field where the developing infographic tools can help. Assisted by the maturing data collection methods (e.g. using satellites and drones), the decision-making procedure is turning from professional experience alone to a systematic, data-supported approach for better understanding and communicating the values of urban forests. For this research, the produced name list will never be the sole contribution of the decision-making framework. Its potential for interactively visualizing the value of urban trees and empowering citizens by unveiling the decision-making process are leading to a pathway towards more participatory urban forest management.

REFERENCES

Alvey, A. A. (2006). Promoting and preserving biodiversity in the urban forest. Urban Forestry & Urban Greening, 5(4), 195-201.

Adams, L. W. (1994). In our own backyard. Journal of Urban Forestry, 92, 24-25.

Ananda, J., & Herath, G. (2005). Evaluating public risk preferences in forest land-use choices using multi-attribute utility theory. Ecological Economics, 55 (3), 408-419.

Anderson, L. M., & Cordell, H. K. (1988). Influence of trees on residential property values in Athens, Georgia (USA): A survey based on actual sales prices. Landscape and Urban Planning, 15 (1-2), 153-164.

Arnberger, A. (2006). Recreation use of urban forests: An inter-area comparison. Urban Forestry & Urban Greening, 4 (3), 135-144.

Baldauf, R., Thoma, E., Hays, M., Shores, R., Kinsey, J., Gullett, B., ... & Khlystov, A. (2008). Traffic and meteorological impacts on near-road air quality: Summary of methods and trends from the Raleigh near-road study. Journal of the Air & Waste Management Association, 58(7), 865-878.

Bassuk, N. L. (1990). Street tree diversity making better choices for the urban landscape, trees for the nineties: landscape tree selection, testing, evaluation and introduction. Proceedings of 7th Conference Metropolitan Tree Improvement Alliance (pp. 71-78). Morton Arboretum, Lisle, IL.

Bell, M. L., Hobbs, B. F., & Ellis, H. (2003). The use of multi-criteria decision-making methods in the integrated assessment of climate change: implications for IA practitioners. Socio-Economic Planning Sciences, 37 (4), 289-316.

Belton, V. & Stewart, T.J., (2001). *Multiple Criteria Decision Analysis: An Integrated Approach*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Benedict, M. A. & McMahon, E. T. (2006). *Green Infrastructure: Smart Conservation for the 21st Century*. Sprawl Watch Clearinghouse Monograph Series. Washington, DC.

Bjerke, T., Østdahl, T., Thrane, C., & Strumse, E. (2006). Vegetation density of urban parks and perceived appropriateness for recreation. Urban Forestry & Urban Greening, 5 (1), 35-44.

Bouyssou, D., Jacquet-Lagrez, E., Perny, P., Slowinski, R., Van-derpooten, & D., Vincke, Ph. (Eds.), (2001). *Aiding Decisions with Multiple Criteria. Essays in Honor of Bernard Roy*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Bradley, G. A. (1995). *Urban forest landscapes: integrating multidisciplinary* *perspectives*. University of Washington Press, Seattle, WA.

Brown, B. J., Hanson, M. E., Liverman, D. M., & Merideth, R. W. (1987). Global sustainability: toward definition. Environmental management, 11(6), 713-719.

Brown, G. (2008). A theory of urban park geography. Journal of leisure research, 40(4), 589-607.

Brown, I. (2007). Wisconsin Statewide Urban Forest Assessment: Development and Implementation. MS Thesis, University of Wisconsin-Stevens Point.

Brundtland, G. (1987). Report of the World Commission on Environment and Development: Our Common Future. [online] Available at: http://www.un-documents.net/our-common-future.pdf.

Bunruamkaew, K., & Murayam, Y. (2011). Site suitability evaluation for ecotourism using GIS & AHP: A case study of Surat Thani province, Thailand. Procedia-Social and Behavioral Sciences, 21, 269-278.

Canedoli, C. (2016). Multiple ecosystem services provided by urban forests in the urban area of Milan. Universita' Degli Studi Milano-Bicocca, Milan.

Cariñanos, P., & Casares-Porcel, M. (2011). Urban green zones and related pollen allergy: A review. Some guidelines for designing spaces with low allergy impact. Landscape and Urban Planning, 101(3), 205-214.

Carreiro, M. M. (2008). Introduction: the growth of cities and urban forestry. In *Ecology, Planning, and Management of Urban Forests* (pp. 3-9). Springer, New York.

Chen, W. Y., & Jim, C. Y. (2008). Assessment and valuation of the ecosystem services provided by urban forests. In *Ecology, Planning, and Management of Urban Forests* (pp. 53-83). Springer, New York.

Chiesura, A. (2004). The role of urban parks for the sustainable city. Landscape and urban planning, 68 (1), 129-138.

Clark, J. R., Matheny, N. P., Cross, G., & Wake, V. (1997). A model of urban forest sustainability. Journal of Arboriculture, 23, 17-30.

Coutts, C., & Hahn, M. (2015). Green infrastructure, ecosystem services, and human health. International journal of environmental research and public health, 12 (8), 9768-9798.

Daumants, L. M. (2004). Factors affecting visual preferences for naturalization and restoration in urban park landscapes. The University of Guelph, Ontario, Canada

De Groot, W. T., & van den Born, R. J. (2003). Visions of nature and landscape type preferences: an exploration in The Netherlands. Landscape and Urban Planning, 63

(3), 127-138.

Diaz-Balteiro, L. & Romero, C., (2008). Making forestry decisions with multiple criteria: a review and an assessment. For. Ecol. Manage. 255 (8-9), 3222-3241.

Dobbs, C., Escobedo, F. J., & Zipperer, W. C. (2011). A framework for developing urban forest ecosystem services and goods indicators. Landscape and urban planning, 99(3-4), 196-206.

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

Dwyer, J. F., Nowak, D. J., & Noble, M. H. (2003). Sustaining urban forests. Journal of Arboriculture, 29, pp. 49-55

Easton, A. (1973). Complex managerial decisions involving multiple objectives. John Wiley & Sons, New York, NY

ESRI (2012). ArcGIS Desktop: Release 10.2.2. Redlands, CA: Environmental Systems Research Institute.

El-Geneidy, A., Grimsrud, M., Wasfi, R., Tétreault, P., & Surprenant-Legault, J. (2014). New evidence on walking distances to transit stops: identifying redundancies and gaps using variable service areas. Transportation, 41(1), 193-210.

Feick, R.D., Hall, G.B., 1999. Consensus-building in a multi-participant spatial decision support system. URISA Journal, 11 (2), 17–23.

Findlay, B. A. (2013). Adaptation of i-Tree Eco to New Zealand. University of Auckland, Auckland.

Fish, R., Burgess, J., Chilvers, J. Footitt, A., Haines-Young, R. Russel, D., Winter, D.M. (2011). Participatory and Deliberative Techniques to embed an Ecosystems Approach into Decision Making: an introductory Guide. (Defra Project Code: NR0124)

Foster, D., & Duinker, P. (2017). *The HRM urban forest in 2016*. Halifax, NS: School for Resource and Environmental Studies, Dalhousie University. Retrieved from: https://www.itreetools.org/resources/reports/FosterDuinker_2017_iTreeEcoForHalifax_F eb2017.pdf

Gerhold, H. D. (2007). Origins of urban forestry. In Urban and Community Forestry in the Northeast (pp. 1-23). Springer, Dordrecht.

Government of Nova Scotia (2014). Air Quality Health Index: Frequently Asked Questions. Retrieved from: https://novascotia.ca/nse/aqhi/faq.asp

Gregerson, H., A. Lundgren, & N. Byron. (1998). Forestry for sustainable development:

Making it happen. J. For. 96 (3), 6-10.

Grimmond, C. S. B., & Oke, T. R. (1995). Comparison of heat fluxes from summertime observations in the suburbs of four North American cities. Journal of Applied Meteorology, 34(4), 873-889.

Heynen, N., & Perkins, H. A. (2005). Scalar dialectics in green: urban private property and the contradictions of the neoliberalization of nature. Capitalism Nature Socialism, *16* (1), 99-113.

Heynen, N., Perkins, H. A., & Roy, P. (2006). The political ecology of uneven urban green space: The impact of political economy on race and ethnicity in producing environmental inequality in Milwaukee. Urban Affairs Review, *42* (1), 3-25.

HRM Urban Forest Planning Team (2013). Halifax Regional Municipality urban forest master plan. Halifax Regional Municipality, Halifax, NS.

Halifax Regional Municipality (2018). Centre Plan. Retrived from: http://centreplan.ca/

Heynen, N. C., & Lindsey, G. (2003). Correlates of urban forest canopy cover: implications for local public works. Public Works Management & Policy, 8(1), 33-47.

Hilde, T., & Paterson, R. (2014). Integrating ecosystem services analysis into scenario planning practice: Accounting for street tree benefits with i-Tree valuation in Central Texas. Journal of environmental management, 146, 524-534.

Hofmann, M., Westermann, J. R., Kowarik, I., & van der Meer, E. (2012). Perceptions of parks and urban derelict land by landscape planners and residents. Urban Forestry & Urban Greening, 11 (3), 303-312.

Hwang, C.L. & Lin, M.J., (1987). Group decision making under multiple criteria. Methods and applications. In: Beckman, M., Krelle, W. (Eds.), *Lecture Notes in Economics and Mathematical Systems*. Springer-Verlag, Berlin.

i-Tree Canopy, (n.d.). What is i-Tree? Retrieved from: https://www.itreetools.org/

Jankowski, P. (2006). Integrating geographical information systems and multiple criteria decision-making methods. Classics from IJGIS: twenty years of the International Journal of Geographical Information Science and System, 9 (3), 265-296.

Jin, S., Guo, J., Wheeler, S., Kan, L., & Che, S. (2014). Evaluation of impacts of trees on PM2. 5 dispersion in urban streets. Atmospheric Environment, 99, 277-287.

Jorgensen, A., Hitchmough, J., & Calvert, T. (2002). Woodland spaces and edges: their impact on perception of safety and preference. Landscape and Urban Planning, 60 (3), 135-150.

Kadir, M. A. A., & Othman, N. (2012). Towards a better tomorrow: street trees and their values in urban areas. Procedia-Social and Behavioral Sciences, 35, 267-274.

Kangas, J., & Kangas, A., (2005). Multiple criteria decision support in forest management – the approach-methods applied, and experiences gained. Forest Ecology and Management, 207, 133-143.

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge University Press, New York.

Kaya, T., & Kahraman, C. (2011). Fuzzy multiple criteria forestry decision making based on an integrated VIKOR and AHP approach. Expert Systems with Applications, *38* (6), 7326-7333.

Keeney, R. (1992). On the Foundations of Prescriptive Decision Analysis. In W. Edwards (Ed.), *Utility theories: Measurement and applications* (pp. 57–72). Boston: Kluwer Academic Publishers.

Kenney, W. A., Van Wassenaer, P. J., & Satel, A. L. (2011). Criteria and indicators for strategic urban forest planning and management. Arboriculture & Urban Forestry, 37 (3), 108-117.

Kimmel, Courtney, David Robertson, R. Bruce Hull, Michael Mortimer, and Kris Wernstedt. (2013). Greening the Grey: An Institutional Analysis of Green Infrastructure for Sustainable Development in the US. Center for Leadership in Global Sustainability, Virginia Tech, 2013D.E.Tallman, G.G. Wallace, Synth. Met. 90 (1997) 13.

King, K. L., & Locke, D. H. (2013). A comparison of three methods for measuring local urban tree canopy cover. Arboriculture & Urban Forestry. 39 (2): 62-67.

Kirnbauer, M. C., Kenney, W. A., Churchill, C. J., & Baetz, B. W. (2009). A prototype decision support system for sustainable urban tree planting programs. Urban Forestry & Urban Greening, 8 (1), 3-19.

Konijnendijk, C. C., Ricard, R. M., Kenney, A., & Randrup, T. B. (2006). Defining urban forestry–A comparative perspective of North America and Europe. Urban Forestry & Urban Greening, 4 (3-4), 93-103.

Konijnendijk, C. C., Thorsen, B. J., Tyrvainen, L., Anthon, S., Nik, A. R., Haron, N., & Ghani, A. A. (2007). Decision-support for land-use planning through valuation of urban forest benefits. Allgemeine Forst Und Jagdzeitung, 178 (4), 74.

Kovacs, K. F., Haight, R. G., McCullough, D. G., Mercader, R. J., Siegert, N. W., & Liebhold, A. M. (2010). Cost of potential emerald ash borer damage in US communities, 2009–2019. Ecological Economics, 69(3), 569-578.

Kuo, F. E., & Sullivan, W. C. (2001). Environment and crime in the inner city: Does vegetation reduce crime?. Environment and behavior, 33(3), 343-367.

Lakicevic, M., Srdjevic, Z., Srdjevic, B., & Zlatic, M. (2014). Decision making in urban forestry by using approval voting and multicriteria approval method (case study: Zvezdarska forest, Belgrade, Serbia). Urban forestry & urban greening, 13 (1), 114-120.

Landry, S. M., & Chakraborty, J. (2009). Street trees and equity: evaluating the spatial distribution of an urban amenity. Environment and Planning, 41(11), 2651-2670. doi:10.1068/a41236

Locke, D. H., Grove, J. M., Lu, J. W., Troy, A., O'Neil-Dunne, J. P., & Beck, B. D. (2010). Prioritizing preferable locations for increasing urban tree canopy in New York City. Cities and the Environment *(CATE)*, *3* (1), 4.

Lopes, A., Oliveira, S., Fragoso, M., Andrade, J. A., & Pedro, P. (2009). Wind risk assessment in urban environments: the case of falling trees during windstorm events in Lisbon. In Bioclimatology and natural hazards (pp. 55-74). Springer, Dordrecht.

Louv, R. (2011). The Nature Principle: Human Restoration and the End of Nature-Deficit Disorder. Algonquin Books of Chapel Hill, Chapel Hill, NC.

Maclaren, V. W. (1996). Urban sustainability reporting. Journal of the American Planning Sssociation, 62 (2), 184-202.

Malczewski, J. (1999). *GIS and multicriteria decision analysis*. John Wiley & Sons, New York.

Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview. Progress in planning, *62* (1), 3-65.

Malczewski, J., & Rinner, C. (2016). *Multicriteria decision analysis in geographic information science*. Springer, New York.

Maser, C., B.T. Bormann, M.H. Brookes, A.R. Keister, & J.R. Weisland. (1994). Sustainable forestry through adaptive ecosystem management is an open-minded experiment, pp 304-340. In Maser, C. (Ed.). Sustainable Forestry: Philosophy, Science, and Economics. St. Lucie Press, Delray Beach, FL

Massam, B.H., (1988). Multi-criteria decision-making techniques in planning. Progress in Planning, 30, 1-84.

McDaniels, T. L., & Roessler, C. (1998). Multiattribute elicitation of wilderness preservation benefits: a constructive approach. Ecological Economic*s, 27*(3), 299-312.

McDonald, R. I. (2015). *Conservation for cities: how to plan & build natural infrastructure*. Island Press, Washington, DC.

McPherson, E. G. (2000). Expenditures associated with conflicts between street tree root growth and hardscape in California, United States. Journal of Arboriculture, 26(6), 289-297.

McPherson, E. G. (2010). Tools for valuing tree and park services. Western Arborist, *36*, 58-63.

McPherson, E. G., & Simpson, J. R. (2002). A comparison of municipal forest benefits and costs in Modesto and Santa Monica, California, USA. Urban Forestry & Urban Greening, 1 (2), 61-74.

Mendoza, G.A., & Martins, H., (2006). Multi-criteria decision analysis in natural resource management: a critical review of methods and new paradigms. Forest Ecology and Management, 230, 1–22.

Mendoza, G. A., & Prabhu, R. (2000). Development of a methodology for selecting criteria and indicators of sustainable forest management: a case study on participatory assessment. Environmental management, *26* (6), 659-673.

Miller, R. W., Hauer, R. J., & Werner, L. P. (2015). *Urban forestry: planning and managing urban greenspaces*. Waveland Press, Long Grove, IL.

Nitoslawski, S. A., Duinker, P. N., & Bush, P. G. (2016). A review of drivers of tree diversity in suburban areas: Research needs for North American cities. Environmental reviews, 24(4), 471-483.

Nova Scotia Power, (2017). TREE TRIMMING. Retrieved from: https://www.nspower.ca/en/home/for-my-home/tree-trimming/default.aspx

Nowak, D. (2014). Urban Tree Effects on Fine Particulate Matter and Human Health. USDA Northern Research Station. Retrieved from: https://www.fs.fed.us/nrs/pubs/jrnl/2014/nrs_2014_nowak_002.pdf

Nowak, D. J., & Crane, D.E. (2000). The urban forest effects (UFORE) model: Quantifying urban forest structure and functions, pp. 714–720. In: Hansen M., and T. Burk (Eds.). In: Proceedings Integrated Tools for Natural Resources Inventories in the 21st Century. IUFRO Conference, 16–20 August 1998, Boise, ID. General Technical Report NC-212, U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN

Nowak, D. J., & Crane, D.E. (2002). Carbon storage and sequestration by urban trees in the USA. Environmental Pollution, 116 (3), 381-389.

Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. Urban forestry & urban greening, 4(3-4), 115-123.

Nowak, D.J., Crane, D.E., Stevens, J.C., & Hoehn, R., (2005). The Urban Forest Effects (UFORE) Model: Field Data Collection Procedures. USDA Forest Service, Northeastern Research Station, Syracuse, NY.

Nowak, D. J. & Dwyer, J. F. (2007). Understanding the benefits and costs of urban forest ecosystems. In J. E. Kuser (Ed.), Urban and Community Forestry in the Northeast. Springer, New York, NY.

Nowak, D. J., Hoehn, R., Crane, D. E., Stevens, J. C., & Walton, J. T. (2007). Assessing urban forest effects and values: New York City's urban forest. USDA Forest Service, Northern Research Station Resource Bulletin NRS-9. Newtown Square: PA.

Nyerges, T. L., & Jankowski, P. (2010). *Regional and urban GIS a decision support approach*. Guilford, New York.

Oke, T. R., Crowther, J. M., McNaughton, K. G., Monteith, J. L., & Gardiner, B. (1989). The micrometeorology of the urban forest [and discussion]. Philosophical Transactions of the Royal Society B: Biological Sciences, 324 (1223), 335-349.

Ordóñez, C., & Duinker, P. N. (2012). Ecological integrity in urban forests. Urban Ecosystems, 15(4), 863-877.

Ordóñez, C & Duinker, P. N. (2013). An analysis of urban forest management plans in Canada: Implications for urban forest management. Landscape and Urban Planning, 116, 36-47.

Ordóñez, C., & Duinker, P. N. (2015). Climate change vulnerability assessment of the urban forest in three Canadian cities. Climatic change, 131(4), 531-543.

Ordóñez, C., Duinker, P. N., Sinclair, A. J., Beckley, T., & Diduck, J. (2016). Determining Public Values of Urban Forests Using a Sidewalk Interception Survey in Fredericton, Halifax, and Winnipeg, Canada. Arboriculture & Urban Forestry, 42 (1), 46-57.

O'Sullivan, D. & Unwin, D. J. (2010). *Geographic Information Analysis* (Second edi.), John Wiley & Sons, Hoboken, NJ.

Özgüner, H., & Kendle, A. D. (2006). Public attitudes towards naturalistic versus designed landscapes in the city of Sheffield (UK). Landscape and urban planning, 74 (2), 139-157.

Ozturk, D., & Batuk, F. (2011). Implementation of GIS-based multicriteria decision analysis withVB in ArcGIS. International Journal of Information Technology and Decision Making, 10 (6), 1023–1042.

Parisi, A. V., & Turnbull, D. J. (2014). Shade provision for UV minimization: a review. Photochemistry and Photobiology, 90 (3), 479-490.

Parker, D. C., Manson, S. M., Janssen, M. A., Hoffmann, M., & Deadman, P. (2003). Multi-agent systems for the simulation of land-use and land-cover change: A review. Annals of the Association of American Geographers, 93 (2), 314–337.

Parsons, R. (1995). Conflict between ecological sustainability and environmental aesthetics: Conundrum, canärd or curiosity. Landscape and Urban Planning, 32 (3), 227-244.

Peckham, S. C., Duinker, P. N., & Ordóñez, C. (2013). Urban forest values in Canada: Views of citizens in Calgary and Halifax. Urban Forestry & Urban Greening, 12 (2), 154-162.

Perkins, H. (2015). Urban forests are social natures: markets, race, class, and gender in relation to (un)just urban environments. In Sandberg, L.A., Bardekjian, A. and Butt, S. (eds) *Urban Forests, Trees, and Green Space: A Political Ecology Perspective*. Earthscan, London.

Perkins, H.A., Heynen, N. & Wilson, J., (2004). Inequity in an urban reforestation program: the impact of housing tenure on urban forests. Cities, 21 (4), 291-299.

Phillips, L. E. (1993). Urban trees: a guide for selection, maintenance, and master planning. McGraw-Hill, London.

Pincetl, S. (2010). Implementing municipal tree planting: Los Angeles million-tree initiative. Environmental management, 45 (2), 227-238.

Pothier, A. J., & Millward, A. A. (2013). Valuing trees on city-centre institutional land: an opportunity for urban forest management. Journal of Environmental Planning and Management, *56* (9), 1380-1402.

Powell, A. S., & Lindquist, E. S. (2011). Effects of power-line maintenance on forest structure in a fragmented urban forest, Raleigh, NC. Southeastern Naturalist, 10(1), 25-38.

Qureshi, M. E., & Harrison, S. R. (2003). Application of the analytic hierarchy process to riparian revegetation policy options. Small-scale forest economics, management and policy, *2* (3), 441.

Randrup, T. B., Konijnendijk, C., Dobbertin, M. K., & Prüller, R. (2005). The concept of urban forestry in Europe. In *Urban Forests and Trees* (pp. 9-21). Springer, Berlin.

Raupp, M. J., Cumming, A. B., & Raupp, E. C. (2006). Street tree diversity in eastern North America and its potential for tree loss to exotic borers. Arboriculture and Urban Forestry, 32 (6), 297.

Rees, W., & Wackernagel, M. (2008). Urban ecological footprints: why cities cannot be sustainable and why they are a key to sustainability. In *Urban Ecology* (pp. 537-555). Springer, Boston, MA.

Register, R. (2006). *Ecocities: Rebuilding cities in balance with nature*. New Society Publishers, Gabriola Island, BC.

Rogers, K., Hansford, D., Sunderland, T., Brunt, A., & Coish, N. (2011, April). Measuring the ecosystem services of Torbay's trees: The Torbay i-Tree Eco pilot project. In Proceedings of the ICF-Urban Tree Research Conference. Birmingham.

Romm, J. (1993). *Sustainable forestry, an adaptive social process*. Island Press, Washington, DC.

Saaty, T. L. (1980). The analytic hierarchy process: planning, priority setting, resources allocation. McGraw-Hill, New York.

Saarikoski, H.; Barton, D.N.; Mustajoki, J.; Keune. H.; Gomez-Baggethun, E. and J. Langemeyer (2015): Multicriteria decision analysis (MCDA) in ecosystem service valuation. In: Potschin, M. and K. Jax (eds): *OpenNESS Ecosystem Service Reference Book*. EC FP7 Grant Agreement no. 308428.

Sander, H., Polasky, S., & Haight, R. G. (2010). The value of urban tree cover: A hedonic property price model in Ramsey and Dakota Counties, Minnesota, USA. Ecological Economics, 69(8), 1646-1656.

Segura, M., Ray, D., & Maroto, C. (2014). Decision support systems for forest management: A comparative analysis and assessment. Computers and Electronics in Agriculture, 101, 55-67.

Sengupta, R. R., & Bennett, D. A. (2003). Agent-based modelling environment for spatial decision support. International Journal of Geographical Information Science, 17(2), 157-180.

Schmoldt, D., Kangas, J., Mendoza, G. A., & Pesonen, M. (Eds.). (2013). The analytic hierarchy process in natural resource and environmental decision making (Vol. 3). Springer Science & Business Media, Berlin.

Schroeder, H. W., & Anderson, L. M. (1984). Perception of personal safety in urban recreation sites. Journal of Leisure Research, 16 (2), 178-194.

Schwarz, K., Fragkias, M., Boone, C. G., Zhou, W., McHale, M., Grove, J. M., ... & Ogden, L. (2015). Trees grow on money: urban tree canopy cover and environmental justice. PLoS One, 10 (4), e0122051.

Shindler, B., & Cramer, L. A. (1999). Shifting public values for forest management: Making sense of wicked problems. Western Journal of Applied Forestry, 14 (1), 28-34.

Stewart, T. J., & Joubert, A. (1998). Conflicts between conservation goals and land use for exotic forest plantations in South Africa. In *Multicriteria Analysis for Land-Use Management* (pp. 17-31). Springer, Dordrecht.

Stillwell, W.G., Seaver, D.A., & Edwards, W., (1981). A comparison of weight approximation techniques in multiattribute utility decision making. Organ. Behav.

Hum. Perform. 28, 62–77.

Ticknor, W. D. (1993). Sustainable forestry: redefining the role of forest management (pp. 260-269). Island Press.

Tyrväinen, L. (2001). Economic valuation of urban forest benefits in Finland. Journal of Environmental management, 62(1), 75-92.

Tyrväinen, L., Mäkinen, K., & Schipperijn, J. (2007). Tools for mapping social values of urban woodlands and other green areas. Landscape and urban planning, 79(1), 5-19.

Tyrväinen, L., Silvennoinen, H., & Kolehmainen, O. (2003). Ecological and aesthetic values in urban forest management. Urban Forestry & Urban Greening, 1 (3), 135-149.

Ulrich, R. (1984). View through a window may influence recovery. Science, 224 (4647), 224-225.

Ulrich, R. S. (1986). Human responses to vegetation and landscapes. Landscape and Urban Planning, 13, 29-44.

Ulrich, R. S. (1999). Effects of gardens on health outcomes: Theory and research. C. Cooper Marcus, M. Barnes (Eds.), *Healing gardens: Therapeutic benefits and design recommendations* (pp. 27-86), John Wiley & Sons, New York.

United Nations, (2012). The future we want. Resolution adopted by the general assembly on 27 July 2012, 66/288. United Nations.

USDA Forest Service. (2016). i-Tree Applications. Retrieved July 30, 2016 from https://www.itreetools.org/applications.php

Vojnovic, I. (2014). Urban sustainability: Research, politics, policy and practice. Cities, 41, S30-S44.

Whitford, V., Ennos, A. R., & Handley, J. F. (2001). "City form and natural process"—indicators for the ecological performance of urban areas and their application to Merseyside, UK. Landscape and Urban Planning, 57(2), 91-103.

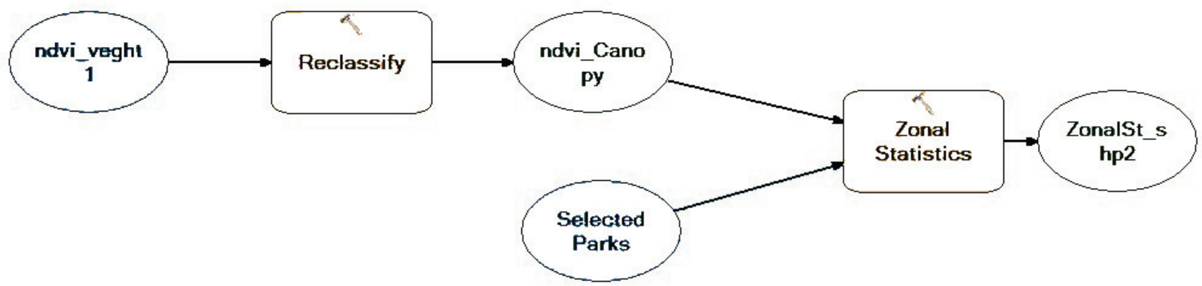
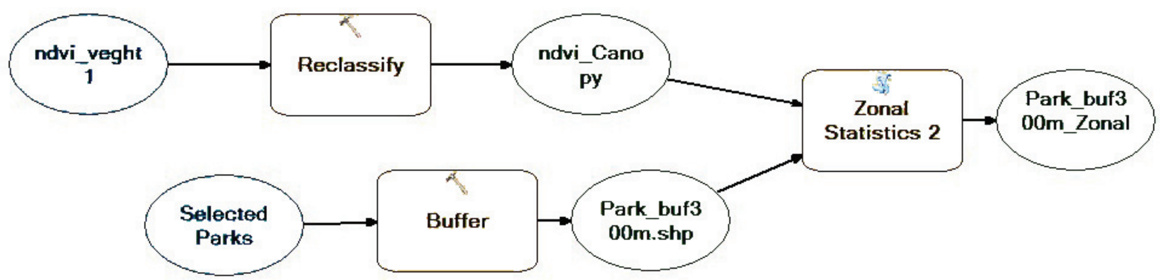
Wiersum, K. F. (1995). 200 years of sustainability in forestry: lessons from history. Environmental management, *19*(3), 321-329.

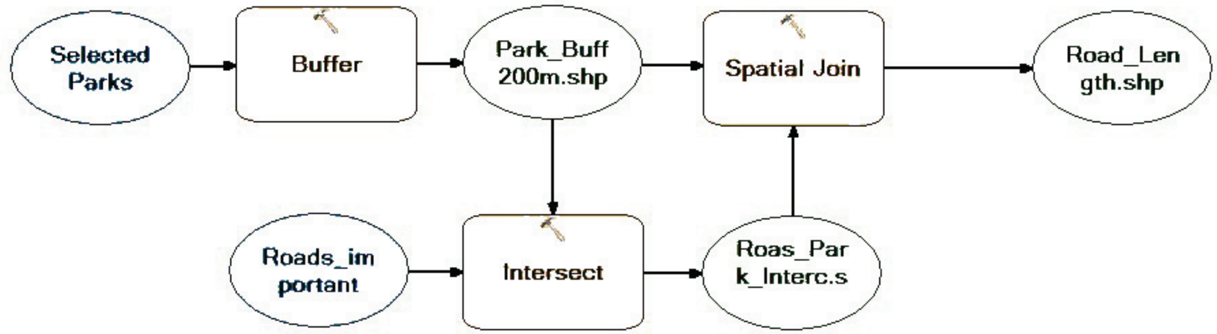
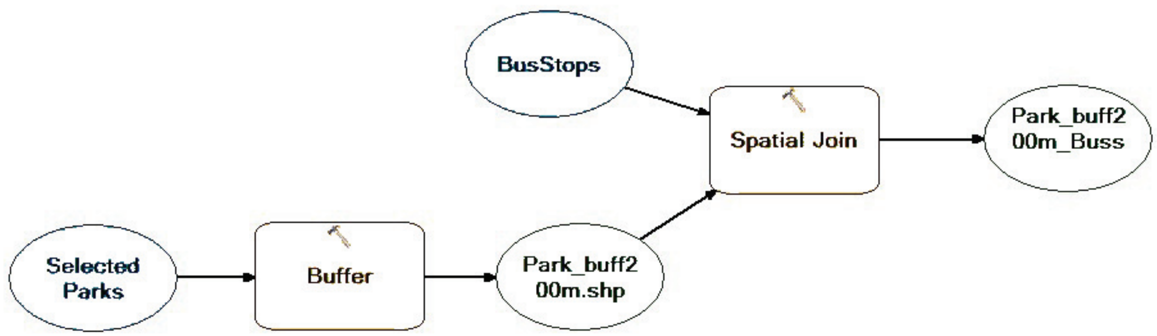
Wolf, K. L. (2003). Public response to the urban forest in inner-city business districts. Journal of Arboriculture, 29, 117-126.

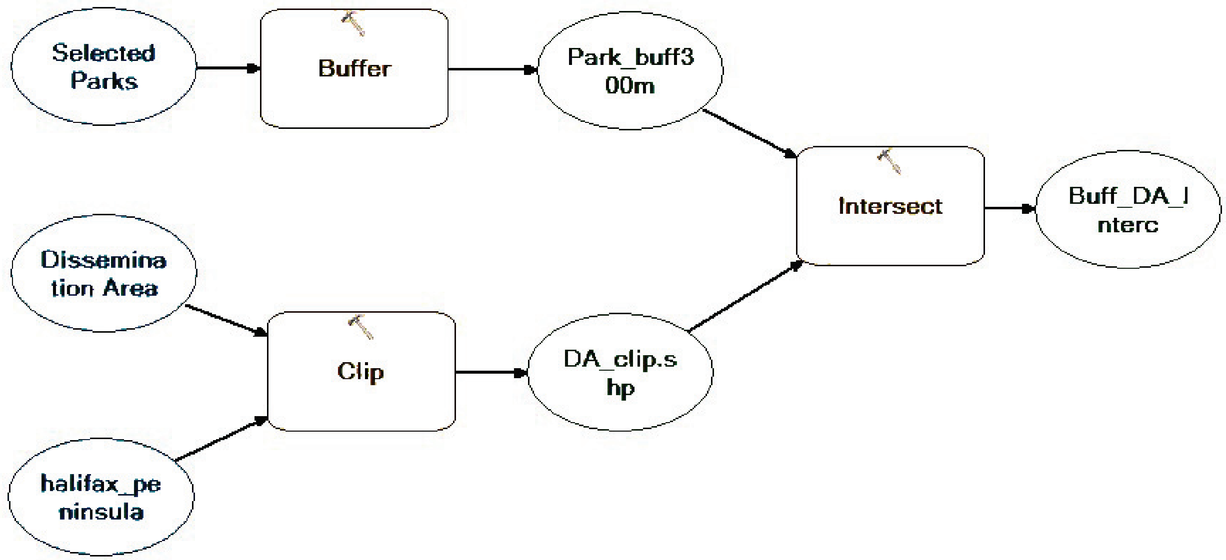
Xiao, Q., McPherson, E. G., Ustin, S. L., Grismer, M. E., & Simpson, J. R. (2000). Winter rainfall interception by two mature open-grown trees in Davis, California. Hydrological Processes, 14(4), 763-784.

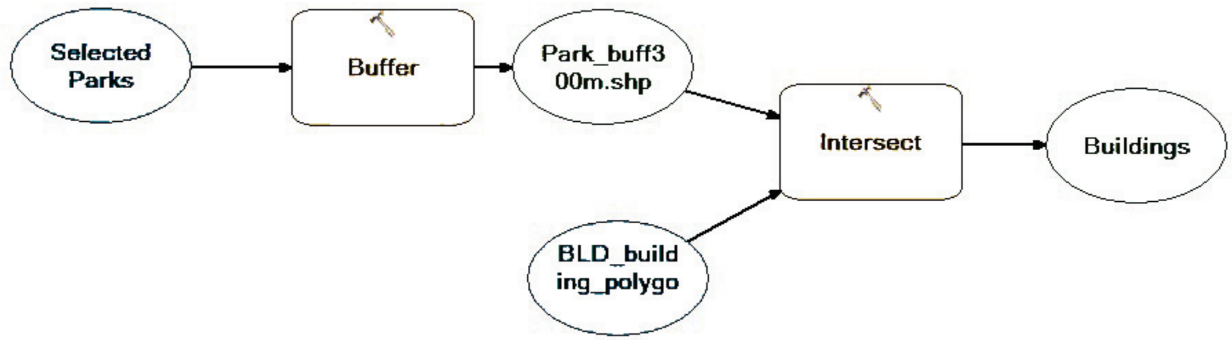
Zucca, A., Sharifi, A. M., & Fabbri, A. G. (2008). Application of spatial multi-criteria analysis to site selection for a local park: A case study in the Bergamo Province, Italy. Journal of Environmental Management, 88 (4), 752-769.

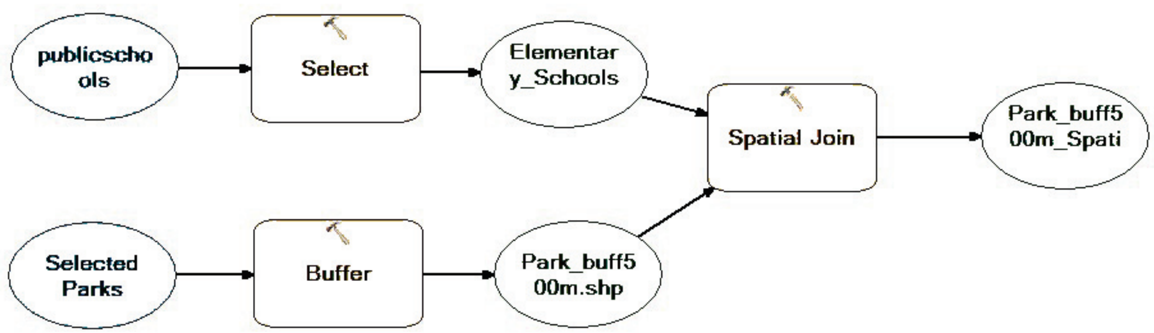
APPENDIX I: GIS PROCESSING FLOW CHART

Criteria	Data Source	Workflow
Park Canopy	Halifax Peninsula Airphoto 2010	
Neighbourhood Canopy	Halifax Peninsula Airphoto 2010	

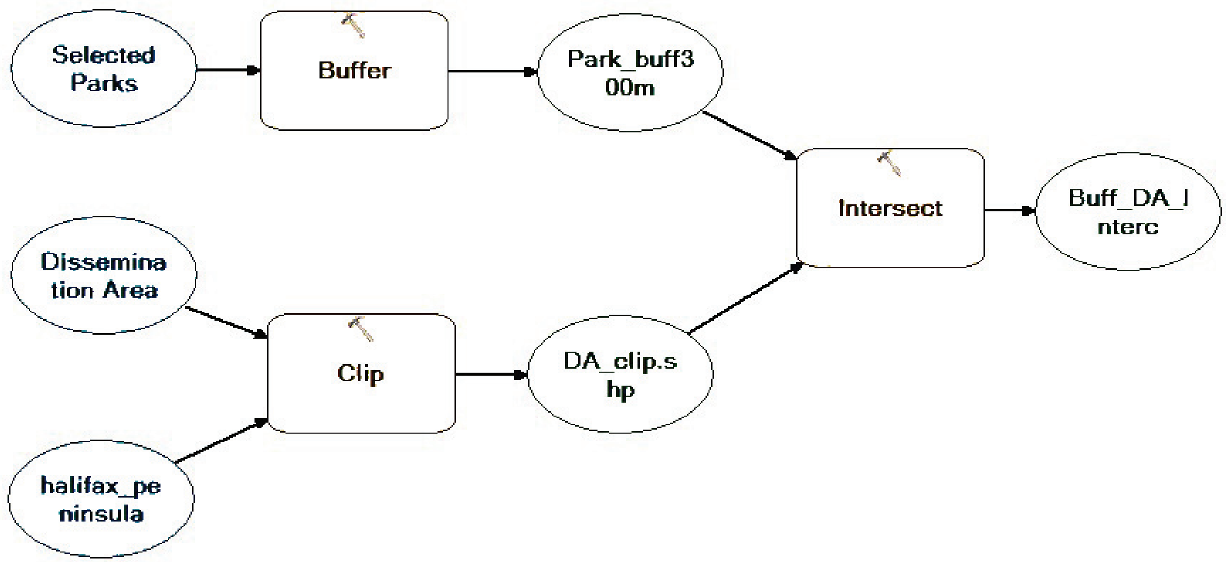
<table>
<tr><td>Road Length</td><td>HRM Geodataset 2012</td><td>
</td></tr>
<tr><td>Bus Stops</td><td>HRM Geodataset 2012</td><td>
</td></tr>
</table>

Population	Statistics Canada 2011	 In the attribute table of “Buff_DA_Interc” file, use “calculate geometry” to get the area of each intersected polygon, set the field name as “Interc_area”. Then use Join by using “Join attributes from a table” based on “Park_ID” field to obtain the polygon areas from the “Park_buff300m.shp” file. Use the “field calculator” to divide the “area” field in by the “Interc_area” field to obtain the intersect area percentage. Times the percentage with population field to obtain weighted population of the intersect polygon with the 300 meter buffered park area. Use “Spatial Join” with “sum” calculation to obtain the population within the buffered area.

<table>
<tr>
<td>Building Coverage</td>
<td>HRM Geodataset 2012</td>
<td>

In the attribute table, use “calculate geometry” to get the area of each intersected polygon, set the field name as “bld_area”.
Then use “Spatial Join” to sum polygon areas to the “Park_buff300m.shp”, name the output file as “Building_Coverage.shp”.
In the attribute table of “Building_Coverage.shp”, use the “field calculator” to divide the “area” field in by the “sum_bld_area” field to obtain the final building coverage.</td>
</tr>
<tr>
<td>Elementary Schools</td>
<td>HRM Geodataset 2012</td>
<td>

In the attribute table of “Buff_DA_Interc” file, use “calculate geometry” to get the area of each intersected polygon, set the field name as “Interc_area”.
Then use Join by using “Join attributes from a table” based on “Park_ID” field to obtain the polygon areas from the</td>
</tr>
</table>

		"Park_buff300m.shp" file. Use the "field calculator" to divide the "area" field in by the "Interc_area" field to obtain the intersect area percentage. Times the percentage with the household income field to obtain weighted population of the intersect polygon with the 300 meter buffered park area. Use "Spatial Join" with "sum" calculation to obtain the population within the buffered area.
Household Income	Statistics Canada 2011	 In the attribute table, use "calculate geometry" to get the area of each intersected polygon, set the field name as "bld_area". Then use "Spatial Join" to sum polygon areas to the "Park_buff300m.shp", name the output file as "Building_Coverage.shp". In the attribute table of "Building_Coverage.shp", use the "field calculator" to divide the "area" field in by the "sum_bld_area" field to obtain the final building coverage.

APPENDIX II: RAW DATA OF GEOSPATIAL SCORES

Park Name	Park Canopy	Neighbourhood Canopy	Road Length	Bus Stops	Population	Building Coverage	Elementary School	Household Income
Africville	0.12	0.16	1524.91	2	382.20	0.01	0	36776.27
Ardmore Park	0.14	0.48	457.91	4	1957.41	0.20	0	34200.92
Bayers Road Windsor Street Park	0.32	0.18	699.28	10	1100.98	0.20	1	32620.24
Chebucto Road School Park	0.23	0.38	2133.80	12	2569.76	0.25	1	32912.83
Connrose Park	0.14	0.47	785.54	1	1465.26	0.14	2	77051.30
Cornwallis Park	0.32	0.17	1497.82	11	2791.20	0.26	1	25225.33
Fort Needham Memorial Park	0.32	0.30	2183.09	17	2238.84	0.18	2	29956.84
George Dixon Centre Park	0.29	0.19	2193.18	14	2950.34	0.21	1	21405.94
Gladstone Ridge Park	0.01	0.18	1883.73	13	1709.55	0.29	2	29969.19
Glebe Street Parkette	0.04	0.17	849.75	3	785.19	0.10	0	35104.91
Gorsebrook Park	0.11	0.35	2052.67	17	3652.77	0.23	3	47410.20
Halifax Central Common	0.11	0.00	6439.12	17	1997.48	0.19	0	52717.27
Halifax North Common	0.05	0.18	6380.86	24	4240.34	0.21	0	41757.77
Hebb Park	0.01	0.16	458.00	4	565.53	0.14	2	32924.66
Horseshoe Island Park	0.14	0.39	1835.32	10	1342.11	0.08	0	39706.06
Isleville Park	0.12	0.26	1865.92	11	1376.70	0.16	1	34488.42
Kenneth Walker Park	0.21	0.30	0.00	3	1127.40	0.17	0	26693.04
Larry Oconnell Park	0.15	0.12	2676.74	6	1807.57	0.16	0	43622.50
Memorial Drive Trail	0.02	0.16	882.09	2	848.09	0.10	0	35480.40
Merv Sullivan Park	0.09	0.11	849.75	13	1686.69	0.13	1	33996.55
Murray Warrington Park	0.11	0.06	1736.33	6	2212.90	0.22	1	19034.18
Saunders Park	0.26	0.36	2840.95	9	2728.64	0.18	1	36953.46
Seaview Lookoff Park	0.27	0.00	2318.59	7	651.33	0.05	0	36346.41
St Andrews Centre Park	0.08	0.10	0.00	2	1577.37	0.13	1	22677.14
St Marys Boat Club Park	0.37	0.06	548.55	0	736.82	0.07	2	87498.50
Upper Flinn Park	0.30	0.05	1593.92	6	1523.08	0.11	0	45076.59
Wanderers Grounds	0.10	0.23	1847.84	4	890.74	0.16	1	60478.65
Westwood Park	0.04	0.14	259.80	6	1646.59	0.16	3	25477.50

APPENDIX III: CONSULTATION

Introduction Content

A Brief Introduction
Xin Liu, MES candidate, Dalhousie University
February 2017

This project aims at providing a framework for prioritizing future tree-planting activities in Halifax public parks. It tries to answer two questions: where to plant more trees in HRM parks, and which planting opportunities should be implemented first. We selected eight criteria to characterize the potential environmental and social effects of more trees in 28 candidate parks of the Halifax peninsula.

They are:

Criterion	Indicator	Description
Park Canopy	Canopy cover in the park	It is a fundamental indicator which reflects whether there are spaces for planting more trees in the candidate park.
Neighbourhood Canopy	Canopy cover of the neighbourhood (a 300-m buffer)	This indicator reflects the exposure of nearby residents to urban trees which indicates the desirability of more trees in the neighbourhood.
Road length	Sum of road length in surrounding area (a 200-m buffer)	This criterion was chosen to reflect the potential air-pollution situation near a park and therefore the benefits to be gained from more trees in the park.
Bus stops	Number of bus stations in the surrounding area (a 200-m buffer)	This criterion reflects the accessibility of the candidate park for citizens to visit by public transportation.
Population	Population density in the neighbourhood (a 300-m buffer)	This criterion depicts the potential population that may benefit from more trees in the neighbourhood.
Building coverage	The building coverage in the neighbourhood (a 300-m buffer)	This criterion reflects potential heat island effect during hot seasons and also partly indicates the human occupancy of the study area.
Education	Number of elementary schools in the surrounding area (a 500-m buffer)	This criterion reflects the potential of new urban trees to be used as environmental education resources.
Household	Average annual household	This criterion indicates areas which demand

Income	income in the neighbourhood (a 300-m buffer)	more efforts in improving social equality by planting more trees.

Weighting Charts

Method 1:

Rating (Weight between 1 and 10):
Give the highest important indicator a 10 and lowest a 1, then weight the rest based on this scale.

Category	**Criterion**	**Indicator**	**Weight**
Environmental	Canopy cover	Canopy cover in the park	
		Canopy cover of the neighbourhood (a 300-m buffer)	
	Road length	Sum of road length in surrounding area (a 200-m buffer)	
Social	Accessibility	Number of bus stations in the surrounding area (a 200-m buffer)	
	Population	Population density in the neighbourhood (a 300-m buffer)	
	Building coverage	The building coverage in the neighbourhood (a 300-m buffer)	
	Education	Number of elementary schools in the surrounding area (a 500-m buffer)	
	Equity	Average annual household income in the neighbourhood (a 300-m buffer)	

Method 2

Pairwise Comparison

Indicator	Park Canopy	Neighbourhood Canopy	Road length	Bus Stops	Population	Building Coverage	Elementary School	Household Income
Park Canopy	1							
Neighbourhood Canopy		1						
Road Length			1					
Bus Stops				1				
Population					1			
Building coverage						1		
Elementary Schools							1	
Household Income								1

Indexing Chart

Definition	Index	Definition	Index
Equally important	1	Equally important	1/1
Slightly more important	3	Slightly less important	1/3
Much more important	5	Way less important	1/5
Far more important	7	Far less important	1/7
Extremely more important	9	Extremely less important	1/9

Commenting Chart

Criterion	Indicator	Description	Validity (Y/N)	Comment
Canopy cover	Canopy cover in the park	It is a fundamental indicator which reflects whether there are spaces for planting more trees in the candidate park.		
	Canopy cover of the neighbourhood (a 300-m buffer)	This indicator reflects the exposure of nearby residents to urban trees which indicates the desirability of more trees in the neighbourhood.		
Road length	Sum of road length in surrounding area (a 200-m buffer)	This criterion was chosen to reflect the potential air-pollution situation near a park and therefore the benefits to be gained from more trees in the park.		
Accessibility	Number of bus stations in the surrounding area (a 200-m buffer)	This criterion reflects the accessibility of the candidate park for citizens to visit by public transportation.		
Population	Population density in the neighbourhood (a 300-m buffer)	This criterion depicts the potential population that may benefit from more trees in the neighbourhood.		
Building coverage	The building coverage in the neighbourhood (a 300-m buffer)	This criterion reflects potential heat island effect during hot seasons and also partly indicates the human occupancy of the study area.		

Education	Number of elementary schools in the surrounding area (a 500-m buffer)	This criterion reflects the potential of new urban trees to be used as environmental education resources.		
Equity	Average annual household income in the neighbourhood (a 300-m buffer)	This criterion indicates areas which demand more efforts in improving social equality by planting more trees.		